

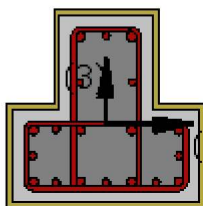
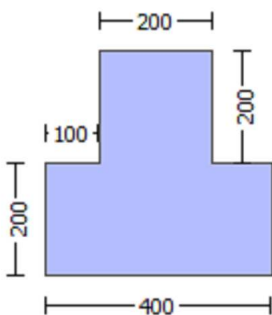
# Detailed Member Calculations

Units: N&mm

Regulation: ASCE 41-17

## Calculation No. 1

- column C1, Floor 1
- Limit State: Immediate Occupancy (data interpolation between analysis steps 1 and 2)
- Analysis: Uniform +X
- Check: Shear capacity VRd
- Edge: Start
- Local Axis: (2)



- Start Of Calculation of Shear Capacity for element: column TC1 of floor 1
- At local axis: 2
- Integration Section: (a)
- Section Type: rctcs
- Constant Properties
- Knowledge Factor,  $\gamma = 0.90$
- Member Shear Force is generally considered as Force-Controlled Action according to Table C7-1, ASCE 41-17.
- Lower-bound strengths are used for Force-Controlled Actions according to 7.5.1.3, ASCE 41-17
- Consequently:
- Existing material of Primary Member: Concrete Strength,  $f_c = f_{c\_lower\_bound} = 10.00$
- Existing material of Primary Member: Steel Strength,  $f_s = f_{s\_lower\_bound} = 400.00$
- Concrete Elasticity,  $E_c = 18203.022$

Steel Elasticity,  $E_s = 200000.00$   
 #####  
 Note: Especially for the calculation of  $\gamma$  for displacement ductility demand,  
 the expected (mean value) strengths are used (7.5.1.3, ASCE 41-17) because bending is considered as  
 Deformation-Controlled Action (Table C7-1, ASCE 41-17).  
 Existing material: Concrete Strength,  $f_c = f_{cm} = 15.00$   
 Existing material: Steel Strength,  $f_s = f_{sm} = 444.44$   
 #####  
 Max Height,  $H_{max} = 400.00$   
 Min Height,  $H_{min} = 200.00$   
 Max Width,  $W_{max} = 400.00$   
 Min Width,  $W_{min} = 200.00$   
 Eccentricity,  $Ecc = 100.00$   
 Cover Thickness,  $c = 25.00$   
 Element Length,  $L = 3000.00$   
 Primary Member  
 Ribbed Bars  
 Ductile Steel  
 Without Detailing for Earthquake Resistance (including stirrups not closed at 135°)  
 Longitudinal Bars With Ends Lapped Starting at the End Sections  
 Lap Length  $l_o = l_b = 300.00$   
 FRP Wrapping Data  
 Type: Carbon  
 Cured laminate properties (design values)  
 Thickness,  $t = 1.016$   
 Tensile Strength,  $f_{fu} = 1055.00$   
 Tensile Modulus,  $E_f = 64828.00$   
 Elongation,  $\epsilon_{fu} = 0.01$   
 Number of directions,  $NoDir = 1$   
 Fiber orientations,  $b_i: 0.00^\circ$   
 Number of layers,  $NL = 1$   
 Radius of rounding corners,  $R = 40.00$

#### Stepwise Properties

EDGE -A-  
 Bending Moment,  $M_a = -8.4385E+006$   
 Shear Force,  $V_a = -2811.342$   
 EDGE -B-  
 Bending Moment,  $M_b = -136.3192$   
 Shear Force,  $V_b = 2811.342$   
 BOTH EDGES  
 Axial Force,  $F = -4735.965$   
 Longitudinal Reinforcement Area Distribution (in 2 divisions)  
 -Tension:  $As_{lt} = 2375.044$   
 -Compression:  $As_{lc} = 2777.168$   
 Longitudinal Reinforcement Area Distribution (in 3 divisions)  
 -Tension:  $As_{l,ten} = 1231.504$   
 -Compression:  $As_{l,com} = 1231.504$   
 -Middle:  $As_{l,mid} = 2689.203$   
 Mean Diameter of Tension Reinforcement,  $Db_{L,ten} = 17.60$

Existing component: From table 7-7, ASCE 41\_17: Final Shear Capacity  $V_R = \phi V_n = 144111.087$   
 $V_n$  ((10.3), ASCE 41-17) =  $k_n \phi V_{CoI} = 160123.429$   
 $V_{CoI} = 160123.429$   
 $k_n = 1.00$   
 $displacement\_ductility\_demand = 0.01556566$

NOTE: In expression (10-3) ' $V_s$ ' is replaced by ' $V_s + \phi V_f$ '  
 where  $V_f$  is the contribution of FRPs (11.3), ACI 440).

$\phi = 1$  (normal-weight concrete)  
 $f'_c = 10.00$ , but  $f'_c^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$M/Vd = 4.00$   
 $\mu_u = 8.4385E+006$   
 $V_u = 2811.342$   
 $d = 0.8 \cdot h = 320.00$   
 $N_u = 4735.965$   
 $A_g = 80000.00$   
 From (11.5.4.8), ACI 318-14:  $V_s = V_{s1} + V_{s2} = 0.00$   
 where:  
 $V_{s1} = 0.00$  is calculated for section web, with:  
 $d = 160.00$   
 $A_v = 157079.633$   
 $f_y = 400.00$   
 $s = 380.00$   
 $V_{s1}$  is multiplied by  $\text{Col1} = 0.00$   
 $s/d = 2.375$   
 $V_{s2} = 0.00$  is calculated for section flange, with:  
 $d = 320.00$   
 $A_v = 157079.633$   
 $f_y = 400.00$   
 $s = 380.00$   
 $V_{s2}$  is multiplied by  $\text{Col2} = 0.00$   
 $s/d = 1.1875$   
 $V_f ((11-3)-(11.4), \text{ACI } 440) = 188111.148$   
 $f = 0.95$ , for fully-wrapped sections  
 $w_f/s_f = 1$  (FRP strips adjacent to one another).  
 In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot a) \sin a$  which is more a generalised expression,  
 where  $a$  is the angle of the crack direction (see KANEPE).  
 This later relation, considered as a function  $V_f(, )$ , is implemented for every different fiber orientation  $a_i$ ,  
 as well as for 2 crack directions,  $a = 45^\circ$  and  $a = -45^\circ$  to take into consideration the cyclic seismic loading.  
 orientation 1:  $a_1 = b_1 + 90^\circ = 90.00$   
 $V_f = \text{Min}(|V_f(45, a_1)|, |V_f(-45, a_1)|)$ , with:  
 total thickness per orientation,  $t_{f1} = N_L \cdot t / N_{oDir} = 1.016$   
 $d_{fv} = d$  (figure 11.2, ACI 440) = 357.00  
 $f_{fe} ((11-5), \text{ACI } 440) = 259.312$   
 $E_f = 64828.00$   
 $f_e = 0.004$ , from (11.6a), ACI 440  
 with  $f_u = 0.01$   
 From (11-11), ACI 440:  $V_s + V_f \leq 134445.642$   
 $b_w = 200.00$

displacement\_ductility\_demand is calculated as  $\delta / y$

- Calculation of  $\delta / y$  for END A -  
 for rotation axis 3 and integ. section (a)

From analysis, chord rotation  $\theta = 0.00032458$   
 $y = (M_y \cdot L_s / 3) / E_{eff} = 0.02085204$  ((4.29), Biskinis Phd))  
 $M_y = 1.3657E+008$   
 $L_s = M/V$  (with  $L_s > 0.1 \cdot L$  and  $L_s < 2 \cdot L$ ) = 3001.586  
 From table 10.5, ASCE 41\_17:  $E_{eff} = \text{factor} \cdot E_c \cdot I_g = 6.5531E+012$   
 factor = 0.30  
 $A_g = 120000.00$   
 $f_c' = 15.00$   
 $N = 4735.965$   
 $E_c \cdot I_g = 2.1844E+013$

Calculation of Yielding Moment  $M_y$

Calculation of  $\delta$  and  $M_y$  according to Annex 7 -

$y = \text{Min}(\delta_{ten}, \delta_{com})$   
 $\delta_{ten} = 5.8874222E-006$   
 with ((10.1), ASCE 41-17)  $f_y = \text{Min}(f_y, 1.25 \cdot f_y \cdot (I_b / d)^{2/3}) = 235.317$

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d = 357.00
y = 0.44020389
A = 0.07244171
B = 0.04070755
with pt = 0.01724796
    pc = 0.01724796
    pv = 0.03766391
    N = 4735.965
    b = 200.00
    " = 0.12044818
y_comp = 1.0162905E-005
with fc* (12.3, (ACI 440)) = 16.12972
    fc = 15.00
    fl = 0.93147527
    b = bmax = 400.00
    h = hmax = 400.00
    Ag = 120000.00
    g = pt + pc + pv = 0.07215983
    rc = 40.00
    Ae/Ac = 0.38686758
    Effective FRP thickness, tf = NL*t*cos(b1) = 1.016
    effective strain from (12.5) and (12.12), efe = 0.004
    fu = 0.01
    Ef = 64828.00
    Ec = 18203.022
    y = 0.43961224
    A = 0.0719519
    B = 0.04042568
    with Es = 200000.00

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Calculation of ratio lb/l<sub>d</sub>

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Lap Length: l<sub>d</sub>/l<sub>d,min</sub> = 0.27567359

l<sub>b</sub> = 300.00

l<sub>d</sub> = 1088.244

Calculation of l according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

= 1

db = 18.00

Mean strength value of all re-bars: f<sub>y</sub> = 444.44

f<sub>c</sub>' = 15.00, but f<sub>c</sub>'<sup>0.5</sup> ≤ 8.3 MPa (22.5.3.1, ACI 318-14)

t = 1.00

s = 0.80

e = 1.00

cb = 24.02082

K<sub>tr</sub> = 0.82673491

A<sub>tr</sub> = Min(A<sub>tr\_x</sub>, A<sub>tr\_y</sub>) = 157.0796

where A<sub>tr\_x</sub>, A<sub>tr\_y</sub> are the sum of the area of all stirrup legs along X and Y local axis

s = 380.00

n = 20.00

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End Of Calculation of Shear Capacity for element: column TC1 of floor 1

At local axis: 2

Integration Section: (a)

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## Calculation No. 2

column C1, Floor 1

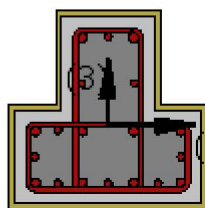
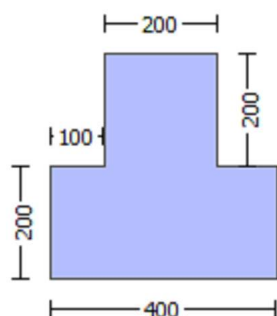
Limit State: Immediate Occupancy (data interpolation between analysis steps 1 and 2)

Analysis: Uniform +X

Check: Chord rotation capacity (  $\phi$  )

Edge: Start

Local Axis: (2)



Start Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1

At Shear local axis: 3

(Bending local axis: 2)

Section Type: rctcs

Constant Properties

Knowledge Factor,  $\phi = 0.90$

Mean strength values are used for both shear and moment calculations.

Consequently:

Existing material of Primary Member: Concrete Strength,  $f_c = f_{cm} = 15.00$

Existing material of Primary Member: Steel Strength,  $f_s = f_{sm} = 444.44$

Concrete Elasticity,  $E_c = 18203.022$

Steel Elasticity,  $E_s = 200000.00$

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Note: Especially for the calculation of moment strengths,

the above steel re-bar strengths are multiplied by 1.25 according to R18.6.5, ACI 318-14

Existing material: Steel Strength,  $f_s = 1.25 \cdot f_{sm} = 555.55$

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Max Height,  $H_{max} = 400.00$

Min Height,  $H_{min} = 200.00$

Max Width,  $W_{max} = 400.00$

Min Width,  $W_{min} = 200.00$

Eccentricity,  $E_{cc} = 100.00$

Cover Thickness,  $c = 25.00$

Mean Confinement Factor overall section = 1.27578

Element Length,  $L = 3000.00$

Primary Member

Ribbed Bars

Ductile Steel

Without Detailing for Earthquake Resistance (including stirrups not closed at 135°)

Longitudinal Bars With Ends Lapped Starting at the End Sections

Lap Length  $l_o = 300.00$

FRP Wrapping Data

Type: Carbon

Cured laminate properties (design values)

Thickness,  $t = 1.016$

Tensile Strength,  $f_{fu} = 1055.00$

Tensile Modulus,  $E_f = 64828.00$

Elongation,  $\epsilon_{fu} = 0.01$   
Number of directions,  $NoDir = 1$   
Fiber orientations,  $bi = 0.00^\circ$   
Number of layers,  $NL = 1$   
Radius of rounding corners,  $R = 40.00$

#### Stepwise Properties

At local axis: 3  
EDGE -A-  
Shear Force,  $V_a = 0.01054019$   
EDGE -B-  
Shear Force,  $V_b = -0.01054019$   
BOTH EDGES  
Axial Force,  $F = -4737.328$   
Longitudinal Reinforcement Area Distribution (in 2 divisions)  
-Tension:  $As_{lt} = 0.00$   
-Compression:  $As_{lc} = 5152.212$   
Longitudinal Reinforcement Area Distribution (in 3 divisions)  
-Tension:  $As_{l,ten} = 2261.947$   
-Compression:  $As_{l,com} = 829.3805$   
-Middle:  $As_{l,mid} = 2060.885$

Calculation of Shear Capacity ratio,  $V_e/V_r = 0.82694402$   
Member Controlled by Flexure ( $V_e/V_r < 1$ )  
Calculation of Shear Demand from fig. R18.6.5, ACI 318-14  $V_e = (M_{pr1} + M_{pr2})/l_n = 162085.836$   
with  
 $M_{pr1} = \max(\mu_{u1+}, \mu_{u1-}) = 2.4313E+008$   
 $\mu_{u1+} = 2.4313E+008$ , is the ultimate moment strength at the edge 1 of the member in the actual moment direction which is defined for the static loading combination  
 $\mu_{u1-} = 1.2706E+008$ , is the ultimate moment strength at the edge 1 of the member in the opposite moment direction which is defined for the static loading combination  
 $M_{pr2} = \max(\mu_{u2+}, \mu_{u2-}) = 2.4313E+008$   
 $\mu_{u2+} = 2.4313E+008$ , is the ultimate moment strength at the edge 2 of the member in the actual moment direction which is defined for the static loading combination  
 $\mu_{u2-} = 1.2706E+008$ , is the ultimate moment strength at the edge 2 of the member in the opposite moment direction which is defined for the static loading combination

#### Calculation of $\mu_{u1+}$

Calculation of ultimate curvature  $\mu_u$  according to 4.1, Biskinis/Fardis 2013:  
 $\mu_u = 2.6161250E-005$   
 $\mu_u = 2.4313E+008$

with full section properties:

$b = 200.00$   
 $d = 357.00$   
 $d' = 43.00$   
 $v = 0.00442328$   
 $N = 4737.328$   
 $f_c = 15.00$   
 $\alpha_1(5A.5, TBDY) = 0.002$   
Final value of  $\mu_u$ :  $\mu_u^* = \text{shear\_factor} * \max(\mu_u, \alpha_1) = 0.018$   
The Shear\_factor is considered equal to 1 (pure moment strength)  
From (5.4b), TBDY:  $\mu_u = 0.018$   
where  $\mu_u^* = \alpha_1 * \mu_u + \alpha_2 * \mu_u^*$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)  
 $\mu_u = 0.15303423$   
Expression ((15B.6), TBDY) is modified as  $\alpha_1 = 1 - (\text{Unconfined area})/(\text{total area})$

$$af = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 51733.333$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A4.4.3(6), } pf = 2tf/bw = 0.01016$$

$$bw = 200.00$$

$$\text{effective stress from (A.35), } ff,e = 524.0792$$

$$fy = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $af = 1 - (\text{Unconfined area})/(\text{total area})$

$$af = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 0.00$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A4.4.3(6), } pf = 2tf/bw = 0.01016$$

$$bw = 200.00$$

$$\text{effective stress from (A.35), } ff,e = 524.0792$$

$$R = 40.00$$

$$\text{Effective FRP thickness, } tf = NL * t * \cos(b1) = 1.016$$

$$fu,f = 1055.00$$

$$Ef = 64828.00$$

$$u,f = 0.015$$

$$ase = \text{Max}(((A_{\text{conf,max}} - A_{\text{noConf}})/A_{\text{conf,max}}) * (A_{\text{conf,min}}/A_{\text{conf,max}}), 0) = 0.00$$

The definitions of  $A_{\text{noConf}}$ ,  $A_{\text{conf,min}}$  and  $A_{\text{conf,max}}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{\text{conf,max}} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{\text{conf,min}} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{\text{conf,max}}$  by a length equal to half the clear spacing between hoops.

$A_{\text{noConf}} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$$psh_{\min} = \text{Min}(psh_x, psh_y) = 0.00165347$$

Expression ((5.4d), TBDY) for  $psh_{\min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$$psh_x \text{ ((5.4d), TBDY)} = L_{\text{stir}} * A_{\text{stir}} / (A_{\text{sec}} * s) = 0.00165347$$

$$L_{\text{stir}} \text{ (Length of stirrups along Y)} = 960.00$$

$$A_{\text{stir}} \text{ (stirrups area)} = 78.53982$$

$$A_{\text{sec}} \text{ (section area)} = 120000.00$$

$$psh_y \text{ ((5.4d), TBDY)} = L_{\text{stir}} * A_{\text{stir}} / (A_{\text{sec}} * s) = 0.00165347$$

$$L_{\text{stir}} \text{ (Length of stirrups along X)} = 960.00$$

$$A_{\text{stir}} \text{ (stirrups area)} = 78.53982$$

$$A_{\text{sec}} \text{ (section area)} = 120000.00$$

$$s = 380.00$$

$$fy_{we} = 555.55$$

$$f_{ce} = 15.00$$

$$\text{From ((5.A5), TBDY), TBDY: } cc = 0.00475778$$

$$c = \text{confinement factor} = 1.27578$$

$$y1 = 0.0010562$$

$$sh1 = 0.00365026$$

$$ft1 = 304.185$$

$$fy1 = 253.4875$$

$$su1 = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$$lo/lou_{\min} = lb/ld = 0.22053887$$

$$su1 = 0.4 * esu1_{\text{nominal}} \text{ ((5.5), TBDY)} = 0.032$$

From table 5A.1, TBDY:  $esu1_{\text{nominal}} = 0.08$ ,

For calculation of  $esu1_{\text{nominal}}$  and  $y1$ ,  $sh1$ ,  $ft1$ ,  $fy1$ , it is considered characteristic value  $fsy1 = fs1/1.2$ , from table 5.1, TBDY.

$y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fs1 = fs = 253.4875$   
 with  $Es1 = Es = 200000.00$   
 $y2 = 0.0010562$   
 $sh2 = 0.00365026$   
 $ft2 = 304.185$   
 $fy2 = 253.4875$   
 $su2 = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $lo/lou, min = lb/lb, min = 0.22053887$   
 $su2 = 0.4 \cdot esu2\_nominal ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esu2\_nominal = 0.08$ ,  
 For calculation of  $esu2\_nominal$  and  $y2, sh2, ft2, fy2$ , it is considered  
 characteristic value  $fsy2 = fs2/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fs2 = fs = 253.4875$   
 with  $Es2 = Es = 200000.00$   
 $yv = 0.0010562$   
 $shv = 0.00365026$   
 $ftv = 304.185$   
 $fyv = 253.4875$   
 $suv = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $lo/lou, min = lb/ld = 0.22053887$   
 $suv = 0.4 \cdot esuv\_nominal ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esuv\_nominal = 0.08$ ,  
 considering characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY  
 For calculation of  $esuv\_nominal$  and  $yv, shv, ftv, fyv$ , it is considered  
 characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fsv = fs = 253.4875$   
 with  $Esv = Es = 200000.00$   
 $1 = Asl, ten / (b \cdot d) \cdot (fs1 / fc) = 0.53536441$   
 $2 = Asl, com / (b \cdot d) \cdot (fs2 / fc) = 0.19630028$   
 $v = Asl, mid / (b \cdot d) \cdot (fsv / fc) = 0.48777647$

and confined core properties:

$b = 140.00$   
 $d = 327.00$   
 $d' = 13.00$   
 $fcc (5A.2, TBDY) = 19.13667$   
 $cc (5A.5, TBDY) = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $1 = Asl, ten / (b \cdot d) \cdot (fs1 / fc) = 0.83497202$   
 $2 = Asl, com / (b \cdot d) \cdot (fs2 / fc) = 0.30615641$   
 $v = Asl, mid / (b \cdot d) \cdot (fsv / fc) = 0.76075229$

Case/Assumption: Unconfined full section - Steel rupture

' satisfies Eq. (4.3)

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$v < vs, y2$  - LHS eq.(4.5) is not satisfied

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$v < vs, c$  - RHS eq.(4.5) is not satisfied

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Case/Assumption Rejected.

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New Case/Assumption: Unconfined full section - Spalling of concrete cover

' satisfies Eq. (4.4)

----

$v < s, y1$  - LHS eq.(4.7) is not satisfied

----

$v < vc, y1$  - RHS eq.(4.6) is satisfied

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$cu (4.10) = 0.46564051$

$MRC (4.17) = 2.0934E+008$



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New Case/Assumption: Ultimate curvature of confined core after spalling of concrete cover

In expressions below, the following modifications have been made

- b, d, d' replaced by geometric parameters of the core:  $b_o$ ,  $d_o$ ,  $d'_o$
- $N$ ,  $\epsilon_1$ ,  $\epsilon_2$ ,  $\nu$  normalised to  $b_o \cdot d_o$ , instead of  $b \cdot d$
- $\epsilon_c$ ,  $\epsilon_{cc}$  parameters of confined concrete,  $f_{cc}$ ,  $\epsilon_{cc}$ , used in lieu of  $f_c$ ,  $\epsilon_{cu}$

--->

Subcase: Rupture of tension steel

--->

$\nu^* < \nu^*_{s,y2}$  - LHS eq.(4.5) is not satisfied

--->

$\nu^* < \nu^*_{s,c}$  - LHS eq.(4.5) is not satisfied

--->

Subcase rejected

--->

New Subcase: Failure of compression zone

--->

$\nu^* < \nu^*_{c,y2}$  - LHS eq.(4.6) is not satisfied

--->

$\nu^* < \nu^*_{c,y1}$  - RHS eq.(4.6) is satisfied

--->

$\epsilon^*_{cu}$  (4.10) = 0.55615794

$M_{Ro}$  (4.17) = 2.4313E+008

--->

$\epsilon_u = \epsilon_{cu}$  (4.2) = 2.6161250E-005

$M_u = M_{Ro}$

-----  
Calculation of ratio  $l_b/l_d$

Lap Length:  $l_b/l_d = 0.22053887$

$l_b = 300.00$

$l_d = 1360.304$

Calculation of  $l_{b,min}$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

= 1

$d_b = 18.00$

Mean strength value of all re-bars:  $f_y = 555.55$

$f'_c = 15.00$ , but  $f_c^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$t = 1.00$

$s = 0.80$

$e = 1.00$

$cb = 24.02082$

$K_{tr} = 0.82673491$

$A_{tr} = \min(A_{tr_x}, A_{tr_y}) = 157.0796$

where  $A_{tr_x}$ ,  $A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis

$s = 380.00$

$n = 20.00$

-----  
Calculation of  $M_{u1}$ -

-----  
Calculation of ultimate curvature  $\epsilon_u$  according to 4.1, Biskinis/Fardis 2013:

$\epsilon_u = 1.3353763E-005$

$M_u = 1.2706E+008$

-----  
with full section properties:

$b = 400.00$

$d = 357.00$

$d' = 43.00$

$\nu = 0.00221164$

$N = 4737.328$

$f_c = 15.00$

$\epsilon_{co}$  (5A.5, TBDY) = 0.002

Final value of  $\epsilon_{cu}$ :  $\epsilon_{cu}^* = \text{shear\_factor} * \max(\epsilon_{cu}, \epsilon_{cc}) = 0.018$

The Shear\_factor is considered equal to 1 (pure moment strength)

From (5.4b), TBDY:  $c_u = 0.018$

we ((5.4c), TBDY) =  $a_{se} * s_{h,min} * f_{ywe} / f_{ce} + \text{Min}(f_x, f_y) = 0.15303423$

where  $f = a_f * p_f * f_{fe} / f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$f_x = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$a_f = 0.43111111$

with Unconfined area =  $((b_{max} - 2R)^2 + (h_{max} - 2R)^2) / 3 = 51733.333$

$b_{max} = 400.00$

$h_{max} = 400.00$

From EC8 A4.4.3(6),  $p_f = 2t_f / b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

$f_y = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$a_f = 0.43111111$

with Unconfined area =  $((b_{max} - 2R)^2 + (h_{max} - 2R)^2) / 3 = 0.00$

$b_{max} = 400.00$

$h_{max} = 400.00$

From EC8 A4.4.3(6),  $p_f = 2t_f / b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

$R = 40.00$

Effective FRP thickness,  $t_f = N L * t * \text{Cos}(b_1) = 1.016$

$f_{u,f} = 1055.00$

$E_f = 64828.00$

$u_{f} = 0.015$

$a_{se} = \text{Max}(((A_{conf,max} - A_{noConf}) / A_{conf,max}) * (A_{conf,min} / A_{conf,max}), 0) = 0.00$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2 / 6$  as defined at (A.2).

$p_{sh,min} = \text{Min}(p_{sh,x}, p_{sh,y}) = 0.00165347$

Expression ((5.4d), TBDY) for  $p_{sh,min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$p_{sh,x}$  ((5.4d), TBDY) =  $L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$

$L_{stir}$  (Length of stirrups along Y) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$p_{sh,y}$  ((5.4d), TBDY) =  $L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$

$L_{stir}$  (Length of stirrups along X) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$s = 380.00$

$f_{ywe} = 555.55$

$f_{ce} = 15.00$

From ((5.A5), TBDY), TBDY:  $c_c = 0.00475778$

$c$  = confinement factor = 1.27578

$y_1 = 0.0010562$

$sh_1 = 0.00365026$

$ft_1 = 304.185$

$fy_1 = 253.4875$

$su_1 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor

and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $l_o/l_{ou,min} = l_b/l_d = 0.22053887$   
 $su_1 = 0.4 * esu_{1,nominal} ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esu_{1,nominal} = 0.08$ ,  
 For calculation of  $esu_{1,nominal}$  and  $y_1, sh_1, ft_1, fy_1$ , it is considered  
 characteristic value  $fsy_1 = fs_1/1.2$ , from table 5.1, TBDY.  
 $y_1, sh_1, ft_1, fy_1$ , are also multiplied by  $\text{Min}(1, 1.25 * (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fs_1 = fs = 253.4875$   
 with  $Es_1 = Es = 200000.00$   
 $y_2 = 0.0010562$   
 $sh_2 = 0.00365026$   
 $ft_2 = 304.185$   
 $fy_2 = 253.4875$   
 $su_2 = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $l_o/l_{ou,min} = l_b/l_{b,min} = 0.22053887$   
 $su_2 = 0.4 * esu_{2,nominal} ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esu_{2,nominal} = 0.08$ ,  
 For calculation of  $esu_{2,nominal}$  and  $y_2, sh_2, ft_2, fy_2$ , it is considered  
 characteristic value  $fsy_2 = fs_2/1.2$ , from table 5.1, TBDY.  
 $y_1, sh_1, ft_1, fy_1$ , are also multiplied by  $\text{Min}(1, 1.25 * (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fs_2 = fs = 253.4875$   
 with  $Es_2 = Es = 200000.00$   
 $y_v = 0.0010562$   
 $sh_v = 0.00365026$   
 $ft_v = 304.185$   
 $fy_v = 253.4875$   
 $suv = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $l_o/l_{ou,min} = l_b/l_d = 0.22053887$   
 $suv = 0.4 * esuv_{nominal} ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esuv_{nominal} = 0.08$ ,  
 considering characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY  
 For calculation of  $esuv_{nominal}$  and  $y_v, sh_v, ft_v, fy_v$ , it is considered  
 characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY.  
 $y_1, sh_1, ft_1, fy_1$ , are also multiplied by  $\text{Min}(1, 1.25 * (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fsv = fs = 253.4875$   
 with  $Esv = Es = 200000.00$   
 $1 = Asl_{ten}/(b*d) * (fs_1/fc) = 0.09815014$   
 $2 = Asl_{com}/(b*d) * (fs_2/fc) = 0.26768221$   
 $v = Asl_{mid}/(b*d) * (fsv/fc) = 0.24388823$   
 and confined core properties:  
 $b = 340.00$   
 $d = 327.00$   
 $d' = 13.00$   
 $f_{cc} (5A.2, TBDY) = 19.13667$   
 $cc (5A.5, TBDY) = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $1 = Asl_{ten}/(b*d) * (fs_1/fc) = 0.1260644$   
 $2 = Asl_{com}/(b*d) * (fs_2/fc) = 0.34381201$   
 $v = Asl_{mid}/(b*d) * (fsv/fc) = 0.31325094$   
 Case/Assumption: Unconfined full section - Steel rupture  
 ' satisfies Eq. (4.3)  
 --->  
 $v < v_{s,y2}$  - LHS eq.(4.5) is satisfied  
 --->  
 $su (4.9) = 0.23431248$   
 $Mu = MRc (4.14) = 1.2706E+008$   
 $u = su (4.1) = 1.3353763E-005$

-----  
 Calculation of ratio  $l_b/l_d$

Lap Length:  $l_b/l_d = 0.22053887$

$l_b = 300.00$

$l_d = 1360.304$

Calculation of  $l_b$ , min according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$= 1$

$d_b = 18.00$

Mean strength value of all re-bars:  $f_y = 555.55$

$f_c' = 15.00$ , but  $f_c'^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$t = 1.00$

$s = 0.80$

$e = 1.00$

$c_b = 24.02082$

$K_{tr} = 0.82673491$

$A_{tr} = \text{Min}(A_{tr_x}, A_{tr_y}) = 157.0796$

where  $A_{tr_x}$ ,  $A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis

$s = 380.00$

$n = 20.00$

Calculation of  $\mu_{2+}$

Calculation of ultimate curvature  $\mu$  according to 4.1, Biskinis/Fardis 2013:

$\mu = 2.6161250E-005$

$\mu = 2.4313E+008$

with full section properties:

$b = 200.00$

$d = 357.00$

$d' = 43.00$

$v = 0.00442328$

$N = 4737.328$

$f_c = 15.00$

$c_o$  (5A.5, TBDY) = 0.002

Final value of  $\mu$ :  $\mu^* = \text{shear\_factor} * \text{Max}(\mu, c_o) = 0.018$

The Shear\_factor is considered equal to 1 (pure moment strength)

From (5.4b), TBDY:  $\mu = 0.018$

we ((5.4c), TBDY) =  $a_s * \text{sh}_{\min} * f_{ywe}/f_{ce} + \text{Min}(f_x, f_y) = 0.15303423$

where  $f = a_f * p_f * f_{fe}/f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$f_x = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area})/(\text{total area})$

$a_f = 0.43111111$

with Unconfined area =  $((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 51733.333$

$b_{\max} = 400.00$

$h_{\max} = 400.00$

From EC8 A.4.4.3(6),  $p_f = 2t_f/b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

$f_y = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area})/(\text{total area})$

$a_f = 0.43111111$

with Unconfined area =  $((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 0.00$

$b_{\max} = 400.00$

$h_{\max} = 400.00$

From EC8 A.4.4.3(6),  $p_f = 2t_f/b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

$R = 40.00$

Effective FRP thickness,  $t_f = N L * t * \text{Cos}(b_1) = 1.016$

$f_{u,f} = 1055.00$

$E_f = 64828.00$

$$u,f = 0.015$$

$$ase = \text{Max}(((A_{conf,max} - A_{noConf}) / A_{conf,max}) * (A_{conf,min} / A_{conf,max}), 0) = 0.00$$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max}$  = 75600.00 is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min}$  = 0.00 is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf}$  = 33066.667 is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$$psh,min = \text{Min}(psh,x, psh,y) = 0.00165347$$

Expression ((5.4d), TBDY) for  $psh,min$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$$psh,x \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$$

$$L_{stir} \text{ (Length of stirrups along Y)} = 960.00$$

$$A_{stir} \text{ (stirrups area)} = 78.53982$$

$$A_{sec} \text{ (section area)} = 120000.00$$

$$psh,y \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$$

$$L_{stir} \text{ (Length of stirrups along X)} = 960.00$$

$$A_{stir} \text{ (stirrups area)} = 78.53982$$

$$A_{sec} \text{ (section area)} = 120000.00$$

$$s = 380.00$$

$$f_{ywe} = 555.55$$

$$f_{ce} = 15.00$$

$$\text{From ((5.A5), TBDY), TBDY: } cc = 0.00475778$$

$$c = \text{confinement factor} = 1.27578$$

$$y_1 = 0.0010562$$

$$sh_1 = 0.00365026$$

$$ft_1 = 304.185$$

$$fy_1 = 253.4875$$

$$su_1 = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$$l_o/l_{ou,min} = l_b/l_d = 0.22053887$$

$$su_1 = 0.4 * esu_{1,nominal} \text{ ((5.5), TBDY)} = 0.032$$

From table 5A.1, TBDY:  $esu_{1,nominal} = 0.08$ ,

For calculation of  $esu_{1,nominal}$  and  $y_1$ ,  $sh_1$ ,  $ft_1$ ,  $fy_1$ , it is considered characteristic value  $fsy_1 = fs_1/1.2$ , from table 5.1, TBDY.

$y_1$ ,  $sh_1$ ,  $ft_1$ ,  $fy_1$ , are also multiplied by  $\text{Min}(1, 1.25 * (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.

$$\text{with } fs_1 = fs = 253.4875$$

$$\text{with } Es_1 = Es = 200000.00$$

$$y_2 = 0.0010562$$

$$sh_2 = 0.00365026$$

$$ft_2 = 304.185$$

$$fy_2 = 253.4875$$

$$su_2 = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$$l_o/l_{ou,min} = l_b/l_{b,min} = 0.22053887$$

$$su_2 = 0.4 * esu_{2,nominal} \text{ ((5.5), TBDY)} = 0.032$$

From table 5A.1, TBDY:  $esu_{2,nominal} = 0.08$ ,

For calculation of  $esu_{2,nominal}$  and  $y_2$ ,  $sh_2$ ,  $ft_2$ ,  $fy_2$ , it is considered characteristic value  $fsy_2 = fs_2/1.2$ , from table 5.1, TBDY.

$y_1$ ,  $sh_1$ ,  $ft_1$ ,  $fy_1$ , are also multiplied by  $\text{Min}(1, 1.25 * (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.

$$\text{with } fs_2 = fs = 253.4875$$

$$\text{with } Es_2 = Es = 200000.00$$

$$y_v = 0.0010562$$

$$sh_v = 0.00365026$$

$$ft_v = 304.185$$

```

fyv = 253.4875
suv = 0.00365026
    using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
    and also multiplied by the shear_factor according to 15.7.1.4, with
    Shear_factor = 1.00
    lo/lo,min = lb/ld = 0.22053887
    suv = 0.4*esuv_nominal ((5.5), TBDY) = 0.032
    From table 5A.1, TBDY: esuv_nominal = 0.08,
    considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY
    For calculation of esuv_nominal and yv, shv,ftv,fyv, it is considered
    characteristic value fsyv = fsv/1.2, from table 5.1, TBDY.
    y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/ld)^ 2/3), from 10.3.5, ASCE 41-17.
    with fsv = fs = 253.4875
    with Esv = Es = 200000.00
    1 = Asl,ten/(b*d)*(fs1/fc) = 0.53536441
    2 = Asl,com/(b*d)*(fs2/fc) = 0.19630028
    v = Asl,mid/(b*d)*(fsv/fc) = 0.48777647
and confined core properties:
b = 140.00
d = 327.00
d' = 13.00
fcc (5A.2, TBDY) = 19.13667
cc (5A.5, TBDY) = 0.00475778
    c = confinement factor = 1.27578
    1 = Asl,ten/(b*d)*(fs1/fc) = 0.83497202
    2 = Asl,com/(b*d)*(fs2/fc) = 0.30615641
    v = Asl,mid/(b*d)*(fsv/fc) = 0.76075229
Case/Assumption: Unconfined full section - Steel rupture
' satisfies Eq. (4.3)
--->
v < vs,y2 - LHS eq.(4.5) is not satisfied
--->
v < vs,c - RHS eq.(4.5) is not satisfied
--->
Case/Assumption Rejected.
--->
New Case/Assumption: Unconfined full section - Spalling of concrete cover
' satisfies Eq. (4.4)
--->
v < s,y1 - LHS eq.(4.7) is not satisfied
--->
v < vc,y1 - RHS eq.(4.6) is satisfied
--->
    cu (4.10) = 0.46564051
    MRc (4.17) = 2.0934E+008
--->
New Case/Assumption: Ultimate curvature of confined core after spalling of concrete cover
In expressions below, the following modifications have been made
- b, d, d' replaced by geometric parameters of the core: bo, do, d'o
- N, 1, 2, v normalised to bo*do, instead of b*d
- - parameters of confined concrete, fcc, cc, used in lieu of fc, ecu
--->
Subcase: Rupture of tension steel
--->
v* < v*s,y2 - LHS eq.(4.5) is not satisfied
--->
v* < v*s,c - LHS eq.(4.5) is not satisfied
--->
Subcase rejected
--->
New Subcase: Failure of compression zone
--->
v* < v*c,y2 - LHS eq.(4.6) is not satisfied
--->
v* < v*c,y1 - RHS eq.(4.6) is satisfied
--->
    *cu (4.10) = 0.55615794

```

$$M_{Ro} (4.17) = 2.4313E+008$$

--->

$$u = cu (4.2) = 2.6161250E-005$$

$$\mu = M_{Ro}$$

Calculation of ratio  $l_b/l_d$

$$\text{Lap Length: } l_b/l_d = 0.22053887$$

$$l_b = 300.00$$

$$l_d = 1360.304$$

Calculation of  $l_b, \min$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$$= 1$$

$$d_b = 18.00$$

Mean strength value of all re-bars:  $f_y = 555.55$

$$f'_c = 15.00, \text{ but } f_c^{0.5} \leq 8.3 \text{ MPa (22.5.3.1, ACI 318-14)}$$

$$t = 1.00$$

$$s = 0.80$$

$$e = 1.00$$

$$c_b = 24.02082$$

$$K_{tr} = 0.82673491$$

$$A_{tr} = \min(A_{tr_x}, A_{tr_y}) = 157.0796$$

where  $A_{tr_x}, A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis

$$s = 380.00$$

$$n = 20.00$$

Calculation of  $\mu_2$ -

Calculation of ultimate curvature  $\mu$  according to 4.1, Biskinis/Fardis 2013:

$$u = 1.3353763E-005$$

$$\mu = 1.2706E+008$$

with full section properties:

$$b = 400.00$$

$$d = 357.00$$

$$d' = 43.00$$

$$v = 0.00221164$$

$$N = 4737.328$$

$$f'_c = 15.00$$

$$c_o (5A.5, \text{ TBDY}) = 0.002$$

$$\text{Final value of } c_u: c_u^* = \text{shear\_factor} * \max(c_u, c_c) = 0.018$$

The Shear\_factor is considered equal to 1 (pure moment strength)

$$\text{From (5.4b), TBDY: } c_u = 0.018$$

$$w_e ((5.4c), \text{ TBDY}) = a_{se} * s_{h, \min} * f_{ywe} / f_{ce} + \min(f_x, f_y) = 0.15303423$$

where  $f = a_f * p_f * f_{fe} / f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$$f_x = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2) / 3 = 51733.333$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } p_f = 2t_f / b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$f_y = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2) / 3 = 0.00$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } p_f = 2t_f / b_w = 0.01016$$

bw = 200.00  
effective stress from (A.35),  $f_{f,e} = 524.0792$

R = 40.00  
Effective FRP thickness,  $t_f = NL \cdot t \cdot \cos(b_1) = 1.016$   
 $f_{u,f} = 1055.00$   
 $E_f = 64828.00$   
 $u_{,f} = 0.015$

$a_{se} = \text{Max}(((A_{conf,max} - A_{noConf}) / A_{conf,max}) \cdot (A_{conf,min} / A_{conf,max}), 0) = 0.00$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988) "Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$p_{sh,min} = \text{Min}(p_{sh,x}, p_{sh,y}) = 0.00165347$

Expression ((5.4d), TBDY) for  $p_{sh,min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$p_{sh,x} \text{ ((5.4d), TBDY)} = L_{stir} \cdot A_{stir} / (A_{sec} \cdot s) = 0.00165347$

$L_{stir}$  (Length of stirrups along Y) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$p_{sh,y} \text{ ((5.4d), TBDY)} = L_{stir} \cdot A_{stir} / (A_{sec} \cdot s) = 0.00165347$

$L_{stir}$  (Length of stirrups along X) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

s = 380.00

$f_{ywe} = 555.55$

$f_{ce} = 15.00$

From ((5.A5), TBDY), TBDY:  $cc = 0.00475778$

c = confinement factor = 1.27578

$y_1 = 0.0010562$

$sh_1 = 0.00365026$

$ft_1 = 304.185$

$fy_1 = 253.4875$

$su_1 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$l_o/l_{ou,min} = l_b/l_d = 0.22053887$

$su_1 = 0.4 \cdot esu1_{nominal} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu1_{nominal} = 0.08$ ,

For calculation of  $esu1_{nominal}$  and  $y_1$ ,  $sh_1$ ,  $ft_1$ ,  $fy_1$ , it is considered characteristic value  $fsy_1 = fs_1/1.2$ , from table 5.1, TBDY.

$y_1$ ,  $sh_1$ ,  $ft_1$ ,  $fy_1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.

with  $fs_1 = fs = 253.4875$

with  $Es_1 = Es = 200000.00$

$y_2 = 0.0010562$

$sh_2 = 0.00365026$

$ft_2 = 304.185$

$fy_2 = 253.4875$

$su_2 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$l_o/l_{ou,min} = l_b/l_{b,min} = 0.22053887$

$su_2 = 0.4 \cdot esu2_{nominal} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu2_{nominal} = 0.08$ ,

For calculation of  $esu2_{nominal}$  and  $y_2$ ,  $sh_2$ ,  $ft_2$ ,  $fy_2$ , it is considered



characteristic value  $fsy2 = fs2/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fs2 = fs = 253.4875$   
 with  $Es2 = Es = 200000.00$   
 $yv = 0.0010562$   
 $shv = 0.00365026$   
 $ftv = 304.185$   
 $fyv = 253.4875$   
 $suv = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $lo/lo_{u,min} = lb/ld = 0.22053887$   
 $suv = 0.4 \cdot esuv_{nominal} ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esuv_{nominal} = 0.08$ ,  
 considering characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY  
 For calculation of  $esuv_{nominal}$  and  $yv, shv, ftv, fyv$ , it is considered  
 characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fsv = fs = 253.4875$   
 with  $Es = Es = 200000.00$   
 $1 = Asl_{ten}/(b \cdot d) \cdot (fs1/fc) = 0.09815014$   
 $2 = Asl_{com}/(b \cdot d) \cdot (fs2/fc) = 0.26768221$   
 $v = Asl_{mid}/(b \cdot d) \cdot (fsv/fc) = 0.24388823$   
 and confined core properties:  
 $b = 340.00$   
 $d = 327.00$   
 $d' = 13.00$   
 $fcc (5A.2, TBDY) = 19.13667$   
 $cc (5A.5, TBDY) = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $1 = Asl_{ten}/(b \cdot d) \cdot (fs1/fc) = 0.1260644$   
 $2 = Asl_{com}/(b \cdot d) \cdot (fs2/fc) = 0.34381201$   
 $v = Asl_{mid}/(b \cdot d) \cdot (fsv/fc) = 0.31325094$   
 Case/Assumption: Unconfined full section - Steel rupture  
 ' satisfies Eq. (4.3)  
 --->  
 $v < vs, y2$  - LHS eq.(4.5) is satisfied  
 --->  
 $su (4.9) = 0.23431248$   
 $Mu = MRc (4.14) = 1.2706E+008$   
 $u = su (4.1) = 1.3353763E-005$

#### Calculation of ratio $lb/ld$

Lap Length:  $lb/ld = 0.22053887$   
 $lb = 300.00$   
 $ld = 1360.304$   
 Calculation of  $lb_{min}$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.  
 $= 1$   
 $db = 18.00$   
 Mean strength value of all re-bars:  $fy = 555.55$   
 $fc' = 15.00$ , but  $fc^{0.5} \leq 8.3 \text{ MPa}$  (22.5.3.1, ACI 318-14)  
 $t = 1.00$   
 $s = 0.80$   
 $e = 1.00$   
 $cb = 24.02082$   
 $Ktr = 0.82673491$   
 $Atr = \text{Min}(Atr_x, Atr_y) = 157.0796$   
 where  $Atr_x, Atr_y$  are the sum of the area of all stirrup legs along X and Y loxal axis  
 $s = 380.00$   
 $n = 20.00$

Calculation of Shear Strength  $V_r = \text{Min}(V_{r1}, V_{r2}) = 196005.816$

Calculation of Shear Strength at edge 1,  $V_{r1} = 227350.021$

$V_{r1} = V_{Col} \text{ ((10.3), ASCE 41-17)} = k_{nl} * V_{Col0}$

$V_{Col0} = 227350.021$

$k_{nl} = 1$  (zero step-static loading)

NOTE: In expression (10-3) ' $V_s$ ' is replaced by ' $V_s + f * V_f$ ' where  $V_f$  is the contribution of FRPs (11.3), ACI 440).

$\lambda = 1$  (normal-weight concrete)

$f'_c = 15.00$ , but  $f'_c^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$M/Vd = 2.00$

$\mu_u = 3.21769$

$\nu_u = 0.01054019$

$d = 0.8 * h = 320.00$

$N_u = 4737.328$

$A_g = 80000.00$

From (11.5.4.8), ACI 318-14:  $V_s = V_{s1} + V_{s2} = 0.00$

where:

$V_{s1} = 0.00$  is calculated for section web, with:

$d = 320.00$

$A_v = 157079.633$

$f_y = 444.44$

$s = 380.00$

$V_{s1}$  is multiplied by  $Col1 = 0.00$

$s/d = 1.1875$

$V_{s2} = 0.00$  is calculated for section flange, with:

$d = 160.00$

$A_v = 157079.633$

$f_y = 444.44$

$s = 380.00$

$V_{s2}$  is multiplied by  $Col2 = 0.00$

$s/d = 2.375$

$V_f \text{ ((11-3)-(11.4), ACI 440)} = 188111.148$

$f = 0.95$ , for fully-wrapped sections

$w_f/s_f = 1$  (FRP strips adjacent to one another).

In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot_a) \sin \alpha$  which is more a generalised expression, where  $\alpha$  is the angle of the crack direction (see KANEPE).

This later relation, considered as a function  $V_f(\alpha)$ , is implemented for every different fiber orientation  $\alpha_i$ , as well as for 2 crack directions,  $\alpha = 45^\circ$  and  $\alpha = -45^\circ$  to take into consideration the cyclic seismic loading.

orientation 1:  $\alpha = b1 + 90^\circ = 90.00$

$V_f = \text{Min}(|V_f(45, \alpha)|, |V_f(-45, \alpha)|)$ , with:

total thickness per orientation,  $t_{f1} = N_L * t / N_{oDir} = 1.016$

$d_{fv} = d$  (figure 11.2, ACI 440) = 357.00

$f_{fe} \text{ ((11-5), ACI 440)} = 259.312$

$E_f = 64828.00$

$f_e = 0.004$ , from (11.6a), ACI 440

with  $f_u = 0.01$

From (11-11), ACI 440:  $V_s + V_f \leq 164661.611$

$b_w = 200.00$

Calculation of Shear Strength at edge 2,  $V_{r2} = 196005.816$

$V_{r2} = V_{Col} \text{ ((10.3), ASCE 41-17)} = k_{nl} * V_{Col0}$

$V_{Col0} = 196005.816$

$k_{nl} = 1$  (zero step-static loading)

NOTE: In expression (10-3) ' $V_s$ ' is replaced by ' $V_s + f * V_f$ ' where  $V_f$  is the contribution of FRPs (11.3), ACI 440).

$\lambda = 1$  (normal-weight concrete)

$f'_c = 15.00$ , but  $f'_c^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$M/Vd = 4.00$

$\mu_u = 23.99609$

$\nu_u = 0.01054019$

$d = 0.8 * h = 320.00$

$N_u = 4737.328$   
 $A_g = 80000.00$   
 From (11.5.4.8), ACI 318-14:  $V_s = V_{s1} + V_{s2} = 0.00$   
 where:  
 $V_{s1} = 0.00$  is calculated for section web, with:  
 $d = 320.00$   
 $A_v = 157079.633$   
 $f_y = 444.44$   
 $s = 380.00$   
 $V_{s1}$  is multiplied by  $Col1 = 0.00$   
 $s/d = 1.1875$   
 $V_{s2} = 0.00$  is calculated for section flange, with:  
 $d = 160.00$   
 $A_v = 157079.633$   
 $f_y = 444.44$   
 $s = 380.00$   
 $V_{s2}$  is multiplied by  $Col2 = 0.00$   
 $s/d = 2.375$   
 $V_f ((11-3)-(11.4), ACI 440) = 188111.148$   
 $f = 0.95$ , for fully-wrapped sections  
 $wf/sf = 1$  (FRP strips adjacent to one another).  
 In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot a) \sin a$  which is more a generalised expression,  
 where  $a$  is the angle of the crack direction (see KANEPE).  
 This later relation, considered as a function  $V_f( , )$ , is implemented for every different fiber orientation  $a_i$ ,  
 as well as for 2 crack directions,  $a = 45^\circ$  and  $a = -45^\circ$  to take into consideration the cyclic seismic loading.  
 orientation 1:  $a_1 = b_1 + 90^\circ = 90.00$   
 $V_f = \text{Min}(|V_f(45, 1)|, |V_f(-45, a_1)|)$ , with:  
 total thickness per orientation,  $t_{f1} = N_L * t / N_{oDir} = 1.016$   
 $d_{fv} = d$  (figure 11.2, ACI 440) = 357.00  
 $f_{fe} ((11-5), ACI 440) = 259.312$   
 $E_f = 64828.00$   
 $f_e = 0.004$ , from (11.6a), ACI 440  
 with  $f_u = 0.01$   
 From (11-11), ACI 440:  $V_s + V_f \leq 164661.611$   
 $b_w = 200.00$

-----  
 End Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1  
 At local axis: 3  
 -----

-----  
 Start Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1  
 At Shear local axis: 2  
 (Bending local axis: 3)  
 Section Type: rctcs

Constant Properties

-----  
 Knowledge Factor,  $\phi = 0.90$   
 Mean strength values are used for both shear and moment calculations.  
 Consequently:  
 Existing material of Primary Member: Concrete Strength,  $f_c = f_{cm} = 15.00$   
 Existing material of Primary Member: Steel Strength,  $f_s = f_{sm} = 444.44$   
 Concrete Elasticity,  $E_c = 18203.022$   
 Steel Elasticity,  $E_s = 200000.00$   
 #####  
 Note: Especially for the calculation of moment strengths,  
 the above steel re-bar strengths are multiplied by 1.25 according to R18.6.5, ACI 318-14  
 Existing material: Steel Strength,  $f_s = 1.25 * f_{sm} = 555.55$   
 #####  
 Max Height,  $H_{max} = 400.00$   
 Min Height,  $H_{min} = 200.00$   
 Max Width,  $W_{max} = 400.00$   
 Min Width,  $W_{min} = 200.00$   
 Eccentricity,  $E_{cc} = 100.00$

Cover Thickness,  $c = 25.00$   
 Mean Confinement Factor overall section = 1.27578  
 Element Length,  $L = 3000.00$   
 Primary Member  
 Ribbed Bars  
 Ductile Steel  
 Without Detailing for Earthquake Resistance (including stirrups not closed at 135°)  
 Longitudinal Bars With Ends Lapped Starting at the End Sections  
 Lap Length  $l_o = 300.00$   
 FRP Wrapping Data  
 Type: Carbon  
 Cured laminate properties (design values)  
 Thickness,  $t = 1.016$   
 Tensile Strength,  $f_{fu} = 1055.00$   
 Tensile Modulus,  $E_f = 64828.00$   
 Elongation,  $\epsilon_{fu} = 0.01$   
 Number of directions,  $NoDir = 1$   
 Fiber orientations,  $b_i: 0.00^\circ$   
 Number of layers,  $NL = 1$   
 Radius of rounding corners,  $R = 40.00$

#### Stepwise Properties

At local axis: 2  
 EDGE -A-  
 Shear Force,  $V_a = 1.5456333E-009$   
 EDGE -B-  
 Shear Force,  $V_b = -1.5456333E-009$   
 BOTH EDGES  
 Axial Force,  $F = -4737.328$   
 Longitudinal Reinforcement Area Distribution (in 2 divisions)  
     -Tension:  $As_t = 0.00$   
     -Compression:  $As_c = 5152.212$   
 Longitudinal Reinforcement Area Distribution (in 3 divisions)  
     -Tension:  $As_{t,ten} = 1231.504$   
     -Compression:  $As_{c,com} = 1231.504$   
     -Middle:  $As_{l,mid} = 2689.203$

Calculation of Shear Capacity ratio ,  $V_e/V_r = 0.55718248$   
 Member Controlled by Flexure ( $V_e/V_r < 1$ )  
 Calculation of Shear Demand from fig. R18.6.5, ACI 318-14  $V_e = (M_{pr1} + M_{pr2})/l_n = 126675.449$   
 with  
 $M_{pr1} = \text{Max}(\mu_{u1+}, \mu_{u1-}) = 1.9001E+008$   
 $\mu_{u1+} = 1.9001E+008$ , is the ultimate moment strength at the edge 1 of the member in the actual moment direction which is defined for the static loading combination  
 $\mu_{u1-} = 1.9001E+008$ , is the ultimate moment strength at the edge 1 of the member in the opposite moment direction which is defined for the static loading combination  
 $M_{pr2} = \text{Max}(\mu_{u2+}, \mu_{u2-}) = 1.9001E+008$   
 $\mu_{u2+} = 1.9001E+008$ , is the ultimate moment strength at the edge 2 of the member in the actual moment direction which is defined for the the static loading combination  
 $\mu_{u2-} = 1.9001E+008$ , is the ultimate moment strength at the edge 2 of the member in the opposite moment direction which is defined for the the static loading combination

#### Calculation of $\mu_{u1+}$

Calculation of ultimate curvature  $\phi_u$  according to 4.1, Biskinis/Fardis 2013:  
 $\phi_u = 1.7086748E-005$   
 $\mu_u = 1.9001E+008$

with full section properties:

b = 200.00  
d = 357.00  
d' = 43.00  
v = 0.00442328  
N = 4737.328

fc = 15.00

co (5A.5, TBDY) = 0.002

Final value of cu:  $cu^* = \text{shear\_factor} * \text{Max}(cu, cc) = 0.018$

The Shear\_factor is considered equal to 1 (pure moment strength)

From (5.4b), TBDY:  $cu = 0.018$

we ((5.4c), TBDY) =  $ase * sh_{min} * fy_{we} / f_{ce} + \text{Min}(fx, fy) = 0.15303423$

where  $f = af * pf * f_{fe} / f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

-----  
 $fx = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $af = 1 - (\text{Unconfined area}) / (\text{total area})$

$af = 0.43111111$

with Unconfined area =  $((b_{max} - 2R)^2 + (h_{max} - 2R)^2) / 3 = 51733.333$

$b_{max} = 400.00$

$h_{max} = 400.00$

From EC8 A4.4.3(6),  $pf = 2tf/bw = 0.01016$

$bw = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

-----  
 $fy = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $af = 1 - (\text{Unconfined area}) / (\text{total area})$

$af = 0.43111111$

with Unconfined area =  $((b_{max} - 2R)^2 + (h_{max} - 2R)^2) / 3 = 0.00$

$b_{max} = 400.00$

$h_{max} = 400.00$

From EC8 A4.4.3(6),  $pf = 2tf/bw = 0.01016$

$bw = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

-----  
 $R = 40.00$

Effective FRP thickness,  $tf = NL * t * \cos(b1) = 1.016$

$f_{u,f} = 1055.00$

$E_f = 64828.00$

$u_{f,f} = 0.015$

$ase = \text{Max}(((A_{conf,max} - A_{noConf}) / A_{conf,max}) * (A_{conf,min} / A_{conf,max}), 0) = 0.00$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$psh_{min} = \text{Min}(psh_x, psh_y) = 0.00165347$

Expression ((5.4d), TBDY) for  $psh_{min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

-----  
 $psh_x ((5.4d), TBDY) = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$

$L_{stir}$  (Length of stirrups along Y) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

-----  
 $psh_y ((5.4d), TBDY) = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$

$L_{stir}$  (Length of stirrups along X) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

-----  
 $s = 380.00$

$fy_{we} = 555.55$

$f_{ce} = 15.00$

From ((5.A.5), TBDY), TBDY:  $cc = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $y1 = 0.0010562$   
 $sh1 = 0.00365026$   
 $ft1 = 304.185$   
 $fy1 = 253.4875$   
 $su1 = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $lo/lou,min = lb/ld = 0.22053887$   
 $su1 = 0.4*esu1\_nominal ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esu1\_nominal = 0.08$ ,  
 For calculation of  $esu1\_nominal$  and  $y1, sh1, ft1, fy1$ , it is considered  
 characteristic value  $fsy1 = fs1/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25*(lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fs1 = fs = 253.4875$   
 with  $Es1 = Es = 200000.00$   
 $y2 = 0.0010562$   
 $sh2 = 0.00365026$   
 $ft2 = 304.185$   
 $fy2 = 253.4875$   
 $su2 = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $lo/lou,min = lb/lb,min = 0.22053887$   
 $su2 = 0.4*esu2\_nominal ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esu2\_nominal = 0.08$ ,  
 For calculation of  $esu2\_nominal$  and  $y2, sh2, ft2, fy2$ , it is considered  
 characteristic value  $fsy2 = fs2/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25*(lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fs2 = fs = 253.4875$   
 with  $Es2 = Es = 200000.00$   
 $yv = 0.0010562$   
 $shv = 0.00365026$   
 $ftv = 304.185$   
 $fyv = 253.4875$   
 $suv = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $lo/lou,min = lb/ld = 0.22053887$   
 $suv = 0.4*esuv\_nominal ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esuv\_nominal = 0.08$ ,  
 considering characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY  
 For calculation of  $esuv\_nominal$  and  $yv, shv, ftv, fyv$ , it is considered  
 characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25*(lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fsv = fs = 253.4875$   
 with  $Esv = Es = 200000.00$   
 $1 = Asl,ten/(b*d)*(fs1/fc) = 0.29147618$   
 $2 = Asl,com/(b*d)*(fs2/fc) = 0.29147618$   
 $v = Asl,mid/(b*d)*(fsv/fc) = 0.6364888$   
 and confined core properties:  
 $b = 140.00$   
 $d = 327.00$   
 $d' = 13.00$   
 $fcc (5A.2, TBDY) = 19.13667$   
 $cc (5A.5, TBDY) = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $1 = Asl,ten/(b*d)*(fs1/fc) = 0.45459588$   
 $2 = Asl,com/(b*d)*(fs2/fc) = 0.45459588$   
 $v = Asl,mid/(b*d)*(fsv/fc) = 0.99268896$   
 Case/Assumption: Unconfined full section - Steel rupture  
 ' satisfies Eq. (4.3)

--->

$v < v_{s,y2}$  - LHS eq.(4.5) is not satisfied

---->

$v < v_{s,c}$  - RHS eq.(4.5) is satisfied

---->

$\mu_u (4.8) = 0.40159417$

$\mu_u = M_{Rc} (4.15) = 1.9001E+008$

$u = \mu_u (4.1) = 1.7086748E-005$

Calculation of ratio  $l_b/l_d$

Lap Length:  $l_b/l_d = 0.22053887$

$l_b = 300.00$

$l_d = 1360.304$

Calculation of  $l_b, \min$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$= 1$

$d_b = 18.00$

Mean strength value of all re-bars:  $f_y = 555.55$

$f_c' = 15.00$ , but  $f_c'^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$t = 1.00$

$s = 0.80$

$e = 1.00$

$c_b = 24.02082$

$K_{tr} = 0.82673491$

$A_{tr} = \min(A_{tr,x}, A_{tr,y}) = 157.0796$

where  $A_{tr,x}$ ,  $A_{tr,y}$  are the sum of the area of all stirrup legs along X and Y local axis

$s = 380.00$

$n = 20.00$

Calculation of  $\mu_{u1}$ -

Calculation of ultimate curvature  $\mu_u$  according to 4.1, Biskinis/Fardis 2013:

$u = 1.7086748E-005$

$\mu_u = 1.9001E+008$

with full section properties:

$b = 200.00$

$d = 357.00$

$d' = 43.00$

$v = 0.00442328$

$N = 4737.328$

$f_c = 15.00$

$\alpha_{co} (5A.5, \text{TB DY}) = 0.002$

Final value of  $\mu_u$ :  $\mu_u^* = \text{shear\_factor} * \max(\mu_u, \alpha_{co}) = 0.018$

The Shear\_factor is considered equal to 1 (pure moment strength)

From (5.4b), TB DY:  $\mu_u = 0.018$

we ((5.4c), TB DY) =  $\alpha_{se} * \frac{f_{y, \min} * f_{y, \text{we}}}{f_{c, \text{e}}} + \min(f_x, f_y) = 0.15303423$

where  $f = \alpha_f * \frac{p_f * f_{f, \text{e}}}{f_{c, \text{e}}}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$f_x = 0.15303423$

Expression ((15B.6), TB DY) is modified as  $\alpha_f = 1 - (\text{Unconfined area})/(\text{total area})$

$\alpha_f = 0.43111111$

with Unconfined area =  $((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 51733.333$

$b_{\max} = 400.00$

$h_{\max} = 400.00$

From EC8 A.4.4.3(6),  $p_f = 2t_f/b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{f, \text{e}} = 524.0792$

$f_y = 0.15303423$

Expression ((15B.6), TB DY) is modified as  $\alpha_f = 1 - (\text{Unconfined area})/(\text{total area})$

$\alpha_f = 0.43111111$

with Unconfined area =  $((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 0.00$

bmax = 400.00  
hmax = 400.00  
From EC8 A4.4.3(6),  $pf = 2tf/bw = 0.01016$   
bw = 200.00  
effective stress from (A.35),  $ff,e = 524.0792$

R = 40.00  
Effective FRP thickness,  $tf = NL*t*Cos(b1) = 1.016$   
 $f_{u,f} = 1055.00$   
 $E_f = 64828.00$   
 $u_{,f} = 0.015$

$ase = \text{Max}(((A_{conf,max} - A_{noConf}) / A_{conf,max}) * (A_{conf,min} / A_{conf,max}), 0) = 0.00$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988) "Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$psh,min = \text{Min}(psh,x, psh,y) = 0.00165347$

Expression ((5.4d), TBDY) for  $psh,min$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$psh,x \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$   
 $L_{stir}$  (Length of stirrups along Y) = 960.00  
 $A_{stir}$  (stirrups area) = 78.53982  
 $A_{sec}$  (section area) = 120000.00

$psh,y \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$   
 $L_{stir}$  (Length of stirrups along X) = 960.00  
 $A_{stir}$  (stirrups area) = 78.53982  
 $A_{sec}$  (section area) = 120000.00

s = 380.00  
 $f_{ywe} = 555.55$   
 $f_{ce} = 15.00$

From ((5.A5), TBDY), TBDY:  $cc = 0.00475778$   
c = confinement factor = 1.27578

$y1 = 0.0010562$   
 $sh1 = 0.00365026$

$ft1 = 304.185$

$fy1 = 253.4875$

$su1 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$lo/lo_{u,min} = lb/ld = 0.22053887$

$su1 = 0.4 * esu1_{nominal} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu1_{nominal} = 0.08$ ,

For calculation of  $esu1_{nominal}$  and  $y1, sh1, ft1, fy1$ , it is considered characteristic value  $fsy1 = fs1/1.2$ , from table 5.1, TBDY.

$y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 * (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.

with  $fs1 = fs = 253.4875$

with  $Es1 = Es = 200000.00$

$y2 = 0.0010562$   
 $sh2 = 0.00365026$

$ft2 = 304.185$

$fy2 = 253.4875$

$su2 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$lo/lo_{u,min} = lb/lb_{,min} = 0.22053887$



```

su2 = 0.4*esu2_nominal ((5.5), TBDY) = 0.032
From table 5A.1, TBDY: esu2_nominal = 0.08,
For calculation of esu2_nominal and y2, sh2,ft2,fy2, it is considered
characteristic value fsy2 = fs2/1.2, from table 5.1, TBDY.
y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/ld)^ 2/3), from 10.3.5, ASCE 41-17.
with fs2 = fs = 253.4875
with Es2 = Es = 200000.00
yv = 0.0010562
shv = 0.00365026
ftv = 304.185
fyv = 253.4875
suv = 0.00365026
using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
and also multiplied by the shear_factor according to 15.7.1.4, with
Shear_factor = 1.00
lo/lou,min = lb/ld = 0.22053887
suv = 0.4*esuv_nominal ((5.5), TBDY) = 0.032
From table 5A.1, TBDY: esuv_nominal = 0.08,
considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY
For calculation of esuv_nominal and yv, shv,ftv,fyv, it is considered
characteristic value fsyv = fsv/1.2, from table 5.1, TBDY.
y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/ld)^ 2/3), from 10.3.5, ASCE 41-17.
with fsv = fs = 253.4875
with Esv = Es = 200000.00
1 = Asl,ten/(b*d)*(fs1/fc) = 0.29147618
2 = Asl,com/(b*d)*(fs2/fc) = 0.29147618
v = Asl,mid/(b*d)*(fsv/fc) = 0.6364888
and confined core properties:
b = 140.00
d = 327.00
d' = 13.00
fcc (5A.2, TBDY) = 19.13667
cc (5A.5, TBDY) = 0.00475778
c = confinement factor = 1.27578
1 = Asl,ten/(b*d)*(fs1/fc) = 0.45459588
2 = Asl,com/(b*d)*(fs2/fc) = 0.45459588
v = Asl,mid/(b*d)*(fsv/fc) = 0.99268896
Case/Assumption: Unconfined full section - Steel rupture
'satisfies Eq. (4.3)
--->
v < vs,y2 - LHS eq.(4.5) is not satisfied
--->
v < vs,c - RHS eq.(4.5) is satisfied
--->
su (4.8) = 0.40159417
Mu = MRc (4.15) = 1.9001E+008
u = su (4.1) = 1.7086748E-005

```

#### Calculation of ratio lb/ld

```

Lap Length: lb/ld = 0.22053887
lb = 300.00
ld = 1360.304
Calculation of lb,min according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.
= 1
db = 18.00
Mean strength value of all re-bars: fy = 555.55
fc' = 15.00, but fc^0.5 <= 8.3 MPa (22.5.3.1, ACI 318-14)
t = 1.00
s = 0.80
e = 1.00
cb = 24.02082
Ktr = 0.82673491
Atr = Min(Atr_x,Atr_y) = 157.0796
where Atr_x, Atr_y are the sum of the area of all stirrup legs along X and Y loxal axis
s = 380.00

```

n = 20.00

Calculation of  $\mu_{2+}$

Calculation of ultimate curvature  $\mu$  according to 4.1, Biskinis/Fardis 2013:

$\mu = 1.7086748E-005$

$\mu_u = 1.9001E+008$

with full section properties:

b = 200.00

d = 357.00

d' = 43.00

v = 0.00442328

N = 4737.328

$f_c = 15.00$

$\mu_c$  (5A.5, TBDY) = 0.002

Final value of  $\mu_c$ :  $\mu_c^* = \text{shear\_factor} * \text{Max}(\mu_c, \mu_c) = 0.018$

The Shear\_factor is considered equal to 1 (pure moment strength)

From (5.4b), TBDY:  $\mu_c = 0.018$

where ((5.4c), TBDY) =  $\mu_c^* * \text{sh}_{\min} * f_{ywe} / f_{ce} + \text{Min}(f_x, f_y) = 0.15303423$

where  $f = \mu_c^* * p_f * f_{fe} / f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$f_x = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $\mu_c = 1 - (\text{Unconfined area}) / (\text{total area})$

$\mu_c = 0.43111111$

with Unconfined area =  $((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2) / 3 = 51733.333$

$b_{\max} = 400.00$

$h_{\max} = 400.00$

From EC8 A4.4.3(6),  $p_f = 2t_f / b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

$f_y = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $\mu_c = 1 - (\text{Unconfined area}) / (\text{total area})$

$\mu_c = 0.43111111$

with Unconfined area =  $((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2) / 3 = 0.00$

$b_{\max} = 400.00$

$h_{\max} = 400.00$

From EC8 A4.4.3(6),  $p_f = 2t_f / b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

R = 40.00

Effective FRP thickness,  $t_f = N L^* t \cos(b_1) = 1.016$

$f_{u,f} = 1055.00$

$E_f = 64828.00$

$\mu_{u,f} = 0.015$

$\mu_{ase} = \text{Max}(((A_{\text{conf,max}} - A_{\text{noConf}}) / A_{\text{conf,max}}) * (A_{\text{conf,min}} / A_{\text{conf,max}}), 0) = 0.00$

The definitions of  $A_{\text{noConf}}$ ,  $A_{\text{conf,min}}$  and  $A_{\text{conf,max}}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{\text{conf,max}} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{\text{conf,min}} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{\text{conf,max}}$  by a length equal to half the clear spacing between hoops.

$A_{\text{noConf}} = 33066.667$  is the unconfined core area which is equal to  $b_i^2 / 6$  as defined at (A.2).

$p_{sh,\min} = \text{Min}(p_{sh,x}, p_{sh,y}) = 0.00165347$

Expression ((5.4d), TBDY) for  $p_{sh,\min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$$psh,x ((5.4d), TBDY) = Lstir * Astir / (Asec * s) = 0.00165347$$

$$Lstir \text{ (Length of stirrups along Y)} = 960.00$$

$$Astir \text{ (stirrups area)} = 78.53982$$

$$Asec \text{ (section area)} = 120000.00$$

$$psh,y ((5.4d), TBDY) = Lstir * Astir / (Asec * s) = 0.00165347$$

$$Lstir \text{ (Length of stirrups along X)} = 960.00$$

$$Astir \text{ (stirrups area)} = 78.53982$$

$$Asec \text{ (section area)} = 120000.00$$

$$s = 380.00$$

$$fywe = 555.55$$

$$fce = 15.00$$

$$\text{From } ((5.A5), TBDY), TBDY: cc = 0.00475778$$

$$c = \text{confinement factor} = 1.27578$$

$$y1 = 0.0010562$$

$$sh1 = 0.00365026$$

$$ft1 = 304.185$$

$$fy1 = 253.4875$$

$$su1 = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00

$$lo/lou,min = lb/ld = 0.22053887$$

$$su1 = 0.4 * esu1\_nominal ((5.5), TBDY) = 0.032$$

$$\text{From table 5A.1, TBDY: } esu1\_nominal = 0.08,$$

For calculation of esu1\_nominal and y1, sh1, ft1, fy1, it is considered  
characteristic value fsy1 = fs1/1.2, from table 5.1, TBDY.

$$y1, sh1, ft1, fy1, \text{ are also multiplied by } \text{Min}(1, 1.25 * (lb/ld)^{2/3}), \text{ from 10.3.5, ASCE 41-17.}$$

$$\text{with } fs1 = fs = 253.4875$$

$$\text{with } Es1 = Es = 200000.00$$

$$y2 = 0.0010562$$

$$sh2 = 0.00365026$$

$$ft2 = 304.185$$

$$fy2 = 253.4875$$

$$su2 = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00

$$lo/lou,min = lb/lb,min = 0.22053887$$

$$su2 = 0.4 * esu2\_nominal ((5.5), TBDY) = 0.032$$

$$\text{From table 5A.1, TBDY: } esu2\_nominal = 0.08,$$

For calculation of esu2\_nominal and y2, sh2, ft2, fy2, it is considered  
characteristic value fsy2 = fs2/1.2, from table 5.1, TBDY.

$$y1, sh1, ft1, fy1, \text{ are also multiplied by } \text{Min}(1, 1.25 * (lb/ld)^{2/3}), \text{ from 10.3.5, ASCE 41-17.}$$

$$\text{with } fs2 = fs = 253.4875$$

$$\text{with } Es2 = Es = 200000.00$$

$$yv = 0.0010562$$

$$shv = 0.00365026$$

$$ftv = 304.185$$

$$fyv = 253.4875$$

$$suv = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00

$$lo/lou,min = lb/ld = 0.22053887$$

$$suv = 0.4 * esuv\_nominal ((5.5), TBDY) = 0.032$$

$$\text{From table 5A.1, TBDY: } esuv\_nominal = 0.08,$$

considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY

For calculation of esuv\_nominal and yv, shv, ftv, fyv, it is considered  
characteristic value fsyv = fsv/1.2, from table 5.1, TBDY.

$$y1, sh1, ft1, fy1, \text{ are also multiplied by } \text{Min}(1, 1.25 * (lb/ld)^{2/3}), \text{ from 10.3.5, ASCE 41-17.}$$

$$\text{with } fsv = fs = 253.4875$$

$$\text{with } Esv = Es = 200000.00$$

$$1 = Asl,ten / (b * d) * (fs1 / fc) = 0.29147618$$

$$2 = Asl,com / (b * d) * (fs2 / fc) = 0.29147618$$

$$v = Asl,mid / (b * d) * (fsv / fc) = 0.6364888$$

and confined core properties:

$$b = 140.00$$

$$d = 327.00$$

$$d' = 13.00$$

$$fcc(5A.2, TBDY) = 19.13667$$

$$cc(5A.5, TBDY) = 0.00475778$$

$$c = \text{confinement factor} = 1.27578$$

$$1 = A_{sl,ten}/(b*d)*(f_{s1}/f_c) = 0.45459588$$

$$2 = A_{sl,com}/(b*d)*(f_{s2}/f_c) = 0.45459588$$

$$v = A_{sl,mid}/(b*d)*(f_{sv}/f_c) = 0.99268896$$

Case/Assumption: Unconfined full section - Steel rupture

' satisfies Eq. (4.3)

--->

$v < v_{s,y2}$  - LHS eq.(4.5) is not satisfied

--->

$v < v_{s,c}$  - RHS eq.(4.5) is satisfied

--->

$$su(4.8) = 0.40159417$$

$$Mu = MR_c(4.15) = 1.9001E+008$$

$$u = su(4.1) = 1.7086748E-005$$

Calculation of ratio  $l_b/d$

Lap Length:  $l_b/d = 0.22053887$

$$l_b = 300.00$$

$$l_d = 1360.304$$

Calculation of  $l_b, \min$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$$= 1$$

$$d_b = 18.00$$

Mean strength value of all re-bars:  $f_y = 555.55$

$$f_c' = 15.00, \text{ but } f_c'^{0.5} \leq 8.3 \text{ MPa (22.5.3.1, ACI 318-14)}$$

$$t = 1.00$$

$$s = 0.80$$

$$e = 1.00$$

$$c_b = 24.02082$$

$$K_{tr} = 0.82673491$$

$$A_{tr} = \min(A_{tr_x}, A_{tr_y}) = 157.0796$$

where  $A_{tr_x}$ ,  $A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y local axis

$$s = 380.00$$

$$n = 20.00$$

Calculation of  $Mu_2$ -

Calculation of ultimate curvature  $u$  according to 4.1, Biskinis/Fardis 2013:

$$u = 1.7086748E-005$$

$$Mu = 1.9001E+008$$

with full section properties:

$$b = 200.00$$

$$d = 357.00$$

$$d' = 43.00$$

$$v = 0.00442328$$

$$N = 4737.328$$

$$f_c = 15.00$$

$$co(5A.5, TBDY) = 0.002$$

$$\text{Final value of } cu: cu^* = \text{shear\_factor} * \max(cu, cc) = 0.018$$

The Shear\_factor is considered equal to 1 (pure moment strength)

$$\text{From (5.4b), TBDY: } cu = 0.018$$

$$\text{we ((5.4c), TBDY) } = a_s e^* sh_{\min} * f_{ywe}/f_{ce} + \min(f_x, f_y) = 0.15303423$$

where  $f = a_f * p_f * f_{fe}/f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$$f_x = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $af = 1 - (\text{Unconfined area})/(\text{total area})$

$af = 0.43111111$

with Unconfined area =  $((b_{max}-2R)^2 + (h_{max}-2R)^2)/3 = 51733.333$

$b_{max} = 400.00$

$h_{max} = 400.00$

From EC8 A.4.4.3(6),  $pf = 2tf/bw = 0.01016$

$bw = 200.00$

effective stress from (A.35),  $ff,e = 524.0792$

$f_y = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $af = 1 - (\text{Unconfined area})/(\text{total area})$

$af = 0.43111111$

with Unconfined area =  $((b_{max}-2R)^2 + (h_{max}-2R)^2)/3 = 0.00$

$b_{max} = 400.00$

$h_{max} = 400.00$

From EC8 A.4.4.3(6),  $pf = 2tf/bw = 0.01016$

$bw = 200.00$

effective stress from (A.35),  $ff,e = 524.0792$

$R = 40.00$

Effective FRP thickness,  $tf = NL \cdot t \cdot \cos(b_1) = 1.016$

$f_{u,f} = 1055.00$

$E_f = 64828.00$

$u_f = 0.015$

$ase = \text{Max}(((A_{conf,max} - A_{noConf})/A_{conf,max}) \cdot (A_{conf,min}/A_{conf,max}), 0) = 0.00$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$p_{sh,min} = \text{Min}(p_{sh,x}, p_{sh,y}) = 0.00165347$

Expression ((5.4d), TBDY) for  $p_{sh,min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$p_{sh,x} \text{ ((5.4d), TBDY)} = L_{stir} \cdot A_{stir} / (A_{sec} \cdot s) = 0.00165347$

$L_{stir}$  (Length of stirrups along Y) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$p_{sh,y} \text{ ((5.4d), TBDY)} = L_{stir} \cdot A_{stir} / (A_{sec} \cdot s) = 0.00165347$

$L_{stir}$  (Length of stirrups along X) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$s = 380.00$

$f_{ywe} = 555.55$

$f_{ce} = 15.00$

From ((5.A5), TBDY), TBDY:  $cc = 0.00475778$

$c$  = confinement factor = 1.27578

$y_1 = 0.0010562$

$sh_1 = 0.00365026$

$ft_1 = 304.185$

$fy_1 = 253.4875$

$su_1 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$lo/lo_{u,min} = lb/ld = 0.22053887$

$su_1 = 0.4 \cdot esu_{1,nominal} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu_{1,nominal} = 0.08$ ,

For calculation of  $esu_{1,nominal}$  and  $y_1$ ,  $sh_1$ ,  $ft_1$ ,  $fy_1$ , it is considered

characteristic value  $f_{sy1} = f_{s1}/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $f_{s1} = f_s = 253.4875$   
 with  $E_{s1} = E_s = 200000.00$   
 $y2 = 0.0010562$   
 $sh2 = 0.00365026$   
 $ft2 = 304.185$   
 $fy2 = 253.4875$   
 $su2 = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $l_o/l_{ou,min} = l_b/l_{b,min} = 0.22053887$   
 $su2 = 0.4 \cdot esu2_{nominal} ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esu2_{nominal} = 0.08$ ,  
 For calculation of  $esu2_{nominal}$  and  $y2, sh2, ft2, fy2$ , it is considered  
 characteristic value  $f_{sy2} = f_{s2}/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $f_{s2} = f_s = 253.4875$   
 with  $E_{s2} = E_s = 200000.00$   
 $yv = 0.0010562$   
 $shv = 0.00365026$   
 $ftv = 304.185$   
 $fyv = 253.4875$   
 $suv = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $l_o/l_{ou,min} = l_b/l_d = 0.22053887$   
 $suv = 0.4 \cdot esuv_{nominal} ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esuv_{nominal} = 0.08$ ,  
 considering characteristic value  $f_{syv} = f_{sv}/1.2$ , from table 5.1, TBDY  
 For calculation of  $esuv_{nominal}$  and  $yv, shv, ftv, fyv$ , it is considered  
 characteristic value  $f_{syv} = f_{sv}/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $f_{sv} = f_s = 253.4875$   
 with  $E_{sv} = E_s = 200000.00$   
 $1 = A_{sl,ten}/(b \cdot d) \cdot (f_{s1}/f_c) = 0.29147618$   
 $2 = A_{sl,com}/(b \cdot d) \cdot (f_{s2}/f_c) = 0.29147618$   
 $v = A_{sl,mid}/(b \cdot d) \cdot (f_{sv}/f_c) = 0.6364888$   
 and confined core properties:  
 $b = 140.00$   
 $d = 327.00$   
 $d' = 13.00$   
 $f_{cc} (5A.2, TBDY) = 19.13667$   
 $cc (5A.5, TBDY) = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $1 = A_{sl,ten}/(b \cdot d) \cdot (f_{s1}/f_c) = 0.45459588$   
 $2 = A_{sl,com}/(b \cdot d) \cdot (f_{s2}/f_c) = 0.45459588$   
 $v = A_{sl,mid}/(b \cdot d) \cdot (f_{sv}/f_c) = 0.99268896$   
 Case/Assumption: Unconfined full section - Steel rupture  
 ' satisfies Eq. (4.3)  
 --->  
 $v < v_{s,y2}$  - LHS eq.(4.5) is not satisfied  
 --->  
 $v < v_{s,c}$  - RHS eq.(4.5) is satisfied  
 --->  
 $su (4.8) = 0.40159417$   
 $Mu = MRc (4.15) = 1.9001E+008$   
 $u = su (4.1) = 1.7086748E-005$

-----  
 Calculation of ratio  $l_b/l_d$   
 -----

Lap Length:  $l_b/l_d = 0.22053887$   
 $l_b = 300.00$   
 $l_d = 1360.304$

Calculation of  $I_{b,min}$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$$= 1$$

$$d_b = 18.00$$

Mean strength value of all re-bars:  $f_y = 555.55$

$$f'_c = 15.00, \text{ but } f_c^{0.5} \leq 8.3 \text{ MPa (22.5.3.1, ACI 318-14)}$$

$$t = 1.00$$

$$s = 0.80$$

$$e = 1.00$$

$$c_b = 24.02082$$

$$K_{tr} = 0.82673491$$

$$A_{tr} = \min(A_{tr_x}, A_{tr_y}) = 157.0796$$

where  $A_{tr_x}$ ,  $A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y local axis

$$s = 380.00$$

$$n = 20.00$$

Calculation of Shear Strength  $V_r = \min(V_{r1}, V_{r2}) = 227350.021$

Calculation of Shear Strength at edge 1,  $V_{r1} = 227350.021$

$$V_{r1} = V_{Col} \text{ ((10.3), ASCE 41-17)} = k_n I^* V_{Col0}$$

$$V_{Col0} = 227350.021$$

$$k_n I = 1 \text{ (zero step-static loading)}$$

NOTE: In expression (10-3) ' $V_s$ ' is replaced by ' $V_s + f^* V_f$ '

where  $V_f$  is the contribution of FRPs (11.3), ACI 440).

$$= 1 \text{ (normal-weight concrete)}$$

$$f'_c = 15.00, \text{ but } f_c^{0.5} \leq 8.3 \text{ MPa (22.5.3.1, ACI 318-14)}$$

$$M/Vd = 2.00$$

$$\mu_u = 0.00988804$$

$$V_u = 1.5456333E-009$$

$$d = 0.8 \cdot h = 320.00$$

$$N_u = 4737.328$$

$$A_g = 80000.00$$

$$\text{From (11.5.4.8), ACI 318-14: } V_s = V_{s1} + V_{s2} = 0.00$$

where:

$V_{s1} = 0.00$  is calculated for section web, with:

$$d = 160.00$$

$$A_v = 157079.633$$

$$f_y = 444.44$$

$$s = 380.00$$

$V_{s1}$  is multiplied by  $\text{Col1} = 0.00$

$$s/d = 2.375$$

$V_{s2} = 0.00$  is calculated for section flange, with:

$$d = 320.00$$

$$A_v = 157079.633$$

$$f_y = 444.44$$

$$s = 380.00$$

$V_{s2}$  is multiplied by  $\text{Col2} = 0.00$

$$s/d = 1.1875$$

$$V_f \text{ ((11-3)-(11.4), ACI 440)} = 188111.148$$

$$f = 0.95, \text{ for fully-wrapped sections}$$

$w_f/s_f = 1$  (FRP strips adjacent to one another).

In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot a) \sin a$  which is more a generalised expression,

where  $a$  is the angle of the crack direction (see KANEPE).

This later relation, considered as a function  $V_f(\theta, a)$ , is implemented for every different fiber orientation  $a_i$ , as well as for 2 crack directions,  $\theta = 45^\circ$  and  $\theta = -45^\circ$  to take into consideration the cyclic seismic loading.

$$\text{orientation 1: } \theta = \theta_1 + 90^\circ = 90.00$$

$$V_f = \min(|V_f(45, \theta_1)|, |V_f(-45, a_1)|), \text{ with:}$$

$$\text{total thickness per orientation, } t_{f1} = N_L \cdot t / N_{\text{Dir}} = 1.016$$

$$d_{fv} = d \text{ (figure 11.2, ACI 440)} = 357.00$$

$$f_{fe} \text{ ((11-5), ACI 440)} = 259.312$$

$$E_f = 64828.00$$

$$f_e = 0.004, \text{ from (11.6a), ACI 440}$$

$$\text{with } f_u = 0.01$$

From (11-11), ACI 440:  $V_s + V_f \leq 164661.611$   
 $bw = 200.00$

Calculation of Shear Strength at edge 2,  $V_{r2} = 227350.021$   
 $V_{r2} = V_{Col} ((10.3), ASCE 41-17) = knl * V_{Col0}$   
 $V_{Col0} = 227350.021$   
 $knl = 1$  (zero step-static loading)

NOTE: In expression (10-3) ' $V_s$ ' is replaced by ' $V_s + f * V_f$ '  
where  $V_f$  is the contribution of FRPs (11.3), ACI 440).

$= 1$  (normal-weight concrete)  
 $f'_c = 15.00$ , but  $f'_c^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$M/Vd = 2.00$

$\mu_u = 0.00525978$

$V_u = 1.5456333E-009$

$d = 0.8 * h = 320.00$

$N_u = 4737.328$

$A_g = 80000.00$

From (11.5.4.8), ACI 318-14:  $V_s = V_{s1} + V_{s2} = 0.00$

where:

$V_{s1} = 0.00$  is calculated for section web, with:

$d = 160.00$

$A_v = 157079.633$

$f_y = 444.44$

$s = 380.00$

$V_{s1}$  is multiplied by  $Col1 = 0.00$

$s/d = 2.375$

$V_{s2} = 0.00$  is calculated for section flange, with:

$d = 320.00$

$A_v = 157079.633$

$f_y = 444.44$

$s = 380.00$

$V_{s2}$  is multiplied by  $Col2 = 0.00$

$s/d = 1.1875$

$V_f ((11-3)-(11.4), ACI 440) = 188111.148$

$f = 0.95$ , for fully-wrapped sections

$w_f/s_f = 1$  (FRP strips adjacent to one another).

In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot a) \sin a$  which is more a generalised expression,  
where  $a$  is the angle of the crack direction (see KANEPE).

This later relation, considered as a function  $V_f(, )$ , is implemented for every different fiber orientation  $a_i$ ,  
as well as for 2 crack directions,  $a = 45^\circ$  and  $a = -45^\circ$  to take into consideration the cyclic seismic loading.

orientation 1:  $a_1 = b_1 + 90^\circ = 90.00$

$V_f = \text{Min}(|V_f(45, 1)|, |V_f(-45, a_1)|)$ , with:

total thickness per orientation,  $t_{f1} = NL * t / N_{oDir} = 1.016$

$d_{fv} = d$  (figure 11.2, ACI 440) = 357.00

$f_{fe} ((11-5), ACI 440) = 259.312$

$E_f = 64828.00$

$f_e = 0.004$ , from (11.6a), ACI 440

with  $f_u = 0.01$

From (11-11), ACI 440:  $V_s + V_f \leq 164661.611$

$bw = 200.00$

End Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1  
At local axis: 2

Start Of Calculation of Chord Rotation Capacity for element: column TC1 of floor 1  
At local axis: 2  
Integration Section: (a)  
Section Type: rctcs

Constant Properties



Knowledge Factor,  $\phi = 0.90$   
Chord Rotation is generally considered as Deformation-Controlled Action according to Table C7-1, ASCE 41-17.  
Mean strengths are used for Deformation-Controlled Actions according to 7.5.1.3, ASCE 41-17  
Consequently:  
Existing material of Primary Member: Concrete Strength,  $f_c = f_{cm} = 15.00$   
Existing material of Primary Member: Steel Strength,  $f_s = f_{sm} = 444.44$   
Concrete Elasticity,  $E_c = 18203.022$   
Steel Elasticity,  $E_s = 200000.00$   
Max Height,  $H_{max} = 400.00$   
Min Height,  $H_{min} = 200.00$   
Max Width,  $W_{max} = 400.00$   
Min Width,  $W_{min} = 200.00$   
Eccentricity,  $Ecc = 100.00$   
Cover Thickness,  $c = 25.00$   
Element Length,  $L = 3000.00$   
Primary Member  
Ribbed Bars  
Ductile Steel  
Without Detailing for Earthquake Resistance (including stirrups not closed at 135°)  
Longitudinal Bars With Ends Lapped Starting at the End Sections  
Lap Length  $l_b = 300.00$   
FRP Wrapping Data  
Type: Carbon  
Cured laminate properties (design values)  
Thickness,  $t = 1.016$   
Tensile Strength,  $f_{fu} = 1055.00$   
Tensile Modulus,  $E_f = 64828.00$   
Elongation,  $\epsilon_{fu} = 0.01$   
Number of directions,  $N_{oDir} = 1$   
Fiber orientations,  $b_i: 0.00^\circ$   
Number of layers,  $N_L = 1$   
Radius of rounding corners,  $R = 40.00$

#### Stepwise Properties

Bending Moment,  $M = 47.67334$   
Shear Force,  $V_2 = -2811.342$   
Shear Force,  $V_3 = -0.02136663$   
Axial Force,  $F = -4735.965$   
Longitudinal Reinforcement Area Distribution (in 2 divisions)  
-Tension:  $As_t = 2375.044$   
-Compression:  $As_c = 2777.168$   
Longitudinal Reinforcement Area Distribution (in 3 divisions)  
-Tension:  $As_{t,ten} = 2261.947$   
-Compression:  $As_{l,com} = 829.3805$   
-Middle:  $As_{l,mid} = 2060.885$   
Mean Diameter of Tension Reinforcement,  $Db_L = 17.77778$

Existing component: From table 7-7, ASCE 41\_17: Final chord rotation Capacity  $u_{,R} = \phi \cdot u = 0.01664493$   
 $u = y + p = 0.01849436$

- Calculation of  $y$  -

$y = (M_y \cdot L_s / 3) / E_{eff} = 0.01849436$  ((4.29), Biskinis Phd))  
 $M_y = 1.9917E+008$   
 $L_s = M/V$  (with  $L_s > 0.1 \cdot L$  and  $L_s < 2 \cdot L$ ) = 2231.206  
From table 10.5, ASCE 41\_17:  $E_{eff} = factor \cdot E_c \cdot I_g = 8.0093E+012$   
factor = 0.30  
 $A_g = 120000.00$   
 $f_c' = 15.00$   
 $N = 4735.965$

$$E_c I_g = 2.6698E+013$$

Calculation of Yielding Moment  $M_y$

Calculation of  $y$  and  $M_y$  according to Annex 7 -

Assuming neutral axis within flange ( $y < t/d$ , compression zone rectangular) with:

flange width,  $b = 400.00$

web width,  $b_w = 200.00$

flange thickness,  $t = 200.00$

$$y = \text{Min}(y_{\text{ten}}, y_{\text{com}})$$

$$y_{\text{ten}} = 5.8877816E-006$$

$$\text{with } ((10.1), \text{ASCE 41-17}) f_y = \text{Min}(f_y, 1.25 \cdot f_y \cdot (l_b/d)^{2/3}) = 235.317$$

$$d = 357.00$$

$$y = 0.44023806$$

$$A = 0.03622085$$

$$B = 0.0247656$$

$$\text{with } p_t = 0.0075814$$

$$p_c = 0.00580799$$

$$p_v = 0.01443197$$

$$N = 4735.965$$

$$b = 400.00$$

$$" = 0.12044818$$

$$y_{\text{comp}} = 1.0200777E-005$$

$$\text{with } f_c' (12.3, (\text{ACI 440})) = 16.19674$$

$$f_c = 15.00$$

$$f_l = 0.93147527$$

$$b = b_{\text{max}} = 400.00$$

$$h = h_{\text{max}} = 400.00$$

$$A_g = 120000.00$$

$$g = p_t + p_c + p_v = 0.03607992$$

$$r_c = 40.00$$

$$A_e/A_c = 0.40981737$$

$$\text{Effective FRP thickness, } t_f = N L \cdot t \cdot \cos(b_1) = 1.016$$

$$\text{effective strain from (12.5) and (12.12), } \epsilon_{fe} = 0.004$$

$$f_u = 0.01$$

$$E_f = 64828.00$$

$$E_c = 18203.022$$

$$y = 0.43979991$$

$$A = 0.03597638$$

$$B = 0.02462466$$

$$\text{with } E_s = 200000.00$$

$$\text{CONFIRMATION: } y = 0.43979991 < t/d$$

Calculation of ratio  $l_b/d$

$$\text{Lap Length: } l_d/d, \text{min} = 0.27567359$$

$$l_b = 300.00$$

$$l_d = 1088.244$$

Calculation of  $I$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$$= 1$$

$$d_b = 18.00$$

$$\text{Mean strength value of all re-bars: } f_y = 444.44$$

$$f_c' = 15.00, \text{ but } f_c'^{0.5} \leq 8.3 \text{ MPa (22.5.3.1, ACI 318-14)}$$

$$t = 1.00$$

$$s = 0.80$$

$$e = 1.00$$

$$c_b = 24.02082$$

$$K_{tr} = 0.82673491$$

$$A_{tr} = \text{Min}(A_{tr_x}, A_{tr_y}) = 157.0796$$

where  $A_{tr_x}$ ,  $A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y local axis

$$s = 380.00$$

n = 20.00

- Calculation of  $\rho$  -

From table 10-8:  $\rho = 0.00$

with:

- Columns controlled by inadequate development or splicing along the clear height because  $l_b/l_d < 1$   
shear control ratio  $V_{yE}/V_{ColOE} = 0.82694402$

d = 357.00

s = 0.00

$t = A_v/(b_w*s) + 2*t_f/b_w*(f_{fe}/f_s) = A_v*L_{stir}/(A_g*s) + 2*t_f/b_w*(f_{fe}/f_s) = 0.0075814$

$A_v = 78.53982$ , is the area of every stirrup

$L_{stir} = 960.00$ , is the total Length of all stirrups parallel to loading (shear) direction

The term  $2*t_f/b_w*(f_{fe}/f_s)$  is implemented to account for FRP contribution

where  $f = 2*t_f/b_w$  is FRP ratio (EC8 - 3, A.4.4.3(6)) and  $f_{fe}/f_s$  normalises  $f$  to steel strength

All these variables have already been given in Shear control ratio calculation.

NUD = 4735.965

$A_g = 120000.00$

$f_{cE} = 15.00$

$f_{yE} = f_{yI} = 444.44$

$\rho_l = \text{Area\_Tot\_Long\_Rein}/(b*d) = 0.03607992$

b = 400.00

d = 357.00

$f_{cE} = 15.00$

End Of Calculation of Chord Rotation Capacity for element: column TC1 of floor 1

At local axis: 2

Integration Section: (a)

### Calculation No. 3

column C1, Floor 1

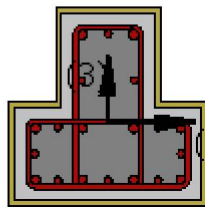
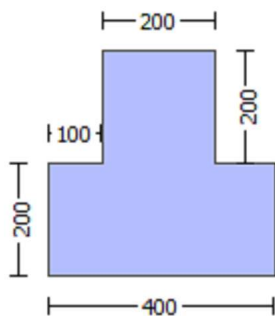
Limit State: Immediate Occupancy (data interpolation between analysis steps 1 and 2)

Analysis: Uniform +X

Check: Shear capacity  $V_{Rd}$

Edge: Start

Local Axis: (3)



Start Of Calculation of Shear Capacity for element: column TC1 of floor 1

At local axis: 3

Integration Section: (a)

Section Type: rctcs

Constant Properties

Knowledge Factor,  $\gamma = 0.90$

Member Shear Force is generally considered as Force-Controlled Action according to Table C7-1, ASCE 41-17.

Lower-bound strengths are used for Force-Controlled Actions according to 7.5.1.3, ASCE 41-17

Consequently:

Existing material of Primary Member: Concrete Strength,  $f_c = f_{c\_lower\_bound} = 10.00$

Existing material of Primary Member: Steel Strength,  $f_s = f_{s\_lower\_bound} = 400.00$

Concrete Elasticity,  $E_c = 18203.022$

Steel Elasticity,  $E_s = 200000.00$

#####

Note: Especially for the calculation of  $\gamma$  for displacement ductility demand, the expected (mean value) strengths are used (7.5.1.3, ASCE 41-17) because bending is considered as Deformation-Controlled Action (Table C7-1, ASCE 41-17).

Existing material: Concrete Strength,  $f_c = f_{cm} = 15.00$

Existing material: Steel Strength,  $f_s = f_{sm} = 444.44$

#####

Max Height,  $H_{max} = 400.00$

Min Height,  $H_{min} = 200.00$

Max Width,  $W_{max} = 400.00$

Min Width,  $W_{min} = 200.00$

Eccentricity,  $Ecc = 100.00$

Cover Thickness,  $c = 25.00$

Element Length,  $L = 3000.00$

Primary Member

Ribbed Bars

Ductile Steel

Without Detailing for Earthquake Resistance (including stirrups not closed at 135°)

Longitudinal Bars With Ends Lapped Starting at the End Sections

Lap Length  $l_o = l_b = 300.00$

FRP Wrapping Data

Type: Carbon

Cured laminate properties (design values)

Thickness,  $t = 1.016$

Tensile Strength,  $f_{fu} = 1055.00$

Tensile Modulus,  $E_f = 64828.00$

Elongation,  $efu = 0.01$

Number of directions,  $NoDir = 1$

Fiber orientations,  $bi: 0.00^\circ$

Number of layers,  $NL = 1$

Radius of rounding corners,  $R = 40.00$

Stepwise Properties

EDGE -A-

Bending Moment,  $Ma = 47.67334$

Shear Force,  $V_a = -0.02136663$   
 EDGE -B-  
 Bending Moment,  $M_b = 21.03175$   
 Shear Force,  $V_b = 0.02136663$   
 BOTH EDGES  
 Axial Force,  $F = -4735.965$   
 Longitudinal Reinforcement Area Distribution (in 2 divisions)  
   -Tension:  $A_{sl,t} = 2375.044$   
   -Compression:  $A_{sl,c} = 2777.168$   
 Longitudinal Reinforcement Area Distribution (in 3 divisions)  
   -Tension:  $A_{sl,ten} = 2261.947$   
   -Compression:  $A_{sl,com} = 829.3805$   
   -Middle:  $A_{sl,mid} = 2060.885$   
 Mean Diameter of Tension Reinforcement,  $Db_{L,ten} = 17.77778$

Existing component: From table 7-7, ASCE 41\_17: Final Shear Capacity  $V_R = V_n = 144111.087$   
 $V_n$  ((10.3), ASCE 41-17) =  $k_n \cdot V_{ColO} = 160123.429$   
 $V_{Col} = 160123.429$   
 $k_n = 1.00$   
 $displacement\_ductility\_demand = 1.7523658E-005$

NOTE: In expression (10-3) ' $V_s$ ' is replaced by ' $V_s + f \cdot V_f$ '  
 where  $V_f$  is the contribution of FRPs ((11.3), ACI 440).

$\phi = 1$  (normal-weight concrete)  
 $f_c' = 10.00$ , but  $f_c'^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)  
 $M/Vd = 4.00$   
 $M_u = 47.67334$   
 $V_u = 0.02136663$   
 $d = 0.8 \cdot h = 320.00$   
 $N_u = 4735.965$   
 $A_g = 80000.00$   
 From ((11.5.4.8), ACI 318-14:  $V_s = V_{s1} + V_{s2} = 0.00$   
 where:  
 $V_{s1} = 0.00$  is calculated for section web, with:  
 $d = 320.00$   
 $A_v = 157079.633$   
 $f_y = 400.00$   
 $s = 380.00$   
 $V_{s1}$  is multiplied by  $Col1 = 0.00$   
 $s/d = 1.1875$   
 $V_{s2} = 0.00$  is calculated for section flange, with:  
 $d = 160.00$   
 $A_v = 157079.633$   
 $f_y = 400.00$   
 $s = 380.00$   
 $V_{s2}$  is multiplied by  $Col2 = 0.00$   
 $s/d = 2.375$   
 $V_f$  ((11-3)-(11.4), ACI 440) =  $188111.148$   
 $f = 0.95$ , for fully-wrapped sections  
 $w_f/s_f = 1$  (FRP strips adjacent to one another).  
 In ((11.3)  $\sin \theta + \cos \theta$  is replaced with  $(\cot \theta + \cot \alpha) \sin \alpha$  which is more a generalised expression,  
 where  $\theta$  is the angle of the crack direction (see KANEPE).  
 This later relation, considered as a function  $V_f(\theta, \alpha)$ , is implemented for every different fiber orientation  $\alpha_i$ ,  
 as well as for 2 crack directions,  $\theta = 45^\circ$  and  $\theta = -45^\circ$  to take into consideration the cyclic seismic loading.  
 orientation 1:  $\theta = b1 + 90^\circ = 90.00$   
 $V_f = \text{Min}(|V_f(45, 1)|, |V_f(-45, \alpha_1)|)$ , with:  
 total thickness per orientation,  $t_{f1} = N_L \cdot t / N_{oDir} = 1.016$   
 $d_{fv} = d$  (figure 11.2, ACI 440) =  $357.00$   
 $f_{fe}$  ((11-5), ACI 440) =  $259.312$   
 $E_f = 64828.00$   
 $f_e = 0.004$ , from ((11.6a), ACI 440)  
 with  $f_u = 0.01$   
 From ((11-11), ACI 440:  $V_s + V_f \leq 134445.642$

bw = 200.00

displacement\_ductility\_demand is calculated as  $\delta / y$

- Calculation of  $\delta / y$  for END A -  
for rotation axis 2 and integ. section (a)

From analysis, chord rotation  $\theta = 3.2408892E-007$   
 $y = (M_y * L_s / 3) / E_{eff} = 0.01849436$  ((4.29), Biskinis Phd))  
 $M_y = 1.9917E+008$   
 $L_s = M/V$  (with  $L_s > 0.1 * L$  and  $L_s < 2 * L$ ) = 2231.206  
From table 10.5, ASCE 41\_17:  $E_{eff} = factor * E_c * I_g = 8.0093E+012$   
factor = 0.30  
 $A_g = 120000.00$   
 $f_c' = 15.00$   
 $N = 4735.965$   
 $E_c * I_g = 2.6698E+013$

Calculation of Yielding Moment  $M_y$

Calculation of  $\delta / y$  and  $M_y$  according to Annex 7 -

Assuming neutral axis within flange ( $y < t/d$ , compression zone rectangular) with:

flange width,  $b = 400.00$   
web width,  $bw = 200.00$   
flange thickness,  $t = 200.00$

$y = \text{Min}(y_{ten}, y_{com})$   
 $y_{ten} = 5.8877816E-006$   
with ((10.1), ASCE 41-17)  $f_y = \text{Min}(f_y, 1.25 * f_y * (l_b / d)^{2/3}) = 235.317$   
 $d = 357.00$   
 $y = 0.44023806$   
 $A = 0.03622085$   
 $B = 0.0247656$   
with  $p_t = 0.01583996$   
 $p_c = 0.00580799$   
 $p_v = 0.01443197$   
 $N = 4735.965$   
 $b = 400.00$   
 $\lambda = 0.12044818$   
 $y_{comp} = 1.0200777E-005$   
with  $f_c' (12.3, (ACI 440)) = 16.19674$   
 $f_c = 15.00$   
 $f_l = 0.93147527$   
 $b = b_{max} = 400.00$   
 $h = h_{max} = 400.00$   
 $A_g = 120000.00$   
 $g = p_t + p_c + p_v = 0.03607992$   
 $rc = 40.00$   
 $A_e / A_c = 0.40981737$   
Effective FRP thickness,  $t_f = N * t * \cos(b_1) = 1.016$   
effective strain from (12.5) and (12.12),  $\epsilon_{fe} = 0.004$   
 $f_u = 0.01$   
 $E_f = 64828.00$   
 $E_c = 18203.022$   
 $y = 0.43979991$   
 $A = 0.03597638$   
 $B = 0.02462466$   
with  $E_s = 200000.00$   
CONFIRMATION:  $y = 0.43979991 < t/d$

#### Calculation of ratio $l_b/l_d$

Lap Length:  $l_d/l_{d,min} = 0.27567359$

$l_b = 300.00$

$l_d = 1088.244$

Calculation of  $l$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.  
 $= 1$

$d_b = 18.00$

Mean strength value of all re-bars:  $f_y = 444.44$

$f'_c = 15.00$ , but  $f_c^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$t = 1.00$

$s = 0.80$

$e = 1.00$

$cb = 24.02082$

$K_{tr} = 0.82673491$

$A_{tr} = \min(A_{tr_x}, A_{tr_y}) = 157.0796$

where  $A_{tr_x}$ ,  $A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y local axis

$s = 380.00$

$n = 20.00$

End Of Calculation of Shear Capacity for element: column TC1 of floor 1

At local axis: 3

Integration Section: (a)

## Calculation No. 4

column C1, Floor 1

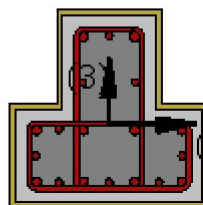
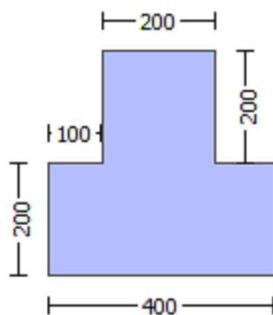
Limit State: Immediate Occupancy (data interpolation between analysis steps 1 and 2)

Analysis: Uniform +X

Check: Chord rotation capacity ( $\phi_r$ )

Edge: Start

Local Axis: (3)



Start Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1

At Shear local axis: 3

(Bending local axis: 2)

Section Type: rctcs

## Constant Properties

Knowledge Factor,  $\phi = 0.90$

Mean strength values are used for both shear and moment calculations.

Consequently:

Existing material of Primary Member: Concrete Strength,  $f_c = f_{cm} = 15.00$

Existing material of Primary Member: Steel Strength,  $f_s = f_{sm} = 444.44$

Concrete Elasticity,  $E_c = 18203.022$

Steel Elasticity,  $E_s = 200000.00$

#####

Note: Especially for the calculation of moment strengths,

the above steel re-bar strengths are multiplied by 1.25 according to R18.6.5, ACI 318-14

Existing material: Steel Strength,  $f_s = 1.25 \cdot f_{sm} = 555.55$

#####

Max Height,  $H_{max} = 400.00$

Min Height,  $H_{min} = 200.00$

Max Width,  $W_{max} = 400.00$

Min Width,  $W_{min} = 200.00$

Eccentricity,  $Ecc = 100.00$

Cover Thickness,  $c = 25.00$

Mean Confinement Factor overall section = 1.27578

Element Length,  $L = 3000.00$

Primary Member

Ribbed Bars

Ductile Steel

Without Detailing for Earthquake Resistance (including stirrups not closed at 135°)

Longitudinal Bars With Ends Lapped Starting at the End Sections

Lap Length  $l_o = 300.00$

FRP Wrapping Data

Type: Carbon

Cured laminate properties (design values)

Thickness,  $t = 1.016$

Tensile Strength,  $f_{fu} = 1055.00$

Tensile Modulus,  $E_f = 64828.00$

Elongation,  $\epsilon_{fu} = 0.01$

Number of directions,  $NoDir = 1$

Fiber orientations,  $b_i: 0.00^\circ$

Number of layers,  $NL = 1$

Radius of rounding corners,  $R = 40.00$

## Stepwise Properties

At local axis: 3

EDGE -A-

Shear Force,  $V_a = 0.01054019$

EDGE -B-

Shear Force,  $V_b = -0.01054019$

BOTH EDGES

Axial Force,  $F = -4737.328$

Longitudinal Reinforcement Area Distribution (in 2 divisions)

-Tension:  $As_t = 0.00$

-Compression:  $As_c = 5152.212$

Longitudinal Reinforcement Area Distribution (in 3 divisions)

-Tension:  $As_{t,ten} = 2261.947$

-Compression:  $As_{c,com} = 829.3805$

-Middle:  $As_{l,mid} = 2060.885$

Calculation of Shear Capacity ratio,  $V_e/V_r = 0.82694402$

Member Controlled by Flexure ( $V_e/V_r < 1$ )

Calculation of Shear Demand from fig. R18.6.5, ACI 318-14  $V_e = (M_{pr1} + M_{pr2})/l_n = 162085.836$

with

$M_{pr1} = \text{Max}(Mu_{1+}, Mu_{1-}) = 2.4313E+008$



Mu1+ = 2.4313E+008, is the ultimate moment strength at the edge 1 of the member in the actual moment direction which is defined for the static loading combination

Mu1- = 1.2706E+008, is the ultimate moment strength at the edge 1 of the member in the opposite moment direction which is defined for the static loading combination

Mpr2 = Max(Mu2+ , Mu2-) = 2.4313E+008

Mu2+ = 2.4313E+008, is the ultimate moment strength at the edge 2 of the member in the actual moment direction which is defined for the the static loading combination

Mu2- = 1.2706E+008, is the ultimate moment strength at the edge 2 of the member in the opposite moment direction which is defined for the the static loading combination

-----  
Calculation of Mu1+  
-----

-----  
Calculation of ultimate curvature  $\phi_u$  according to 4.1, Biskinis/Fardis 2013:

$\phi_u = 2.6161250E-005$

Mu = 2.4313E+008  
-----

with full section properties:

b = 200.00

d = 357.00

d' = 43.00

v = 0.00442328

N = 4737.328

fc = 15.00

co (5A.5, TBDY) = 0.002

Final value of  $\phi_u$ :  $\phi_u^* = \text{shear\_factor} * \text{Max}(\phi_u, \phi_c) = 0.018$

The Shear\_factor is considered equal to 1 (pure moment strength)

From (5.4b), TBDY:  $\phi_u = 0.018$

$\phi_{ue}$  ((5.4c), TBDY) =  $\phi_{se} * \phi_{sh,min} * f_{ywe}/f_{ce} + \text{Min}(\phi_{fx}, \phi_{fy}) = 0.15303423$

where  $\phi_{fx} = \phi_{af} * \phi_{pf} * f_{fe}/f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

-----  
 $\phi_{fx} = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $\phi_{af} = 1 - (\text{Unconfined area})/(\text{total area})$

$\phi_{af} = 0.43111111$

with Unconfined area =  $((b_{max}-2R)^2 + (h_{max}-2R)^2)/3 = 51733.333$

$b_{max} = 400.00$

$h_{max} = 400.00$

From EC8 A4.4.3(6),  $\phi_{pf} = 2t_f/b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

-----  
 $\phi_{fy} = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $\phi_{af} = 1 - (\text{Unconfined area})/(\text{total area})$

$\phi_{af} = 0.43111111$

with Unconfined area =  $((b_{max}-2R)^2 + (h_{max}-2R)^2)/3 = 0.00$

$b_{max} = 400.00$

$h_{max} = 400.00$

From EC8 A4.4.3(6),  $\phi_{pf} = 2t_f/b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

-----  
R = 40.00

Effective FRP thickness,  $t_f = NL * t * \text{Cos}(\beta_1) = 1.016$

$f_{u,f} = 1055.00$

$E_f = 64828.00$

$\phi_{u,f} = 0.015$

$\phi_{ase} = \text{Max}(((A_{conf,max} - A_{noConf})/A_{conf,max}) * (A_{conf,min}/A_{conf,max}), 0) = 0.00$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and

is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and

is calculated by reducing all the dimensions of the area Aconf,max by a length equal to half the clear spacing between hoops.

AnoConf = 33066.667 is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

psh,min = Min(psh,x , psh,y) = 0.00165347

Expression ((5.4d), TBDY) for psh,min has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

psh,x ((5.4d), TBDY) = Lstir\*Astir/(Asec\*s) = 0.00165347

Lstir (Length of stirrups along Y) = 960.00

Astir (stirrups area) = 78.53982

Asec (section area) = 120000.00

psh,y ((5.4d), TBDY) = Lstir\*Astir/(Asec\*s) = 0.00165347

Lstir (Length of stirrups along X) = 960.00

Astir (stirrups area) = 78.53982

Asec (section area) = 120000.00

s = 380.00

fywe = 555.55

fce = 15.00

From ((5.A5), TBDY), TBDY: cc = 0.00475778

c = confinement factor = 1.27578

y1 = 0.0010562

sh1 = 0.00365026

ft1 = 304.185

fy1 = 253.4875

su1 = 0.00365026

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

lo/lou,min = lb/lb = 0.22053887

su1 = 0.4\*esu1\_nominal ((5.5), TBDY) = 0.032

From table 5A.1, TBDY: esu1\_nominal = 0.08,

For calculation of esu1\_nominal and y1, sh1,ft1,fy1, it is considered characteristic value fsy1 = fs1/1.2, from table 5.1, TBDY.

y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25\*(lb/lb)^2/3), from 10.3.5, ASCE 41-17.

with fs1 = fs = 253.4875

with Es1 = Es = 200000.00

y2 = 0.0010562

sh2 = 0.00365026

ft2 = 304.185

fy2 = 253.4875

su2 = 0.00365026

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

lo/lou,min = lb/lb,min = 0.22053887

su2 = 0.4\*esu2\_nominal ((5.5), TBDY) = 0.032

From table 5A.1, TBDY: esu2\_nominal = 0.08,

For calculation of esu2\_nominal and y2, sh2,ft2,fy2, it is considered characteristic value fsy2 = fs2/1.2, from table 5.1, TBDY.

y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25\*(lb/lb)^2/3), from 10.3.5, ASCE 41-17.

with fs2 = fs = 253.4875

with Es2 = Es = 200000.00

yv = 0.0010562

shv = 0.00365026

ftv = 304.185

fyv = 253.4875

suv = 0.00365026

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

lo/lou,min = lb/lb = 0.22053887

suv = 0.4\*esuv\_nominal ((5.5), TBDY) = 0.032

From table 5A.1, TBDY: esuv\_nominal = 0.08,

considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY

For calculation of esuv\_nominal and yv, shv,ftv,fyv, it is considered

```

characteristic value  $f_{sv} = f_{sv}/1.2$ , from table 5.1, TBDY.
 $y_1, sh_1, ft_1, fy_1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.
with  $f_{sv} = f_s = 253.4875$ 
with  $E_{sv} = E_s = 200000.00$ 
 $1 = A_{sl,ten}/(b \cdot d) \cdot (f_{s1}/f_c) = 0.53536441$ 
 $2 = A_{sl,com}/(b \cdot d) \cdot (f_{s2}/f_c) = 0.19630028$ 
 $v = A_{sl,mid}/(b \cdot d) \cdot (f_{sv}/f_c) = 0.48777647$ 
and confined core properties:
 $b = 140.00$ 
 $d = 327.00$ 
 $d' = 13.00$ 
 $f_{cc} \text{ (5A.2, TBDY)} = 19.13667$ 
 $cc \text{ (5A.5, TBDY)} = 0.00475778$ 
 $c = \text{confinement factor} = 1.27578$ 
 $1 = A_{sl,ten}/(b \cdot d) \cdot (f_{s1}/f_c) = 0.83497202$ 
 $2 = A_{sl,com}/(b \cdot d) \cdot (f_{s2}/f_c) = 0.30615641$ 
 $v = A_{sl,mid}/(b \cdot d) \cdot (f_{sv}/f_c) = 0.76075229$ 
Case/Assumption: Unconfined full section - Steel rupture
' satisfies Eq. (4.3)
---->
 $v < v_{s,y2}$  - LHS eq.(4.5) is not satisfied
---->
 $v < v_{s,c}$  - RHS eq.(4.5) is not satisfied
---->
Case/Assumption Rejected.
---->
New Case/Assumption: Unconfined full section - Spalling of concrete cover
' satisfies Eq. (4.4)
---->
 $v < s_{y1}$  - LHS eq.(4.7) is not satisfied
---->
 $v < v_{c,y1}$  - RHS eq.(4.6) is satisfied
---->
 $c_u \text{ (4.10)} = 0.46564051$ 
 $M_{Rc} \text{ (4.17)} = 2.0934E+008$ 
---->
New Case/Assumption: Ultimate curvature of confined core after spalling of concrete cover
In expressions below, the following modifications have been made
-  $b, d, d'$  replaced by geometric parameters of the core:  $b_o, d_o, d'_o$ 
-  $N, 1, 2, v$  normalised to  $b_o \cdot d_o$ , instead of  $b \cdot d$ 
-  $f_{cc}, cc$  parameters of confined concrete,  $f_{cc}, cc$ , used in lieu of  $f_c, e_{cu}$ 
---->
Subcase: Rupture of tension steel
---->
 $v^* < v^*_{s,y2}$  - LHS eq.(4.5) is not satisfied
---->
 $v^* < v^*_{s,c}$  - LHS eq.(4.5) is not satisfied
---->
Subcase rejected
---->
New Subcase: Failure of compression zone
---->
 $v^* < v^*_{c,y2}$  - LHS eq.(4.6) is not satisfied
---->
 $v^* < v^*_{c,y1}$  - RHS eq.(4.6) is satisfied
---->
 $*c_u \text{ (4.10)} = 0.55615794$ 
 $M_{Ro} \text{ (4.17)} = 2.4313E+008$ 
---->
 $u = c_u \text{ (4.2)} = 2.6161250E-005$ 
 $\mu = M_{Ro}$ 
-----

Calculation of ratio  $l_b/l_d$ 
-----
Lap Length:  $l_b/l_d = 0.22053887$ 
 $l_b = 300.00$ 

```

$$I_d = 1360.304$$

Calculation of  $I_{b,min}$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.  
 $= 1$

$$d_b = 18.00$$

Mean strength value of all re-bars:  $f_y = 555.55$

$$f_c' = 15.00, \text{ but } f_c'^{0.5} \leq 8.3 \text{ MPa (22.5.3.1, ACI 318-14)}$$

$$t = 1.00$$

$$s = 0.80$$

$$e = 1.00$$

$$c_b = 24.02082$$

$$K_{tr} = 0.82673491$$

$$A_{tr} = \text{Min}(A_{tr_x}, A_{tr_y}) = 157.0796$$

where  $A_{tr_x}$ ,  $A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis

$$s = 380.00$$

$$n = 20.00$$

Calculation of  $\mu_{u1}$ -

Calculation of ultimate curvature  $\mu_u$  according to 4.1, Biskinis/Fardis 2013:

$$\mu_u = 1.3353763E-005$$

$$\mu_u = 1.2706E+008$$

with full section properties:

$$b = 400.00$$

$$d = 357.00$$

$$d' = 43.00$$

$$v = 0.00221164$$

$$N = 4737.328$$

$$f_c = 15.00$$

$$\phi (5A.5, \text{ TBDY}) = 0.002$$

$$\text{Final value of } \mu_u: \mu_u^* = \text{shear\_factor} * \text{Max}(\mu_u, \mu_c) = 0.018$$

The Shear\_factor is considered equal to 1 (pure moment strength)

$$\text{From (5.4b), TBDY: } \mu_u = 0.018$$

$$\mu_u ((5.4c), \text{ TBDY}) = a_s e^* \text{sh}_{min} * f_{ywe} / f_{ce} + \text{Min}(\mu_{fx}, \mu_{fy}) = 0.15303423$$

where  $\mu_f = a_f * p_f * f_{fe} / f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$$\mu_{fx} = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{max} - 2R)^2 + (h_{max} - 2R)^2) / 3 = 51733.333$$

$$b_{max} = 400.00$$

$$h_{max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } p_f = 2t_f / b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$\mu_{fy} = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{max} - 2R)^2 + (h_{max} - 2R)^2) / 3 = 0.00$$

$$b_{max} = 400.00$$

$$h_{max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } p_f = 2t_f / b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$R = 40.00$$

$$\text{Effective FRP thickness, } t_f = N_L * t * \text{Cos}(b_1) = 1.016$$

$$f_{u,f} = 1055.00$$

$$E_f = 64828.00$$

$$u_{f,f} = 0.015$$

$$a_s = \text{Max}(((A_{conf,max} - A_{noConf}) / A_{conf,max}) * (A_{conf,min} / A_{conf,max}), 0) = 0.00$$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization

of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$p_{sh,min} = \text{Min}(p_{sh,x}, p_{sh,y}) = 0.00165347$

Expression ((5.4d), TBDY) for  $p_{sh,min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$p_{sh,x} \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$

$L_{stir}$  (Length of stirrups along Y) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$p_{sh,y} \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$

$L_{stir}$  (Length of stirrups along X) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$s = 380.00$

$f_{ywe} = 555.55$

$f_{ce} = 15.00$

From ((5.A5), TBDY), TBDY:  $cc = 0.00475778$

$c$  = confinement factor = 1.27578

$y_1 = 0.0010562$

$sh_1 = 0.00365026$

$ft_1 = 304.185$

$fy_1 = 253.4875$

$su_1 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$lo/lou,min = lb/ld = 0.22053887$

$su_1 = 0.4 * esu1_{nominal} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu1_{nominal} = 0.08$ ,

For calculation of  $esu1_{nominal}$  and  $y_1, sh_1, ft_1, fy_1$ , it is considered characteristic value  $fsy_1 = fs_1/1.2$ , from table 5.1, TBDY.

$y_1, sh_1, ft_1, fy_1$ , are also multiplied by  $\text{Min}(1, 1.25 * (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.

with  $fs_1 = fs = 253.4875$

with  $Es_1 = Es = 200000.00$

$y_2 = 0.0010562$

$sh_2 = 0.00365026$

$ft_2 = 304.185$

$fy_2 = 253.4875$

$su_2 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$lo/lou,min = lb/lb,min = 0.22053887$

$su_2 = 0.4 * esu2_{nominal} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu2_{nominal} = 0.08$ ,

For calculation of  $esu2_{nominal}$  and  $y_2, sh_2, ft_2, fy_2$ , it is considered characteristic value  $fsy_2 = fs_2/1.2$ , from table 5.1, TBDY.

$y_2, sh_2, ft_2, fy_2$ , are also multiplied by  $\text{Min}(1, 1.25 * (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.

with  $fs_2 = fs = 253.4875$

with  $Es_2 = Es = 200000.00$

$y_v = 0.0010562$

$sh_v = 0.00365026$

$ft_v = 304.185$

$fy_v = 253.4875$

$su_v = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor

and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $l_o/l_{ou,min} = l_b/l_d = 0.22053887$   
 $s_{uv} = 0.4 * e_{suv,nominal} ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $e_{suv,nominal} = 0.08$ ,  
 considering characteristic value  $f_{syv} = f_{sv}/1.2$ , from table 5.1, TBDY  
 For calculation of  $e_{suv,nominal}$  and  $y_v, sh_v, ft_v, fy_v$ , it is considered  
 characteristic value  $f_{syv} = f_{sv}/1.2$ , from table 5.1, TBDY.  
 $y_1, sh_1, ft_1, fy_1$ , are also multiplied by  $\text{Min}(1, 1.25 * (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $f_{sv} = f_s = 253.4875$   
 with  $E_{sv} = E_s = 200000.00$   
 $1 = A_{sl,ten}/(b*d) * (f_{s1}/f_c) = 0.09815014$   
 $2 = A_{sl,com}/(b*d) * (f_{s2}/f_c) = 0.26768221$   
 $v = A_{sl,mid}/(b*d) * (f_{sv}/f_c) = 0.24388823$   
 and confined core properties:  
 $b = 340.00$   
 $d = 327.00$   
 $d' = 13.00$   
 $f_{cc} (5A.2, TBDY) = 19.13667$   
 $cc (5A.5, TBDY) = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $1 = A_{sl,ten}/(b*d) * (f_{s1}/f_c) = 0.1260644$   
 $2 = A_{sl,com}/(b*d) * (f_{s2}/f_c) = 0.34381201$   
 $v = A_{sl,mid}/(b*d) * (f_{sv}/f_c) = 0.31325094$   
 Case/Assumption: Unconfined full section - Steel rupture  
 ' satisfies Eq. (4.3)  
 --->  
 $v < v_{s,y2}$  - LHS eq.(4.5) is satisfied  
 --->  
 $su (4.9) = 0.23431248$   
 $M_u = M_{Rc} (4.14) = 1.2706E+008$   
 $u = su (4.1) = 1.3353763E-005$

#### Calculation of ratio $l_b/l_d$

Lap Length:  $l_b/l_d = 0.22053887$   
 $l_b = 300.00$   
 $l_d = 1360.304$   
 Calculation of  $l_b,min$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.  
 $= 1$   
 $db = 18.00$   
 Mean strength value of all re-bars:  $f_y = 555.55$   
 $f_c' = 15.00$ , but  $f_c'^{0.5} \leq 8.3 \text{ MPa}$  (22.5.3.1, ACI 318-14)  
 $t = 1.00$   
 $s = 0.80$   
 $e = 1.00$   
 $cb = 24.02082$   
 $K_{tr} = 0.82673491$   
 $A_{tr} = \text{Min}(A_{tr,x}, A_{tr,y}) = 157.0796$   
 where  $A_{tr,x}, A_{tr,y}$  are the sum of the area of all stirrup legs along X and Y local axis  
 $s = 380.00$   
 $n = 20.00$

#### Calculation of $M_{u2+}$

Calculation of ultimate curvature  $u$  according to 4.1, Biskinis/Fardis 2013:

$u = 2.6161250E-005$   
 $M_u = 2.4313E+008$

with full section properties:

$b = 200.00$   
 $d = 357.00$

$$d' = 43.00$$

$$v = 0.00442328$$

$$N = 4737.328$$

$$f_c = 15.00$$

$$c_o(5A.5, \text{TBDY}) = 0.002$$

$$\text{Final value of } c_u: c_u^* = \text{shear\_factor} * \text{Max}(c_u, c_c) = 0.018$$

The Shear\_factor is considered equal to 1 (pure moment strength)

$$\text{From (5.4b), TBDY: } c_u = 0.018$$

$$w_e(5.4c, \text{TBDY}) = a_{se} * s_{h,min} * f_{ywe}/f_{ce} + \text{Min}(f_x, f_y) = 0.15303423$$

where  $f = a_f * p_f * f_{fe}/f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$$f_x = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area})/(\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{max}-2R)^2 + (h_{max}-2R)^2)/3 = 51733.333$$

$$b_{max} = 400.00$$

$$h_{max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } p_f = 2t_f/b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$f_y = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area})/(\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{max}-2R)^2 + (h_{max}-2R)^2)/3 = 0.00$$

$$b_{max} = 400.00$$

$$h_{max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } p_f = 2t_f/b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$R = 40.00$$

$$\text{Effective FRP thickness, } t_f = N L * t * \text{Cos}(b_1) = 1.016$$

$$f_{u,f} = 1055.00$$

$$E_f = 64828.00$$

$$u_{,f} = 0.015$$

$$a_{se} = \text{Max}(((A_{conf,max}-A_{noConf})/A_{conf,max}) * (A_{conf,min}/A_{conf,max}), 0) = 0.00$$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$$p_{sh,min} = \text{Min}(p_{sh,x}, p_{sh,y}) = 0.00165347$$

Expression ((5.4d), TBDY) for  $p_{sh,min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$$p_{sh,x}((5.4d), \text{TBDY}) = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$$

$$L_{stir} (\text{Length of stirrups along Y}) = 960.00$$

$$A_{stir} (\text{stirrups area}) = 78.53982$$

$$A_{sec} (\text{section area}) = 120000.00$$

$$p_{sh,y}((5.4d), \text{TBDY}) = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$$

$$L_{stir} (\text{Length of stirrups along X}) = 960.00$$

$$A_{stir} (\text{stirrups area}) = 78.53982$$

$$A_{sec} (\text{section area}) = 120000.00$$

$$s = 380.00$$

$$f_{ywe} = 555.55$$

$$f_{ce} = 15.00$$

$$\text{From ((5.A5), TBDY), TBDY: } c_c = 0.00475778$$

$$c = \text{confinement factor} = 1.27578$$

```

y1 = 0.0010562
sh1 = 0.00365026
ft1 = 304.185
fy1 = 253.4875
su1 = 0.00365026
using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
and also multiplied by the shear_factor according to 15.7.1.4, with
Shear_factor = 1.00
lo/lou,min = lb/ld = 0.22053887
su1 = 0.4*esu1_nominal ((5.5), TBDY) = 0.032
From table 5A.1, TBDY: esu1_nominal = 0.08,
For calculation of esu1_nominal and y1, sh1,ft1,fy1, it is considered
characteristic value fsy1 = fs1/1.2, from table 5.1, TBDY.
y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/ld)^ 2/3), from 10.3.5, ASCE 41-17.
with fs1 = fs = 253.4875
with Es1 = Es = 200000.00
y2 = 0.0010562
sh2 = 0.00365026
ft2 = 304.185
fy2 = 253.4875
su2 = 0.00365026
using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
and also multiplied by the shear_factor according to 15.7.1.4, with
Shear_factor = 1.00
lo/lou,min = lb/lb,min = 0.22053887
su2 = 0.4*esu2_nominal ((5.5), TBDY) = 0.032
From table 5A.1, TBDY: esu2_nominal = 0.08,
For calculation of esu2_nominal and y2, sh2,ft2,fy2, it is considered
characteristic value fsy2 = fs2/1.2, from table 5.1, TBDY.
y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/ld)^ 2/3), from 10.3.5, ASCE 41-17.
with fs2 = fs = 253.4875
with Es2 = Es = 200000.00
yv = 0.0010562
shv = 0.00365026
ftv = 304.185
fyv = 253.4875
suv = 0.00365026
using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
and also multiplied by the shear_factor according to 15.7.1.4, with
Shear_factor = 1.00
lo/lou,min = lb/ld = 0.22053887
suv = 0.4*esuv_nominal ((5.5), TBDY) = 0.032
From table 5A.1, TBDY: esuv_nominal = 0.08,
considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY
For calculation of esuv_nominal and yv, shv,ftv,fyv, it is considered
characteristic value fsyv = fsv/1.2, from table 5.1, TBDY.
y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/ld)^ 2/3), from 10.3.5, ASCE 41-17.
with fsv = fs = 253.4875
with Esv = Es = 200000.00
1 = Asl,ten/(b*d)*(fs1/fc) = 0.53536441
2 = Asl,com/(b*d)*(fs2/fc) = 0.19630028
v = Asl,mid/(b*d)*(fsv/fc) = 0.48777647
and confined core properties:
b = 140.00
d = 327.00
d' = 13.00
fcc (5A.2, TBDY) = 19.13667
cc (5A.5, TBDY) = 0.00475778
c = confinement factor = 1.27578
1 = Asl,ten/(b*d)*(fs1/fc) = 0.83497202
2 = Asl,com/(b*d)*(fs2/fc) = 0.30615641
v = Asl,mid/(b*d)*(fsv/fc) = 0.76075229
Case/Assumption: Unconfined full section - Steel rupture
'satisfies Eq. (4.3)
---->
v < vs,y2 - LHS eq.(4.5) is not satisfied
---->

```



$v < v_{s,c}$  - RHS eq.(4.5) is not satisfied

--->

Case/Assumption Rejected.

--->

New Case/Assumption: Unconfined full section - Spalling of concrete cover

' satisfies Eq. (4.4)

--->

$v < s_{y1}$  - LHS eq.(4.7) is not satisfied

--->

$v < v_{c,y1}$  - RHS eq.(4.6) is satisfied

--->

$\epsilon_{cu}$  (4.10) = 0.46564051

$M_{Rc}$  (4.17) = 2.0934E+008

--->

New Case/Assumption: Ultimate curvature of confined core after spalling of concrete cover

In expressions below, the following modifications have been made

- $b, d, d'$  replaced by geometric parameters of the core:  $b_o, d_o, d'_o$
- $N, \epsilon_1, \epsilon_2, v$  normalised to  $b_o*d_o$ , instead of  $b*d$
- $\epsilon_c$  - parameters of confined concrete,  $\epsilon_{cc}, \epsilon_{cu}$ , used in lieu of  $\epsilon_c, \epsilon_{cu}$

--->

Subcase: Rupture of tension steel

--->

$v^* < v^*_{s,y2}$  - LHS eq.(4.5) is not satisfied

--->

$v^* < v^*_{s,c}$  - LHS eq.(4.5) is not satisfied

--->

Subcase rejected

--->

New Subcase: Failure of compression zone

--->

$v^* < v^*_{c,y2}$  - LHS eq.(4.6) is not satisfied

--->

$v^* < v^*_{c,y1}$  - RHS eq.(4.6) is satisfied

--->

$\epsilon^*_{cu}$  (4.10) = 0.55615794

$M_{Ro}$  (4.17) = 2.4313E+008

--->

$u = \epsilon_{cu}$  (4.2) = 2.6161250E-005

$M_u = M_{Ro}$

-----  
Calculation of ratio  $l_b/l_d$

-----  
Lap Length:  $l_b/l_d = 0.22053887$

$l_b = 300.00$

$l_d = 1360.304$

Calculation of  $l_{b,min}$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$\lambda = 1$

$d_b = 18.00$

Mean strength value of all re-bars:  $f_y = 555.55$

$f'_c = 15.00$ , but  $f_c^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$t = 1.00$

$s = 0.80$

$e = 1.00$

$c_b = 24.02082$

$K_{tr} = 0.82673491$

$A_{tr} = \min(A_{tr_x}, A_{tr_y}) = 157.0796$

where  $A_{tr_x}, A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y local axis

$s = 380.00$

$n = 20.00$

-----  
Calculation of  $M_{u2}$ -  
-----  
-----

Calculation of ultimate curvature  $\phi_u$  according to 4.1, Biskinis/Fardis 2013:

$$u = 1.3353763E-005$$

$$Mu = 1.2706E+008$$

with full section properties:

$$b = 400.00$$

$$d = 357.00$$

$$d' = 43.00$$

$$v = 0.00221164$$

$$N = 4737.328$$

$$f_c = 15.00$$

$$\omega (5A.5, \text{TBDY}) = 0.002$$

$$\text{Final value of } \phi_u^* = \text{shear\_factor} * \text{Max}(\phi_u, \phi_c) = 0.018$$

The Shear\_factor is considered equal to 1 (pure moment strength)

$$\text{From (5.4b), TBDY: } \phi_u = 0.018$$

$$\omega_e ((5.4c), \text{TBDY}) = a_s e * \phi_{u, \min} * f_{ywe} / f_{ce} + \text{Min}(\phi_{ux}, \phi_{uy}) = 0.15303423$$

where  $\phi = a_s * \phi_f * f_{fe} / f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$$\phi_{ux} = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2) / 3 = 51733.333$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } \phi_f = 2t_f / b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$\phi_{uy} = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2) / 3 = 0.00$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } \phi_f = 2t_f / b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$R = 40.00$$

$$\text{Effective FRP thickness, } t_f = N L * t * \cos(b_1) = 1.016$$

$$f_{u,f} = 1055.00$$

$$E_f = 64828.00$$

$$u_{f} = 0.015$$

$$a_s e = \text{Max}(((A_{\text{conf,max}} - A_{\text{noConf}}) / A_{\text{conf,max}}) * (A_{\text{conf,min}} / A_{\text{conf,max}}), 0) = 0.00$$

The definitions of  $A_{\text{noConf}}$ ,  $A_{\text{conf,min}}$  and  $A_{\text{conf,max}}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{\text{conf,max}} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{\text{conf,min}} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{\text{conf,max}}$  by a length equal to half the clear spacing between hoops.

$A_{\text{noConf}} = 33066.667$  is the unconfined core area which is equal to  $b_i^2 / 6$  as defined at (A.2).

$$\phi_{sh, \min} = \text{Min}(\phi_{sh,x}, \phi_{sh,y}) = 0.00165347$$

Expression ((5.4d), TBDY) for  $\phi_{sh, \min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$$\phi_{sh,x} ((5.4d), \text{TBDY}) = L_{\text{stir}} * A_{\text{stir}} / (A_{\text{sec}} * s) = 0.00165347$$

$$L_{\text{stir}} (\text{Length of stirrups along Y}) = 960.00$$

$$A_{\text{stir}} (\text{stirrups area}) = 78.53982$$

$$A_{\text{sec}} (\text{section area}) = 120000.00$$

$$\phi_{sh,y} ((5.4d), \text{TBDY}) = L_{\text{stir}} * A_{\text{stir}} / (A_{\text{sec}} * s) = 0.00165347$$

$$L_{\text{stir}} (\text{Length of stirrups along X}) = 960.00$$

$$A_{\text{stir}} (\text{stirrups area}) = 78.53982$$

Asec (section area) = 120000.00

s = 380.00

fywe = 555.55

fce = 15.00

From ((5.A.5), TBDY), TBDY: cc = 0.00475778

c = confinement factor = 1.27578

y1 = 0.0010562

sh1 = 0.00365026

ft1 = 304.185

fy1 = 253.4875

su1 = 0.00365026

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00

lo/lou,min = lb/ld = 0.22053887

su1 = 0.4\*esu1\_nominal ((5.5), TBDY) = 0.032

From table 5A.1, TBDY: esu1\_nominal = 0.08,

For calculation of esu1\_nominal and y1, sh1,ft1,fy1, it is considered  
characteristic value fsy1 = fs1/1.2, from table 5.1, TBDY.

y1, sh1,ft1,fy1, are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.

with fs1 = fs = 253.4875

with Es1 = Es = 200000.00

y2 = 0.0010562

sh2 = 0.00365026

ft2 = 304.185

fy2 = 253.4875

su2 = 0.00365026

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00

lo/lou,min = lb/lb,min = 0.22053887

su2 = 0.4\*esu2\_nominal ((5.5), TBDY) = 0.032

From table 5A.1, TBDY: esu2\_nominal = 0.08,

For calculation of esu2\_nominal and y2, sh2,ft2,fy2, it is considered  
characteristic value fsy2 = fs2/1.2, from table 5.1, TBDY.

y1, sh1,ft1,fy1, are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.

with fs2 = fs = 253.4875

with Es2 = Es = 200000.00

yv = 0.0010562

shv = 0.00365026

ftv = 304.185

fyv = 253.4875

suv = 0.00365026

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00

lo/lou,min = lb/ld = 0.22053887

suv = 0.4\*esuv\_nominal ((5.5), TBDY) = 0.032

From table 5A.1, TBDY: esuv\_nominal = 0.08,

considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY

For calculation of esuv\_nominal and yv, shv,ftv,fyv, it is considered  
characteristic value fsyv = fsv/1.2, from table 5.1, TBDY.

y1, sh1,ft1,fy1, are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.

with fsv = fs = 253.4875

with Esv = Es = 200000.00

1 = Asl,ten/(b\*d)\*(fs1/fc) = 0.09815014

2 = Asl,com/(b\*d)\*(fs2/fc) = 0.26768221

v = Asl,mid/(b\*d)\*(fsv/fc) = 0.24388823

and confined core properties:

b = 340.00

d = 327.00

d' = 13.00

fcc (5A.2, TBDY) = 19.13667

cc (5A.5, TBDY) = 0.00475778

c = confinement factor = 1.27578

1 = Asl,ten/(b\*d)\*(fs1/fc) = 0.1260644

$$2 = A_{sl,com}/(b*d)*(f_s2/f_c) = 0.34381201$$

$$v = A_{sl,mid}/(b*d)*(f_{sv}/f_c) = 0.31325094$$

Case/Assumption: Unconfined full section - Steel rupture

' satisfies Eq. (4.3)

--->

$v < v_{s,y2}$  - LHS eq.(4.5) is satisfied

--->

$$s_u(4.9) = 0.23431248$$

$$M_u = M_{Rc}(4.14) = 1.2706E+008$$

$$u = s_u(4.1) = 1.3353763E-005$$

Calculation of ratio  $l_b/l_d$

$$\text{Lap Length: } l_b/l_d = 0.22053887$$

$$l_b = 300.00$$

$$l_d = 1360.304$$

Calculation of  $l_b, \min$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$$= 1$$

$$d_b = 18.00$$

Mean strength value of all re-bars:  $f_y = 555.55$

$$f'_c = 15.00, \text{ but } f_c^{0.5} \leq 8.3 \text{ MPa (22.5.3.1, ACI 318-14)}$$

$$t = 1.00$$

$$s = 0.80$$

$$e = 1.00$$

$$c_b = 24.02082$$

$$K_{tr} = 0.82673491$$

$$A_{tr} = \min(A_{tr_x}, A_{tr_y}) = 157.0796$$

where  $A_{tr_x}$ ,  $A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis

$$s = 380.00$$

$$n = 20.00$$

Calculation of Shear Strength  $V_r = \min(V_{r1}, V_{r2}) = 196005.816$

Calculation of Shear Strength at edge 1,  $V_{r1} = 227350.021$

$$V_{r1} = V_{Col} \text{ ((10.3), ASCE 41-17)} = k_{nl} * V_{Col0}$$

$$V_{Col0} = 227350.021$$

$k_{nl} = 1$  (zero step-static loading)

NOTE: In expression (10-3) ' $V_s$ ' is replaced by ' $V_{s+} + f^*V_f$ '

where  $V_f$  is the contribution of FRPs (11.3), ACI 440).

$$= 1 \text{ (normal-weight concrete)}$$

$$f'_c = 15.00, \text{ but } f_c^{0.5} \leq 8.3 \text{ MPa (22.5.3.1, ACI 318-14)}$$

$$M/Vd = 2.00$$

$$M_u = 3.21769$$

$$V_u = 0.01054019$$

$$d = 0.8 * h = 320.00$$

$$N_u = 4737.328$$

$$A_g = 80000.00$$

$$\text{From (11.5.4.8), ACI 318-14: } V_s = V_{s1} + V_{s2} = 0.00$$

where:

$V_{s1} = 0.00$  is calculated for section web, with:

$$d = 320.00$$

$$A_v = 157079.633$$

$$f_y = 444.44$$

$$s = 380.00$$

$V_{s1}$  is multiplied by  $Col1 = 0.00$

$$s/d = 1.1875$$

$V_{s2} = 0.00$  is calculated for section flange, with:

$$d = 160.00$$

$$A_v = 157079.633$$

$$f_y = 444.44$$

$$s = 380.00$$

$V_{s2}$  is multiplied by  $Col2 = 0.00$   
 $s/d = 2.375$   
 $V_f ((11-3)-(11.4), ACI 440) = 188111.148$   
 $f = 0.95$ , for fully-wrapped sections  
 $wf/sf = 1$  (FRP strips adjacent to one another).  
 In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot a)\sin a$  which is more a generalised expression,  
 where  $a$  is the angle of the crack direction (see KANEPE).  
 This later relation, considered as a function  $V_f( , )$ , is implemented for every different fiber orientation  $a_i$ ,  
 as well as for 2 crack directions,  $= 45^\circ$  and  $= -45^\circ$  to take into consideration the cyclic seismic loading.  
 orientation 1:  $\theta = b1 + 90^\circ = 90.00$   
 $V_f = \text{Min}(|V_f(45, \theta)|, |V_f(-45, a1)|)$ , with:  
 total thickness per orientation,  $tf1 = NL * t / NoDir = 1.016$   
 $d_{fv} = d$  (figure 11.2, ACI 440) = 357.00  
 $f_{fe} ((11-5), ACI 440) = 259.312$   
 $E_f = 64828.00$   
 $f_e = 0.004$ , from (11.6a), ACI 440  
 with  $f_u = 0.01$   
 From (11-11), ACI 440:  $V_s + V_f \leq 164661.611$   
 $bw = 200.00$

Calculation of Shear Strength at edge 2,  $V_{r2} = 196005.816$   
 $V_{r2} = V_{Col} ((10.3), ASCE 41-17) = knl * V_{Col0}$   
 $V_{Col0} = 196005.816$   
 $knl = 1$  (zero step-static loading)

NOTE: In expression (10-3) ' $V_s$ ' is replaced by ' $V_{s+} + f * V_f$ '  
 where  $V_f$  is the contribution of FRPs (11.3), ACI 440).

$= 1$  (normal-weight concrete)  
 $f_c' = 15.00$ , but  $f_c'^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)  
 $M/Vd = 4.00$   
 $M_u = 23.99609$   
 $V_u = 0.01054019$   
 $d = 0.8 * h = 320.00$   
 $N_u = 4737.328$   
 $A_g = 80000.00$   
 From (11.5.4.8), ACI 318-14:  $V_s = V_{s1} + V_{s2} = 0.00$   
 where:  
 $V_{s1} = 0.00$  is calculated for section web, with:  
 $d = 320.00$   
 $A_v = 157079.633$   
 $f_y = 444.44$   
 $s = 380.00$

$V_{s1}$  is multiplied by  $Col1 = 0.00$   
 $s/d = 1.1875$   
 $V_{s2} = 0.00$  is calculated for section flange, with:  
 $d = 160.00$   
 $A_v = 157079.633$   
 $f_y = 444.44$   
 $s = 380.00$

$V_{s2}$  is multiplied by  $Col2 = 0.00$   
 $s/d = 2.375$   
 $V_f ((11-3)-(11.4), ACI 440) = 188111.148$   
 $f = 0.95$ , for fully-wrapped sections  
 $wf/sf = 1$  (FRP strips adjacent to one another).  
 In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot a)\sin a$  which is more a generalised expression,  
 where  $a$  is the angle of the crack direction (see KANEPE).  
 This later relation, considered as a function  $V_f( , )$ , is implemented for every different fiber orientation  $a_i$ ,  
 as well as for 2 crack directions,  $= 45^\circ$  and  $= -45^\circ$  to take into consideration the cyclic seismic loading.  
 orientation 1:  $\theta = b1 + 90^\circ = 90.00$   
 $V_f = \text{Min}(|V_f(45, \theta)|, |V_f(-45, a1)|)$ , with:  
 total thickness per orientation,  $tf1 = NL * t / NoDir = 1.016$   
 $d_{fv} = d$  (figure 11.2, ACI 440) = 357.00  
 $f_{fe} ((11-5), ACI 440) = 259.312$   
 $E_f = 64828.00$   
 $f_e = 0.004$ , from (11.6a), ACI 440

with  $f_u = 0.01$   
From (11-11), ACI 440:  $V_s + V_f \leq 164661.611$   
 $b_w = 200.00$

-----  
End Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1  
At local axis: 3  
-----

Start Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1  
At Shear local axis: 2  
(Bending local axis: 3)  
Section Type: rctcs

#### Constant Properties

-----  
Knowledge Factor,  $\phi = 0.90$   
Mean strength values are used for both shear and moment calculations.  
Consequently:  
Existing material of Primary Member: Concrete Strength,  $f_c = f_{cm} = 15.00$   
Existing material of Primary Member: Steel Strength,  $f_s = f_{sm} = 444.44$   
Concrete Elasticity,  $E_c = 18203.022$   
Steel Elasticity,  $E_s = 200000.00$   
#####  
Note: Especially for the calculation of moment strengths,  
the above steel re-bar strengths are multiplied by 1.25 according to R18.6.5, ACI 318-14  
Existing material: Steel Strength,  $f_s = 1.25 \cdot f_{sm} = 555.55$   
#####  
Max Height,  $H_{max} = 400.00$   
Min Height,  $H_{min} = 200.00$   
Max Width,  $W_{max} = 400.00$   
Min Width,  $W_{min} = 200.00$   
Eccentricity,  $Ecc = 100.00$   
Cover Thickness,  $c = 25.00$   
Mean Confinement Factor overall section = 1.27578  
Element Length,  $L = 3000.00$   
Primary Member  
Ribbed Bars  
Ductile Steel  
Without Detailing for Earthquake Resistance (including stirrups not closed at 135°)  
Longitudinal Bars With Ends Lapped Starting at the End Sections  
Lap Length  $l_o = 300.00$   
FRP Wrapping Data  
Type: Carbon  
Cured laminate properties (design values)  
Thickness,  $t = 1.016$   
Tensile Strength,  $f_{fu} = 1055.00$   
Tensile Modulus,  $E_f = 64828.00$   
Elongation,  $\epsilon_{fu} = 0.01$   
Number of directions,  $NoDir = 1$   
Fiber orientations,  $b_i: 0.00^\circ$   
Number of layers,  $NL = 1$   
Radius of rounding corners,  $R = 40.00$   
-----

#### Stepwise Properties

-----  
At local axis: 2  
EDGE -A-  
Shear Force,  $V_a = 1.5456333E-009$   
EDGE -B-  
Shear Force,  $V_b = -1.5456333E-009$   
BOTH EDGES  
Axial Force,  $F = -4737.328$   
Longitudinal Reinforcement Area Distribution (in 2 divisions)

-Tension:  $As_t = 0.00$   
 -Compression:  $As_c = 5152.212$   
 Longitudinal Reinforcement Area Distribution (in 3 divisions)  
 -Tension:  $As_{t,ten} = 1231.504$   
 -Compression:  $As_{c,com} = 1231.504$   
 -Middle:  $As_{mid} = 2689.203$

Calculation of Shear Capacity ratio,  $V_e/V_r = 0.55718248$   
 Member Controlled by Flexure ( $V_e/V_r < 1$ )  
 Calculation of Shear Demand from fig. R18.6.5, ACI 318-14  $V_e = (M_{pr1} + M_{pr2})/l_n = 126675.449$   
 with  
 $M_{pr1} = \text{Max}(Mu_{1+}, Mu_{1-}) = 1.9001E+008$   
 $Mu_{1+} = 1.9001E+008$ , is the ultimate moment strength at the edge 1 of the member in the actual moment direction which is defined for the static loading combination  
 $Mu_{1-} = 1.9001E+008$ , is the ultimate moment strength at the edge 1 of the member in the opposite moment direction which is defined for the static loading combination  
 $M_{pr2} = \text{Max}(Mu_{2+}, Mu_{2-}) = 1.9001E+008$   
 $Mu_{2+} = 1.9001E+008$ , is the ultimate moment strength at the edge 2 of the member in the actual moment direction which is defined for the static loading combination  
 $Mu_{2-} = 1.9001E+008$ , is the ultimate moment strength at the edge 2 of the member in the opposite moment direction which is defined for the static loading combination

Calculation of  $Mu_{1+}$

Calculation of ultimate curvature  $\phi_u$  according to 4.1, Biskinis/Fardis 2013:  
 $\phi_u = 1.7086748E-005$   
 $M_u = 1.9001E+008$

with full section properties:

$b = 200.00$   
 $d = 357.00$   
 $d' = 43.00$   
 $v = 0.00442328$   
 $N = 4737.328$   
 $f_c = 15.00$   
 $\phi_{co} (5A.5, \text{TB DY}) = 0.002$   
 Final value of  $\phi_{cu}$ :  $\phi_{cu}^* = \text{shear\_factor} * \text{Max}(\phi_{cu}, \phi_{co}) = 0.018$   
 The Shear\_factor is considered equal to 1 (pure moment strength)  
 From (5.4b), TB DY:  $\phi_{cu} = 0.018$   
 $\phi_{we} ((5.4c), \text{TB DY}) = a s_e * \phi_{sh,min} * f_{ywe}/f_{ce} + \text{Min}(\phi_{fx}, \phi_{fy}) = 0.15303423$   
 where  $\phi_{fx} = a f * \phi_{pf} * f_{fe}/f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$\phi_{fx} = 0.15303423$   
 Expression ((15B.6), TB DY) is modified as  $a f = 1 - (\text{Unconfined area})/(\text{total area})$   
 $a f = 0.43111111$   
 with Unconfined area =  $((b_{max}-2R)^2 + (h_{max}-2R)^2)/3 = 51733.333$   
 $b_{max} = 400.00$   
 $h_{max} = 400.00$   
 From EC8 A.4.4.3(6),  $\phi_{pf} = 2t_f/b_w = 0.01016$   
 $b_w = 200.00$   
 effective stress from (A.35),  $f_{fe} = 524.0792$

$\phi_{fy} = 0.15303423$   
 Expression ((15B.6), TB DY) is modified as  $a f = 1 - (\text{Unconfined area})/(\text{total area})$   
 $a f = 0.43111111$   
 with Unconfined area =  $((b_{max}-2R)^2 + (h_{max}-2R)^2)/3 = 0.00$   
 $b_{max} = 400.00$   
 $h_{max} = 400.00$   
 From EC8 A.4.4.3(6),  $\phi_{pf} = 2t_f/b_w = 0.01016$   
 $b_w = 200.00$   
 effective stress from (A.35),  $f_{fe} = 524.0792$

$R = 40.00$   
 Effective FRP thickness,  $t_f = NL \cdot t \cdot \cos(b_1) = 1.016$   
 $f_{u,f} = 1055.00$   
 $E_f = 64828.00$   
 $u_f = 0.015$   
 $a_{se} = \text{Max}(((A_{conf,max} - A_{noConf}) / A_{conf,max}) \cdot (A_{conf,min} / A_{conf,max}), 0) = 0.00$   
 The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).  
 The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988) "Theoretical Stress-Strain Model for Confined Concrete."  
 J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.  
 $A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.  
 $A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.  
 $A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).  
 $p_{sh,min} = \text{Min}(p_{sh,x}, p_{sh,y}) = 0.00165347$   
 Expression ((5.4d), TBDY) for  $p_{sh,min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$p_{sh,x} \text{ ((5.4d), TBDY)} = L_{stir} \cdot A_{stir} / (A_{sec} \cdot s) = 0.00165347$   
 $L_{stir}$  (Length of stirrups along Y) = 960.00  
 $A_{stir}$  (stirrups area) = 78.53982  
 $A_{sec}$  (section area) = 120000.00

$p_{sh,y} \text{ ((5.4d), TBDY)} = L_{stir} \cdot A_{stir} / (A_{sec} \cdot s) = 0.00165347$   
 $L_{stir}$  (Length of stirrups along X) = 960.00  
 $A_{stir}$  (stirrups area) = 78.53982  
 $A_{sec}$  (section area) = 120000.00

$s = 380.00$   
 $f_{ywe} = 555.55$   
 $f_{ce} = 15.00$   
 From ((5.A5), TBDY), TBDY:  $cc = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $y_1 = 0.0010562$   
 $sh_1 = 0.00365026$   
 $ft_1 = 304.185$   
 $fy_1 = 253.4875$   
 $su_1 = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00  
 $l_o/l_{ou,min} = l_b/l_d = 0.22053887$   
 $su_1 = 0.4 \cdot esu1_{nominal} \text{ ((5.5), TBDY)} = 0.032$   
 From table 5A.1, TBDY:  $esu1_{nominal} = 0.08$ ,  
 For calculation of  $esu1_{nominal}$  and  $y_1, sh_1, ft_1, fy_1$ , it is considered characteristic value  $fsy_1 = fs_1/1.2$ , from table 5.1, TBDY.  
 $y_1, sh_1, ft_1, fy_1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fs_1 = fs = 253.4875$   
 with  $Es_1 = Es = 200000.00$   
 $y_2 = 0.0010562$   
 $sh_2 = 0.00365026$   
 $ft_2 = 304.185$   
 $fy_2 = 253.4875$   
 $su_2 = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00  
 $l_o/l_{ou,min} = l_b/l_{b,min} = 0.22053887$   
 $su_2 = 0.4 \cdot esu2_{nominal} \text{ ((5.5), TBDY)} = 0.032$   
 From table 5A.1, TBDY:  $esu2_{nominal} = 0.08$ ,  
 For calculation of  $esu2_{nominal}$  and  $y_2, sh_2, ft_2, fy_2$ , it is considered characteristic value  $fsy_2 = fs_2/1.2$ , from table 5.1, TBDY.  
 $y_1, sh_1, ft_1, fy_1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.



```

with fs2 = fs = 253.4875
with Es2 = Es = 200000.00
yv = 0.0010562
shv = 0.00365026
ftv = 304.185
fyv = 253.4875
suv = 0.00365026
using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
and also multiplied by the shear_factor according to 15.7.1.4, with
Shear_factor = 1.00
lo/lou,min = lb/ld = 0.22053887
suv = 0.4*esuv_nominal ((5.5), TBDY) = 0.032
From table 5A.1, TBDY: esuv_nominal = 0.08,
considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY
For calculation of esuv_nominal and yv, shv,ftv,fyv, it is considered
characteristic value fsyv = fsv/1.2, from table 5.1, TBDY.
y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/ld)^2/3), from 10.3.5, ASCE 41-17.
with fsv = fs = 253.4875
with Esv = Es = 200000.00
1 = Asl,ten/(b*d)*(fs1/fc) = 0.29147618
2 = Asl,com/(b*d)*(fs2/fc) = 0.29147618
v = Asl,mid/(b*d)*(fsv/fc) = 0.6364888
and confined core properties:
b = 140.00
d = 327.00
d' = 13.00
fcc (5A.2, TBDY) = 19.13667
cc (5A.5, TBDY) = 0.00475778
c = confinement factor = 1.27578
1 = Asl,ten/(b*d)*(fs1/fc) = 0.45459588
2 = Asl,com/(b*d)*(fs2/fc) = 0.45459588
v = Asl,mid/(b*d)*(fsv/fc) = 0.99268896
Case/Assumption: Unconfined full section - Steel rupture
'satisfies Eq. (4.3)
--->
v < vs,y2 - LHS eq.(4.5) is not satisfied
--->
v < vs,c - RHS eq.(4.5) is satisfied
--->
su (4.8) = 0.40159417
Mu = MRc (4.15) = 1.9001E+008
u = su (4.1) = 1.7086748E-005

```

Calculation of ratio lb/ld

```

Lap Length: lb/ld = 0.22053887
lb = 300.00
ld = 1360.304
Calculation of lb,min according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.
= 1
db = 18.00
Mean strength value of all re-bars: fy = 555.55
fc' = 15.00, but fc^0.5 <= 8.3 MPa (22.5.3.1, ACI 318-14)
t = 1.00
s = 0.80
e = 1.00
cb = 24.02082
Ktr = 0.82673491
Atr = Min(Atr_x,Atr_y) = 157.0796
where Atr_x, Atr_y are the sum of the area of all stirrup legs along X and Y loxal axis
s = 380.00
n = 20.00

```

Calculation of Mu1-

Calculation of ultimate curvature  $\phi_u$  according to 4.1, Biskinis/Fardis 2013:

$$u = 1.7086748E-005$$

$$\mu_u = 1.9001E+008$$

with full section properties:

$$b = 200.00$$

$$d = 357.00$$

$$d' = 43.00$$

$$v = 0.00442328$$

$$N = 4737.328$$

$$f_c = 15.00$$

$$\phi_{co} (5A.5, TBDY) = 0.002$$

$$\text{Final value of } \phi_{cu}: \phi_{cu}^* = \text{shear\_factor} * \text{Max}(\phi_{cu}, \phi_{cc}) = 0.018$$

The Shear\_factor is considered equal to 1 (pure moment strength)

$$\text{From (5.4b), TBDY: } \phi_{cu} = 0.018$$

$$\phi_{we} ((5.4c), TBDY) = a_{se} * \phi_{sh, \min} * f_{ywe} / f_{ce} + \text{Min}(\phi_{fx}, \phi_{fy}) = 0.15303423$$

where  $\phi_f = a_f * \phi_f^* * f_{fe} / f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$$\phi_{fx} = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2) / 3 = 51733.333$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } \phi_f = 2t_f / b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$\phi_{fy} = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2) / 3 = 0.00$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } \phi_f = 2t_f / b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$R = 40.00$$

$$\text{Effective FRP thickness, } t_f = N L^* t \cos(b_1) = 1.016$$

$$f_{u,f} = 1055.00$$

$$E_f = 64828.00$$

$$u_{f,f} = 0.015$$

$$a_{se} = \text{Max}(((A_{\text{conf,max}} - A_{\text{noConf}}) / A_{\text{conf,max}}) * (A_{\text{conf,min}} / A_{\text{conf,max}}), 0) = 0.00$$

The definitions of  $A_{\text{noConf}}$ ,  $A_{\text{conf,min}}$  and  $A_{\text{conf,max}}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{\text{conf,max}} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{\text{conf,min}} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{\text{conf,max}}$  by a length equal to half the clear spacing between hoops.

$A_{\text{noConf}} = 33066.667$  is the unconfined core area which is equal to  $b_i^2 / 6$  as defined at (A.2).

$$\phi_{psh, \min} = \text{Min}(\phi_{psh,x}, \phi_{psh,y}) = 0.00165347$$

Expression ((5.4d), TBDY) for  $\phi_{psh, \min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$$\phi_{psh,x} ((5.4d), TBDY) = L_{\text{stir}} * A_{\text{stir}} / (A_{\text{sec}} * s) = 0.00165347$$

$$L_{\text{stir}} (\text{Length of stirrups along } Y) = 960.00$$

$$A_{\text{stir}} (\text{stirrups area}) = 78.53982$$

$$A_{\text{sec}} (\text{section area}) = 120000.00$$

$$psh,y ((5.4d), TBDY) = Lstir*Astir/(Asec*s) = 0.00165347$$

$$Lstir \text{ (Length of stirrups along X)} = 960.00$$

$$Astir \text{ (stirrups area)} = 78.53982$$

$$Asec \text{ (section area)} = 120000.00$$

$$s = 380.00$$

$$fywe = 555.55$$

$$fce = 15.00$$

$$\text{From } ((5.A5), TBDY), TBDY: cc = 0.00475778$$

$$c = \text{confinement factor} = 1.27578$$

$$y1 = 0.0010562$$

$$sh1 = 0.00365026$$

$$ft1 = 304.185$$

$$fy1 = 253.4875$$

$$su1 = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00

$$lo/lou,min = lb/ld = 0.22053887$$

$$su1 = 0.4*esu1\_nominal ((5.5), TBDY) = 0.032$$

From table 5A.1, TBDY: esu1\_nominal = 0.08,

For calculation of esu1\_nominal and y1, sh1,ft1,fy1, it is considered  
characteristic value fsy1 = fs1/1.2, from table 5.1, TBDY.

y1, sh1,ft1,fy1, are also multiplied by  $\text{Min}(1, 1.25*(lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.

$$\text{with } fs1 = fs = 253.4875$$

$$\text{with } Es1 = Es = 200000.00$$

$$y2 = 0.0010562$$

$$sh2 = 0.00365026$$

$$ft2 = 304.185$$

$$fy2 = 253.4875$$

$$su2 = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00

$$lo/lou,min = lb/lb,min = 0.22053887$$

$$su2 = 0.4*esu2\_nominal ((5.5), TBDY) = 0.032$$

From table 5A.1, TBDY: esu2\_nominal = 0.08,

For calculation of esu2\_nominal and y2, sh2,ft2,fy2, it is considered  
characteristic value fsy2 = fs2/1.2, from table 5.1, TBDY.

y1, sh1,ft1,fy1, are also multiplied by  $\text{Min}(1, 1.25*(lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.

$$\text{with } fs2 = fs = 253.4875$$

$$\text{with } Es2 = Es = 200000.00$$

$$yv = 0.0010562$$

$$shv = 0.00365026$$

$$ftv = 304.185$$

$$fyv = 253.4875$$

$$suv = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00

$$lo/lou,min = lb/ld = 0.22053887$$

$$suv = 0.4*esuv\_nominal ((5.5), TBDY) = 0.032$$

From table 5A.1, TBDY: esuv\_nominal = 0.08,

considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY

For calculation of esuv\_nominal and yv, shv,ftv,fyv, it is considered  
characteristic value fsyv = fsv/1.2, from table 5.1, TBDY.

y1, sh1,ft1,fy1, are also multiplied by  $\text{Min}(1, 1.25*(lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.

$$\text{with } fsv = fs = 253.4875$$

$$\text{with } Esv = Es = 200000.00$$

$$1 = Asl,ten/(b*d)*(fs1/fc) = 0.29147618$$

$$2 = Asl,com/(b*d)*(fs2/fc) = 0.29147618$$

$$v = Asl,mid/(b*d)*(fsv/fc) = 0.6364888$$

and confined core properties:

$$b = 140.00$$

$$d = 327.00$$

$$d' = 13.00$$

$$fcc \text{ (5A.2, TBDY)} = 19.13667$$

```

cc (5A.5, TBDY) = 0.00475778
c = confinement factor = 1.27578
1 = Asl,ten/(b*d)*(fs1/fc) = 0.45459588
2 = Asl,com/(b*d)*(fs2/fc) = 0.45459588
v = Asl,mid/(b*d)*(fsv/fc) = 0.99268896
Case/Assumption: Unconfined full section - Steel rupture
'satisfies Eq. (4.3)
--->
v < vs,y2 - LHS eq.(4.5) is not satisfied
--->
v < vs,c - RHS eq.(4.5) is satisfied
--->
su (4.8) = 0.40159417
Mu = MRc (4.15) = 1.9001E+008
u = su (4.1) = 1.7086748E-005

```

Calculation of ratio lb/ld

```

Lap Length: lb/ld = 0.22053887
lb = 300.00
ld = 1360.304
Calculation of lb,min according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.
= 1
db = 18.00
Mean strength value of all re-bars: fy = 555.55
fc' = 15.00, but fc^0.5 <= 8.3 MPa (22.5.3.1, ACI 318-14)
t = 1.00
s = 0.80
e = 1.00
cb = 24.02082
Ktr = 0.82673491
Atr = Min(Atr_x,Atr_y) = 157.0796
where Atr_x, Atr_y are the sum of the area of all stirrup legs along X and Y loxal axis
s = 380.00
n = 20.00

```

Calculation of Mu2+

```

Calculation of ultimate curvature u according to 4.1, Biskinis/Fardis 2013:
u = 1.7086748E-005
Mu = 1.9001E+008

```

with full section properties:

```

b = 200.00
d = 357.00
d' = 43.00
v = 0.00442328
N = 4737.328
fc = 15.00
co (5A.5, TBDY) = 0.002
Final value of cu: cu* = shear_factor * Max( cu, cc) = 0.018
The Shear_factor is considered equal to 1 (pure moment strength)
From (5.4b), TBDY: cu = 0.018
we ((5.4c), TBDY) = ase* sh,min*fywe/fce+ Min( fx, fy) = 0.15303423
where f = af*pf*ffe/fce is accounting for FRP contribution like EC8-part3 A.4.4.3(6)
fx = 0.15303423
Expression ((15B.6), TBDY) is modified as af = 1 - (Unconfined area)/(total area)
af = 0.43111111
with Unconfined area = ((bmax-2R)^2+(hmax-2R)^2)/3 = 51733.333
bmax = 400.00
hmax = 400.00

```

From EC8 A4.4.3(6),  $pf = 2tf/bw = 0.01016$   
 $bw = 200.00$   
effective stress from (A.35),  $ff,e = 524.0792$

$f_y = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $af = 1 - (\text{Unconfined area})/(\text{total area})$

$af = 0.43111111$

with Unconfined area =  $((b_{max}-2R)^2 + (h_{max}-2R)^2)/3 = 0.00$

$b_{max} = 400.00$

$h_{max} = 400.00$

From EC8 A4.4.3(6),  $pf = 2tf/bw = 0.01016$

$bw = 200.00$

effective stress from (A.35),  $ff,e = 524.0792$

$R = 40.00$

Effective FRP thickness,  $tf = NL*t*\cos(b1) = 1.016$

$f_{u,f} = 1055.00$

$E_f = 64828.00$

$u,f = 0.015$

$ase = \text{Max}(((A_{conf,max}-A_{noConf})/A_{conf,max})*(A_{conf,min}/A_{conf,max}),0) = 0.00$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$psh,min = \text{Min}(psh,x, psh,y) = 0.00165347$

Expression ((5.4d), TBDY) for  $psh,min$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$psh,x \text{ ((5.4d), TBDY)} = L_{stir}*A_{stir}/(A_{sec}*s) = 0.00165347$

$L_{stir}$  (Length of stirrups along Y) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$psh,y \text{ ((5.4d), TBDY)} = L_{stir}*A_{stir}/(A_{sec}*s) = 0.00165347$

$L_{stir}$  (Length of stirrups along X) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$s = 380.00$

$f_{ywe} = 555.55$

$f_{ce} = 15.00$

From ((5.A5), TBDY), TBDY:  $cc = 0.00475778$

$c$  = confinement factor = 1.27578

$y1 = 0.0010562$

$sh1 = 0.00365026$

$ft1 = 304.185$

$fy1 = 253.4875$

$su1 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$lo/lo_{u,min} = lb/l_d = 0.22053887$

$su1 = 0.4*esu1_{nominal} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu1_{nominal} = 0.08$ ,

For calculation of  $esu1_{nominal}$  and  $y1, sh1, ft1, fy1$ , it is considered characteristic value  $fsy1 = fs1/1.2$ , from table 5.1, TBDY.

$y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25*(lb/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.

with  $fs1 = fs = 253.4875$

with  $Es1 = Es = 200000.00$

$y2 = 0.0010562$

```

sh2 = 0.00365026
ft2 = 304.185
fy2 = 253.4875
su2 = 0.00365026
    using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
    and also multiplied by the shear_factor according to 15.7.1.4, with
    Shear_factor = 1.00
    lo/lo,min = lb/lb,min = 0.22053887
    su2 = 0.4*esu2_nominal ((5.5), TBDY) = 0.032
    From table 5A.1, TBDY: esu2_nominal = 0.08,
    For calculation of esu2_nominal and y2, sh2,ft2,fy2, it is considered
    characteristic value fsy2 = fs2/1.2, from table 5.1, TBDY.
    y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/lb)^ 2/3), from 10.3.5, ASCE 41-17.
    with fs2 = fs = 253.4875
    with Es2 = Es = 200000.00
yv = 0.0010562
shv = 0.00365026
ftv = 304.185
fyv = 253.4875
suv = 0.00365026
    using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
    and also multiplied by the shear_factor according to 15.7.1.4, with
    Shear_factor = 1.00
    lo/lo,min = lb/lb = 0.22053887
    suv = 0.4*esuv_nominal ((5.5), TBDY) = 0.032
    From table 5A.1, TBDY: esuv_nominal = 0.08,
    considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY
    For calculation of esuv_nominal and yv, shv,ftv,fyv, it is considered
    characteristic value fsyv = fsv/1.2, from table 5.1, TBDY.
    y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/lb)^ 2/3), from 10.3.5, ASCE 41-17.
    with fsv = fs = 253.4875
    with Esv = Es = 200000.00
1 = Asl,ten/(b*d)*(fs1/fc) = 0.29147618
2 = Asl,com/(b*d)*(fs2/fc) = 0.29147618
v = Asl,mid/(b*d)*(fsv/fc) = 0.6364888
and confined core properties:
b = 140.00
d = 327.00
d' = 13.00
fcc (5A.2, TBDY) = 19.13667
cc (5A.5, TBDY) = 0.00475778
c = confinement factor = 1.27578
1 = Asl,ten/(b*d)*(fs1/fc) = 0.45459588
2 = Asl,com/(b*d)*(fs2/fc) = 0.45459588
v = Asl,mid/(b*d)*(fsv/fc) = 0.99268896
Case/Assumption: Unconfined full section - Steel rupture
'satisfies Eq. (4.3)
--->
v < vs,y2 - LHS eq.(4.5) is not satisfied
--->
v < vs,c - RHS eq.(4.5) is satisfied
--->
su (4.8) = 0.40159417
Mu = MRc (4.15) = 1.9001E+008
u = su (4.1) = 1.7086748E-005

```

Calculation of ratio lb/lb

```

Lap Length: lb/lb = 0.22053887
lb = 300.00
ld = 1360.304
Calculation of lb,min according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.
= 1
db = 18.00
Mean strength value of all re-bars: fy = 555.55
fc' = 15.00, but fc^0.5 <= 8.3 MPa (22.5.3.1, ACI 318-14)

```

$t = 1.00$   
 $s = 0.80$   
 $e = 1.00$   
 $cb = 24.02082$   
 $K_{tr} = 0.82673491$   
 $A_{tr} = \text{Min}(A_{tr\_x}, A_{tr\_y}) = 157.0796$   
 where  $A_{tr\_x}$ ,  $A_{tr\_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis  
 $s = 380.00$   
 $n = 20.00$

#### Calculation of $\mu_2$ -

Calculation of ultimate curvature  $\mu$  according to 4.1, Biskinis/Fardis 2013:

$\mu = 1.7086748E-005$   
 $\mu_u = 1.9001E+008$

with full section properties:

$b = 200.00$   
 $d = 357.00$   
 $d' = 43.00$   
 $v = 0.00442328$   
 $N = 4737.328$   
 $f_c = 15.00$   
 $\alpha_1(5A.5, \text{TBDY}) = 0.002$   
 Final value of  $\mu$ :  $\mu^* = \text{shear\_factor} * \text{Max}(\mu, \mu_c) = 0.018$   
 The Shear\_factor is considered equal to 1 (pure moment strength)  
 From (5.4b), TBDY:  $\mu = 0.018$   
 $\mu_c(5.4c, \text{TBDY}) = \alpha_1 * \text{sh}_{\min} * f_{ywe}/f_{ce} + \text{Min}(f_x, f_y) = 0.15303423$   
 where  $f = \alpha_1 * \rho_f * f_{fe}/f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$f_x = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $\alpha_f = 1 - (\text{Unconfined area})/(\text{total area})$

$\alpha_f = 0.43111111$

with Unconfined area =  $((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 51733.333$

$b_{\max} = 400.00$

$h_{\max} = 400.00$

From EC8 A4.4.3(6),  $\rho_f = 2t_f/b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

$f_y = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $\alpha_f = 1 - (\text{Unconfined area})/(\text{total area})$

$\alpha_f = 0.43111111$

with Unconfined area =  $((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 0.00$

$b_{\max} = 400.00$

$h_{\max} = 400.00$

From EC8 A4.4.3(6),  $\rho_f = 2t_f/b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

$R = 40.00$

Effective FRP thickness,  $t_f = NL * t * \cos(b_1) = 1.016$

$f_{u,f} = 1055.00$

$E_f = 64828.00$

$\mu_{u,f} = 0.015$

$\alpha_{se} = \text{Max}(((A_{\text{conf,max}} - A_{\text{noConf}})/A_{\text{conf,max}}) * (A_{\text{conf,min}}/A_{\text{conf,max}}), 0) = 0.00$

The definitions of  $A_{\text{noConf}}$ ,  $A_{\text{conf,min}}$  and  $A_{\text{conf,max}}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{\text{conf,max}}$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

Aconf,min = 0.00 is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area Aconf,max by a length equal to half the clear spacing between hoops.

AnoConf = 33066.667 is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

psh,min = Min(psh,x , psh,y) = 0.00165347

Expression ((5.4d), TBDY) for psh,min has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

psh,x ((5.4d), TBDY) = Lstir\*Astir/(Asec\*s) = 0.00165347

Lstir (Length of stirrups along Y) = 960.00

Astir (stirrups area) = 78.53982

Asec (section area) = 120000.00

psh,y ((5.4d), TBDY) = Lstir\*Astir/(Asec\*s) = 0.00165347

Lstir (Length of stirrups along X) = 960.00

Astir (stirrups area) = 78.53982

Asec (section area) = 120000.00

s = 380.00

fywe = 555.55

fce = 15.00

From ((5.A5), TBDY), TBDY: cc = 0.00475778

c = confinement factor = 1.27578

y1 = 0.0010562

sh1 = 0.00365026

ft1 = 304.185

fy1 = 253.4875

su1 = 0.00365026

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

lo/lou,min = lb/l\_d = 0.22053887

su1 = 0.4\*esu1\_nominal ((5.5), TBDY) = 0.032

From table 5A.1, TBDY: esu1\_nominal = 0.08,

For calculation of esu1\_nominal and y1, sh1,ft1,fy1, it is considered characteristic value fsy1 = fs1/1.2, from table 5.1, TBDY.

y1, sh1,ft1,fy1, are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.

with fs1 = fs = 253.4875

with Es1 = Es = 200000.00

y2 = 0.0010562

sh2 = 0.00365026

ft2 = 304.185

fy2 = 253.4875

su2 = 0.00365026

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

lo/lou,min = lb/lb,min = 0.22053887

su2 = 0.4\*esu2\_nominal ((5.5), TBDY) = 0.032

From table 5A.1, TBDY: esu2\_nominal = 0.08,

For calculation of esu2\_nominal and y2, sh2,ft2,fy2, it is considered characteristic value fsy2 = fs2/1.2, from table 5.1, TBDY.

y1, sh1,ft1,fy1, are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.

with fs2 = fs = 253.4875

with Es2 = Es = 200000.00

yv = 0.0010562

shv = 0.00365026

ftv = 304.185

fyv = 253.4875

suv = 0.00365026

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

lo/lou,min = lb/l\_d = 0.22053887

suv = 0.4\*esuv\_nominal ((5.5), TBDY) = 0.032

From table 5A.1, TBDY: esuv\_nominal = 0.08,

considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY



For calculation of  $\epsilon_{suv\_nominal}$  and  $\gamma_v$ ,  $\Delta v$ ,  $\Delta f_v$ ,  $\Delta f_y$ , it is considered characteristic value  $f_{sv} = f_{sv}/1.2$ , from table 5.1, TBDY.

$\gamma_1$ ,  $\Delta v_1$ ,  $\Delta f_{v1}$ ,  $\Delta f_{y1}$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.

with  $f_{sv} = f_s = 253.4875$

with  $E_{sv} = E_s = 200000.00$

$1 = A_{sl,ten}/(b \cdot d) \cdot (f_{s1}/f_c) = 0.29147618$

$2 = A_{sl,com}/(b \cdot d) \cdot (f_{s2}/f_c) = 0.29147618$

$v = A_{sl,mid}/(b \cdot d) \cdot (f_{sv}/f_c) = 0.6364888$

and confined core properties:

$b = 140.00$

$d = 327.00$

$d' = 13.00$

$f_{cc} \text{ (5A.2, TBDY)} = 19.13667$

$c_c \text{ (5A.5, TBDY)} = 0.00475778$

$c = \text{confinement factor} = 1.27578$

$1 = A_{sl,ten}/(b \cdot d) \cdot (f_{s1}/f_c) = 0.45459588$

$2 = A_{sl,com}/(b \cdot d) \cdot (f_{s2}/f_c) = 0.45459588$

$v = A_{sl,mid}/(b \cdot d) \cdot (f_{sv}/f_c) = 0.99268896$

Case/Assumption: Unconfined full section - Steel rupture

' satisfies Eq. (4.3)

--->

$v < v_{s,y2}$  - LHS eq.(4.5) is not satisfied

--->

$v < v_{s,c}$  - RHS eq.(4.5) is satisfied

--->

$\mu_u \text{ (4.8)} = 0.40159417$

$\mu_u = M_{Rc} \text{ (4.15)} = 1.9001E+008$

$u = \mu_u \text{ (4.1)} = 1.7086748E-005$

Calculation of ratio  $l_b/l_d$

Lap Length:  $l_b/l_d = 0.22053887$

$l_b = 300.00$

$l_d = 1360.304$

Calculation of  $l_{b,min}$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$= 1$

$d_b = 18.00$

Mean strength value of all re-bars:  $f_y = 555.55$

$f'_c = 15.00$ , but  $f_c^{0.5} \leq 8.3 \text{ MPa}$  (22.5.3.1, ACI 318-14)

$t = 1.00$

$s = 0.80$

$e = 1.00$

$c_b = 24.02082$

$K_{tr} = 0.82673491$

$A_{tr} = \text{Min}(A_{tr,x}, A_{tr,y}) = 157.0796$

where  $A_{tr,x}$ ,  $A_{tr,y}$  are the sum of the area of all stirrup legs along X and Y loxal axis

$s = 380.00$

$n = 20.00$

Calculation of Shear Strength  $V_r = \text{Min}(V_{r1}, V_{r2}) = 227350.021$

Calculation of Shear Strength at edge 1,  $V_{r1} = 227350.021$

$V_{r1} = V_{Col} \text{ ((10.3), ASCE 41-17)} = k_{nl} \cdot V_{Col0}$

$V_{Col0} = 227350.021$

$k_{nl} = 1$  (zero step-static loading)

NOTE: In expression (10-3) ' $V_s$ ' is replaced by ' $V_s + f \cdot V_f$ '

where  $V_f$  is the contribution of FRPs (11.3), ACI 440).

$= 1$  (normal-weight concrete)

$f'_c = 15.00$ , but  $f_c^{0.5} \leq 8.3 \text{ MPa}$  (22.5.3.1, ACI 318-14)

$M/V_d = 2.00$

$\mu_u = 0.00988804$

$V_u = 1.5456333E-009$   
 $d = 0.8 \cdot h = 320.00$   
 $N_u = 4737.328$   
 $A_g = 80000.00$   
 From (11.5.4.8), ACI 318-14:  $V_s = V_{s1} + V_{s2} = 0.00$   
 where:  
 $V_{s1} = 0.00$  is calculated for section web, with:  
 $d = 160.00$   
 $A_v = 157079.633$   
 $f_y = 444.44$   
 $s = 380.00$   
 $V_{s1}$  is multiplied by  $Col1 = 0.00$   
 $s/d = 2.375$   
 $V_{s2} = 0.00$  is calculated for section flange, with:  
 $d = 320.00$   
 $A_v = 157079.633$   
 $f_y = 444.44$   
 $s = 380.00$   
 $V_{s2}$  is multiplied by  $Col2 = 0.00$   
 $s/d = 1.1875$   
 $V_f ((11-3)-(11.4), ACI 440) = 188111.148$   
 $f = 0.95$ , for fully-wrapped sections  
 $w_f/s_f = 1$  (FRP strips adjacent to one another).  
 In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot a) \sin a$  which is more a generalised expression,  
 where  $a$  is the angle of the crack direction (see KANEPE).  
 This later relation, considered as a function  $V_f( , )$ , is implemented for every different fiber orientation  $a_i$ ,  
 as well as for 2 crack directions,  $a = 45^\circ$  and  $a = -45^\circ$  to take into consideration the cyclic seismic loading.  
 orientation 1:  $\theta = b1 + 90^\circ = 90.00$   
 $V_f = \text{Min}(|V_f(45, \theta)|, |V_f(-45, a1)|)$ , with:  
 total thickness per orientation,  $t_{f1} = N_L \cdot t / N_{oDir} = 1.016$   
 $d_{fv} = d$  (figure 11.2, ACI 440) = 357.00  
 $f_{fe} ((11-5), ACI 440) = 259.312$   
 $E_f = 64828.00$   
 $f_e = 0.004$ , from (11.6a), ACI 440  
 with  $f_u = 0.01$   
 From (11-11), ACI 440:  $V_s + V_f \leq 164661.611$   
 $b_w = 200.00$

Calculation of Shear Strength at edge 2,  $V_{r2} = 227350.021$   
 $V_{r2} = V_{Col} ((10.3), ASCE 41-17) = k_n l \cdot V_{Col0}$   
 $V_{Col0} = 227350.021$   
 $k_n l = 1$  (zero step-static loading)

NOTE: In expression (10-3) ' $V_s$ ' is replaced by ' $V_s + f \cdot V_f$ '  
 where  $V_f$  is the contribution of FRPs (11.3), ACI 440).

$= 1$  (normal-weight concrete)  
 $f_c' = 15.00$ , but  $f_c'^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)  
 $M/Vd = 2.00$   
 $\mu_u = 0.00525978$   
 $V_u = 1.5456333E-009$   
 $d = 0.8 \cdot h = 320.00$   
 $N_u = 4737.328$   
 $A_g = 80000.00$   
 From (11.5.4.8), ACI 318-14:  $V_s = V_{s1} + V_{s2} = 0.00$   
 where:  
 $V_{s1} = 0.00$  is calculated for section web, with:  
 $d = 160.00$   
 $A_v = 157079.633$   
 $f_y = 444.44$   
 $s = 380.00$   
 $V_{s1}$  is multiplied by  $Col1 = 0.00$   
 $s/d = 2.375$   
 $V_{s2} = 0.00$  is calculated for section flange, with:  
 $d = 320.00$   
 $A_v = 157079.633$

$f_y = 444.44$   
 $s = 380.00$   
 $V_{s2}$  is multiplied by  $\text{Col2} = 0.00$   
 $s/d = 1.1875$   
 $V_f((11-3)-(11.4), \text{ACI 440}) = 188111.148$   
 $f = 0.95$ , for fully-wrapped sections  
 $w_f/s_f = 1$  (FRP strips adjacent to one another).  
 $\ln(11.3) \sin + \cos$  is replaced with  $(\cot + \cot a) \sin a$  which is more a generalised expression,  
 where  $a$  is the angle of the crack direction (see KANEPE).  
 This later relation, considered as a function  $V_f(\theta, a)$ , is implemented for every different fiber orientation  $a_i$ ,  
 as well as for 2 crack directions,  $\theta = 45^\circ$  and  $\theta = -45^\circ$  to take into consideration the cyclic seismic loading.  
 orientation 1:  $\theta_1 = \theta_1 + 90^\circ = 90.00$   
 $V_f = \text{Min}(|V_f(45, \theta_1)|, |V_f(-45, a_1)|)$ , with:  
 total thickness per orientation,  $t_{f1} = NL * t / \text{NoDir} = 1.016$   
 $d_{fv} = d$  (figure 11.2, ACI 440) = 357.00  
 $f_{fe}((11-5), \text{ACI 440}) = 259.312$   
 $E_f = 64828.00$   
 $f_e = 0.004$ , from (11.6a), ACI 440  
 with  $f_u = 0.01$   
 From (11-11), ACI 440:  $V_s + V_f \leq 164661.611$   
 $b_w = 200.00$

-----  
 End Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1  
 At local axis: 2  
 -----

-----  
 Start Of Calculation of Chord Rotation Capacity for element: column TC1 of floor 1  
 At local axis: 3  
 Integration Section: (a)  
 Section Type: rctcs

#### Constant Properties

-----  
 Knowledge Factor,  $\phi = 0.90$   
 Chord Rotation is generally considered as Deformation-Controlled Action according to Table C7-1, ASCE 41-17.  
 Mean strengths are used for Deformation-Controlled Actions according to 7.5.1.3, ASCE 41-17  
 Consequently:  
 Existing material of Primary Member: Concrete Strength,  $f_c = f_{cm} = 15.00$   
 Existing material of Primary Member: Steel Strength,  $f_s = f_{sm} = 444.44$   
 Concrete Elasticity,  $E_c = 18203.022$   
 Steel Elasticity,  $E_s = 200000.00$   
 Max Height,  $H_{max} = 400.00$   
 Min Height,  $H_{min} = 200.00$   
 Max Width,  $W_{max} = 400.00$   
 Min Width,  $W_{min} = 200.00$   
 Eccentricity,  $Ecc = 100.00$   
 Cover Thickness,  $c = 25.00$   
 Element Length,  $L = 3000.00$   
 Primary Member  
 Ribbed Bars  
 Ductile Steel  
 Without Detailing for Earthquake Resistance (including stirrups not closed at  $135^\circ$ )  
 Longitudinal Bars With Ends Lapped Starting at the End Sections  
 Lap Length  $l_b = 300.00$   
 FRP Wrapping Data  
 Type: Carbon  
 Cured laminate properties (design values)  
 Thickness,  $t = 1.016$   
 Tensile Strength,  $f_{fu} = 1055.00$   
 Tensile Modulus,  $E_f = 64828.00$   
 Elongation,  $e_{fu} = 0.01$   
 Number of directions,  $\text{NoDir} = 1$   
 Fiber orientations,  $b_i: 0.00^\circ$   
 Number of layers,  $NL = 1$

Radius of rounding corners,  $R = 40.00$

#### Stepwise Properties

Bending Moment,  $M = -8.4385\text{E}+006$

Shear Force,  $V2 = -2811.342$

Shear Force,  $V3 = -0.02136663$

Axial Force,  $F = -4735.965$

Longitudinal Reinforcement Area Distribution (in 2 divisions)

-Tension:  $As_t = 2375.044$

-Compression:  $As_c = 2777.168$

Longitudinal Reinforcement Area Distribution (in 3 divisions)

-Tension:  $As_{t,ten} = 1231.504$

-Compression:  $As_{c,com} = 1231.504$

-Middle:  $As_{c,mid} = 2689.203$

Mean Diameter of Tension Reinforcement,  $Db_L = 17.60$

Existing component: From table 7-7, ASCE 41\_17: Final chord rotation Capacity  $u_R = \quad * u = 0.01876684$

$u = y + p = 0.02085204$

- Calculation of  $y$  -

$y = (M_y * L_s / 3) / E_{eff} = 0.02085204$  ((4.29), Biskinis Phd))

$M_y = 1.3657\text{E}+008$

$L_s = M/V$  (with  $L_s > 0.1 * L$  and  $L_s < 2 * L$ ) = 3001.586

From table 10.5, ASCE 41\_17:  $E_{eff} = \text{factor} * E_c * I_g = 6.5531\text{E}+012$

factor = 0.30

$A_g = 120000.00$

$f_c' = 15.00$

$N = 4735.965$

$E_c * I_g = 2.1844\text{E}+013$

Calculation of Yielding Moment  $M_y$

Calculation of  $y$  and  $M_y$  according to Annex 7 -

$y = \text{Min}(y_{ten}, y_{com})$

$y_{ten} = 5.8874222\text{E}-006$

with ((10.1), ASCE 41-17)  $f_y = \text{Min}(f_y, 1.25 * f_y * (b/d)^{2/3}) = 235.317$

$d = 357.00$

$y = 0.44020389$

$A = 0.07244171$

$B = 0.04070755$

with  $pt = 0.0075814$

$pc = 0.01724796$

$pv = 0.03766391$

$N = 4735.965$

$b = 200.00$

" = 0.12044818

$y_{comp} = 1.0162905\text{E}-005$

with  $f_c' (12.3, (ACI 440)) = 16.12972$

$f_c = 15.00$

$f_l = 0.93147527$

$b = b_{max} = 400.00$

$h = h_{max} = 400.00$

$A_g = 120000.00$

$g = pt + pc + pv = 0.07215983$

$rc = 40.00$

$A_e/A_c = 0.38686758$

Effective FRP thickness,  $t_f = NL * t * \cos(b_1) = 1.016$

effective strain from (12.5) and (12.12),  $\epsilon_{fe} = 0.004$   
 $f_u = 0.01$   
 $E_f = 64828.00$   
 $E_c = 18203.022$   
 $\gamma = 0.43961224$   
 $A = 0.0719519$   
 $B = 0.04042568$   
 with  $E_s = 200000.00$

Calculation of ratio  $l_b/l_d$

Lap Length:  $l_d/l_{d,min} = 0.27567359$

$l_b = 300.00$

$l_d = 1088.244$

Calculation of  $I$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$= 1$

$d_b = 18.00$

Mean strength value of all re-bars:  $f_y = 444.44$

$f_c' = 15.00$ , but  $f_c'^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$t = 1.00$

$s = 0.80$

$e = 1.00$

$c_b = 24.02082$

$K_{tr} = 0.82673491$

$A_{tr} = \min(A_{tr_x}, A_{tr_y}) = 157.0796$

where  $A_{tr_x}$ ,  $A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y local axis

$s = 380.00$

$n = 20.00$

- Calculation of  $p$  -

From table 10-8:  $p = 0.00$

with:

- Columns controlled by inadequate development or splicing along the clear height because  $l_b/l_d < 1$

shear control ratio  $V_{yE}/V_{ColOE} = 0.55718248$

$d = 357.00$

$s = 0.00$

$t = A_v/(b_w*s) + 2*t_f/b_w*(f_{fe}/f_s) = A_v*L_{stir}/(A_g*s) + 2*t_f/b_w*(f_{fe}/f_s) = 0.0075814$

$A_v = 78.53982$ , is the area of every stirrup

$L_{stir} = 960.00$ , is the total Length of all stirrups parallel to loading (shear) direction

The term  $2*t_f/b_w*(f_{fe}/f_s)$  is implemented to account for FRP contribution

where  $f = 2*t_f/b_w$  is FRP ratio (EC8 - 3, A.4.4.3(6)) and  $f_{fe}/f_s$  normalises  $f$  to steel strength

All these variables have already been given in Shear control ratio calculation.

$NUD = 4735.965$

$A_g = 120000.00$

$f_{cE} = 15.00$

$f_{yE} = f_{yI} = 444.44$

$p_l = \text{Area\_Tot\_Long\_Rein}/(b*d) = 0.07215983$

$b = 200.00$

$d = 357.00$

$f_{cE} = 15.00$

End Of Calculation of Chord Rotation Capacity for element: column TC1 of floor 1

At local axis: 3

Integration Section: (a)

## Calculation No. 5

column C1, Floor 1

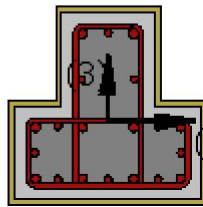
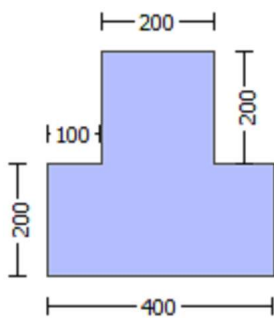
Limit State: Immediate Occupancy (data interpolation between analysis steps 1 and 2)

Analysis: Uniform +X

Check: Shear capacity  $V_{Rd}$

Edge: End

Local Axis: (2)



Start Of Calculation of Shear Capacity for element: column TC1 of floor 1

At local axis: 2

Integration Section: (b)

Section Type: rctcs

Constant Properties

Knowledge Factor,  $\gamma = 0.90$

Member Shear Force is generally considered as Force-Controlled Action according to Table C7-1, ASCE 41-17.

Lower-bound strengths are used for Force-Controlled Actions according to 7.5.1.3, ASCE 41-17

Consequently:

Existing material of Primary Member: Concrete Strength,  $f_c = f_{c\_lower\_bound} = 10.00$

Existing material of Primary Member: Steel Strength,  $f_s = f_{s\_lower\_bound} = 400.00$

Concrete Elasticity,  $E_c = 18203.022$

Steel Elasticity,  $E_s = 200000.00$

#####

Note: Especially for the calculation of  $\gamma$  for displacement ductility demand, the expected (mean value) strengths are used (7.5.1.3, ASCE 41-17) because bending is considered as Deformation-Controlled Action (Table C7-1, ASCE 41-17).

Existing material: Concrete Strength,  $f_c = f_{cm} = 15.00$

Existing material: Steel Strength,  $f_s = f_{sm} = 444.44$

#####

Max Height,  $H_{max} = 400.00$

Min Height,  $H_{min} = 200.00$

Max Width,  $W_{max} = 400.00$

Min Width,  $W_{min} = 200.00$

Eccentricity,  $E_{cc} = 100.00$

Cover Thickness,  $c = 25.00$

Element Length,  $L = 3000.00$

Primary Member

Ribbed Bars

Ductile Steel

Without Detailing for Earthquake Resistance (including stirrups not closed at 135°)  
 Longitudinal Bars With Ends Lapped Starting at the End Sections  
 Lap Length  $l_o = l_b = 300.00$   
 FRP Wrapping Data  
 Type: Carbon  
 Cured laminate properties (design values)  
 Thickness,  $t = 1.016$   
 Tensile Strength,  $f_{fu} = 1055.00$   
 Tensile Modulus,  $E_f = 64828.00$   
 Elongation,  $\epsilon_{fu} = 0.01$   
 Number of directions,  $N_{oDir} = 1$   
 Fiber orientations,  $b_i: 0.00^\circ$   
 Number of layers,  $N_L = 1$   
 Radius of rounding corners,  $R = 40.00$

#### Stepwise Properties

EDGE -A-  
 Bending Moment,  $M_a = -8.4385E+006$   
 Shear Force,  $V_a = -2811.342$   
 EDGE -B-  
 Bending Moment,  $M_b = -136.3192$   
 Shear Force,  $V_b = 2811.342$   
 BOTH EDGES  
 Axial Force,  $F = -4735.965$   
 Longitudinal Reinforcement Area Distribution (in 2 divisions)  
   -Tension:  $A_{sl,t} = 0.00$   
   -Compression:  $A_{sl,c} = 5152.212$   
 Longitudinal Reinforcement Area Distribution (in 3 divisions)  
   -Tension:  $A_{sl,ten} = 1231.504$   
   -Compression:  $A_{sl,com} = 1231.504$   
   -Middle:  $A_{sl,mid} = 2689.203$   
 Mean Diameter of Tension Reinforcement,  $Db_{L,ten} = 17.60$

Existing component: From table 7-7, ASCE 41\_17: Final Shear Capacity  $V_R = \phi V_n = 167221.095$   
 $V_n ((10.3), ASCE 41-17) = knl * V_{Col0} = 185801.217$   
 $V_{Col} = 185801.217$   
 $knl = 1.00$   
 $displacement\_ductility\_demand = 0.09266918$

NOTE: In expression (10-3) 'Vs' is replaced by 'Vs+  $\phi V_f$ '  
 where  $V_f$  is the contribution of FRPs (11.3), ACI 440).

= 1 (normal-weight concrete)  
 $f'_c = 10.00$ , but  $f_c^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)  
 $M/Vd = 2.00$   
 $\mu_u = 136.3192$   
 $V_u = 2811.342$   
 $d = 0.8 * h = 320.00$   
 $N_u = 4735.965$   
 $A_g = 80000.00$   
 From (11.5.4.8), ACI 318-14:  $V_s = V_{s1} + V_{s2} = 0.00$   
 where:  
 $V_{s1} = 0.00$  is calculated for section web, with:  
 $d = 160.00$   
 $A_v = 157079.633$   
 $f_y = 400.00$   
 $s = 380.00$   
 $V_{s1}$  is multiplied by  $Col1 = 0.00$   
 $s/d = 2.375$   
 $V_{s2} = 0.00$  is calculated for section flange, with:  
 $d = 320.00$   
 $A_v = 157079.633$

$f_y = 400.00$   
 $s = 380.00$   
 $V_{s2}$  is multiplied by  $\text{Col2} = 0.00$   
 $s/d = 1.1875$   
 $V_f((11-3)-(11.4), \text{ACI 440}) = 188111.148$   
 $f = 0.95$ , for fully-wrapped sections  
 $w_f/s_f = 1$  (FRP strips adjacent to one another).  
 $\ln(11.3) \sin + \cos$  is replaced with  $(\cot + \cot a) \sin a$  which is more a generalised expression,  
 where  $\alpha$  is the angle of the crack direction (see KANEPE).  
 This later relation, considered as a function  $V_f(\alpha)$ , is implemented for every different fiber orientation  $\alpha_i$ ,  
 as well as for 2 crack directions,  $\alpha = 45^\circ$  and  $\alpha = -45^\circ$  to take into consideration the cyclic seismic loading.  
 orientation 1:  $\alpha_1 = b_1 + 90^\circ = 90.00$   
 $V_f = \text{Min}(|V_f(45, 1)|, |V_f(-45, a_1)|)$ , with:  
 total thickness per orientation,  $t_{f1} = N_L * t / N_{oDir} = 1.016$   
 $d_{fv} = d$  (figure 11.2, ACI 440) = 357.00  
 $f_{fe}((11-5), \text{ACI 440}) = 259.312$   
 $E_f = 64828.00$   
 $f_e = 0.004$ , from (11.6a), ACI 440  
 with  $f_u = 0.01$   
 From (11-11), ACI 440:  $V_s + V_f \leq 134445.642$   
 $b_w = 200.00$

displacement\_ductility\_demand is calculated as  $\delta / y$

- Calculation of  $\delta / y$  for END B -  
 for rotation axis 3 and integ. section (b)

From analysis, chord rotation  $\theta = 0.00019313$   
 $y = (M_y * L_s / 3) / E_{eff} = 0.0020841$  ((4.29), Biskinis Phd))  
 $M_y = 1.3657E+008$   
 $L_s = M/V$  (with  $L_s > 0.1 * L$  and  $L_s < 2 * L$ ) = 300.00  
 From table 10.5, ASCE 41\_17:  $E_{eff} = \text{factor} * E_c * I_g = 6.5531E+012$   
 $\text{factor} = 0.30$   
 $A_g = 120000.00$   
 $f_c' = 15.00$   
 $N = 4735.965$   
 $E_c * I_g = 2.1844E+013$

Calculation of Yielding Moment  $M_y$

Calculation of  $\delta$  and  $M_y$  according to Annex 7 -

$y = \text{Min}(y_{ten}, y_{com})$   
 $y_{ten} = 5.8874222E-006$   
 with ((10.1), ASCE 41-17)  $f_y = \text{Min}(f_y, 1.25 * f_y * (I_b / I_d)^{2/3}) = 235.317$   
 $d = 357.00$   
 $y = 0.44020389$   
 $A = 0.07244171$   
 $B = 0.04070755$   
 with  $p_t = 0.01724796$   
 $p_c = 0.01724796$   
 $p_v = 0.03766391$   
 $N = 4735.965$   
 $b = 200.00$   
 $\alpha = 0.12044818$   
 $y_{comp} = 1.0162905E-005$   
 with  $f_c' (12.3, \text{ACI 440}) = 16.12972$   
 $f_c = 15.00$   
 $f_l = 0.93147527$   
 $b = b_{max} = 400.00$   
 $h = h_{max} = 400.00$   
 $A_g = 120000.00$   
 $g = p_t + p_c + p_v = 0.07215983$



rc = 40.00  
Ae/Ac = 0.38686758  
Effective FRP thickness,  $t_f = NL \cdot t \cdot \cos(b1) = 1.016$   
effective strain from (12.5) and (12.12),  $\epsilon_{fe} = 0.004$   
 $f_u = 0.01$   
 $E_f = 64828.00$   
 $E_c = 18203.022$   
 $y = 0.43961224$   
 $A = 0.0719519$   
 $B = 0.04042568$   
with  $E_s = 200000.00$

Calculation of ratio  $I_b/I_d$

Lap Length:  $I_d/I_{d,min} = 0.27567359$

$I_b = 300.00$

$I_d = 1088.244$

Calculation of  $I$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.  
 $= 1$

$d_b = 18.00$

Mean strength value of all re-bars:  $f_y = 444.44$

$f'_c = 15.00$ , but  $f_c^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$t = 1.00$

$s = 0.80$

$e = 1.00$

$c_b = 24.02082$

$K_{tr} = 0.82673491$

$A_{tr} = \min(A_{tr_x}, A_{tr_y}) = 157.0796$

where  $A_{tr_x}$ ,  $A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y local axis

$s = 380.00$

$n = 20.00$

End Of Calculation of Shear Capacity for element: column TC1 of floor 1

At local axis: 2

Integration Section: (b)

## Calculation No. 6

column C1, Floor 1

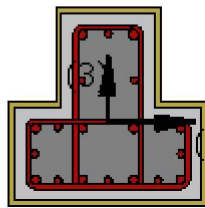
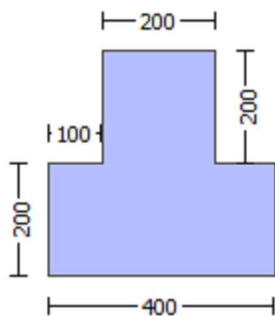
Limit State: Immediate Occupancy (data interpolation between analysis steps 1 and 2)

Analysis: Uniform +X

Check: Chord rotation capacity (  $\theta$  )

Edge: End

Local Axis: (2)



Start Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1

At Shear local axis: 3

(Bending local axis: 2)

Section Type: rctcs

Constant Properties

Knowledge Factor,  $\gamma = 0.90$

Mean strength values are used for both shear and moment calculations.

Consequently:

Existing material of Primary Member: Concrete Strength,  $f_c = f_{cm} = 15.00$

Existing material of Primary Member: Steel Strength,  $f_s = f_{sm} = 444.44$

Concrete Elasticity,  $E_c = 18203.022$

Steel Elasticity,  $E_s = 200000.00$

#####

Note: Especially for the calculation of moment strengths,

the above steel re-bar strengths are multiplied by 1.25 according to R18.6.5, ACI 318-14

Existing material: Steel Strength,  $f_s = 1.25 \cdot f_{sm} = 555.55$

#####

Max Height,  $H_{max} = 400.00$

Min Height,  $H_{min} = 200.00$

Max Width,  $W_{max} = 400.00$

Min Width,  $W_{min} = 200.00$

Eccentricity,  $Ecc = 100.00$

Cover Thickness,  $c = 25.00$

Mean Confinement Factor overall section = 1.27578

Element Length,  $L = 3000.00$

Primary Member

Ribbed Bars

Ductile Steel

Without Detailing for Earthquake Resistance (including stirrups not closed at 135°)

Longitudinal Bars With Ends Lapped Starting at the End Sections

Lap Length  $l_o = 300.00$

FRP Wrapping Data

Type: Carbon

Cured laminate properties (design values)

Thickness,  $t = 1.016$

Tensile Strength,  $f_{fu} = 1055.00$

Tensile Modulus,  $E_f = 64828.00$

Elongation,  $ef_u = 0.01$

Number of directions,  $NoDir = 1$

Fiber orientations,  $bi: 0.00^\circ$

Number of layers,  $NL = 1$

Radius of rounding corners,  $R = 40.00$

Stepwise Properties

At local axis: 3

EDGE -A-

Shear Force,  $V_a = 0.01054019$

EDGE -B-

Shear Force,  $V_b = -0.01054019$   
 BOTH EDGES  
 Axial Force,  $F = -4737.328$   
 Longitudinal Reinforcement Area Distribution (in 2 divisions)  
   -Tension:  $As_t = 0.00$   
   -Compression:  $As_c = 5152.212$   
 Longitudinal Reinforcement Area Distribution (in 3 divisions)  
   -Tension:  $As_{t,ten} = 2261.947$   
   -Compression:  $As_{c,com} = 829.3805$   
   -Middle:  $As_{mid} = 2060.885$

Calculation of Shear Capacity ratio,  $V_e/V_r = 0.82694402$   
 Member Controlled by Flexure ( $V_e/V_r < 1$ )  
 Calculation of Shear Demand from fig. R18.6.5, ACI 318-14  $V_e = (M_{pr1} + M_{pr2})/l_n = 162085.836$   
 with  
 $M_{pr1} = \text{Max}(\mu_{u1+}, \mu_{u1-}) = 2.4313E+008$   
 $\mu_{u1+} = 2.4313E+008$ , is the ultimate moment strength at the edge 1 of the member in the actual moment direction which is defined for the static loading combination  
 $\mu_{u1-} = 1.2706E+008$ , is the ultimate moment strength at the edge 1 of the member in the opposite moment direction which is defined for the static loading combination  
 $M_{pr2} = \text{Max}(\mu_{u2+}, \mu_{u2-}) = 2.4313E+008$   
 $\mu_{u2+} = 2.4313E+008$ , is the ultimate moment strength at the edge 2 of the member in the actual moment direction which is defined for the static loading combination  
 $\mu_{u2-} = 1.2706E+008$ , is the ultimate moment strength at the edge 2 of the member in the opposite moment direction which is defined for the static loading combination

Calculation of  $\mu_{u1+}$

Calculation of ultimate curvature  $\mu_u$  according to 4.1, Biskinis/Fardis 2013:  
 $\mu_u = 2.6161250E-005$   
 $\mu_u = 2.4313E+008$

with full section properties:

$b = 200.00$   
 $d = 357.00$   
 $d' = 43.00$   
 $v = 0.00442328$   
 $N = 4737.328$   
 $f_c = 15.00$   
 $\alpha = 0.85$  (5A.5, TBDY) = 0.002

Final value of  $\mu_u$ :  $\mu_u^* = \text{shear\_factor} * \text{Max}(\mu_u, \alpha) = 0.018$

The Shear\_factor is considered equal to 1 (pure moment strength)

From (5.4b), TBDY:  $\mu_u = 0.018$

we ((5.4c), TBDY) =  $\alpha * \mu_u / (f_c + \mu_u) = 0.15303423$

where  $\mu_u = \mu_u^* / \alpha$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$\mu_u = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $\alpha_f = 1 - (\text{Unconfined area})/(\text{total area})$

$\alpha_f = 0.43111111$

with Unconfined area =  $((b_{max}-2R)^2 + (h_{max}-2R)^2)/3 = 51733.333$

$b_{max} = 400.00$

$h_{max} = 400.00$

From EC8 A.4.4.3(6),  $\mu_u = 2t_f/b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

$\mu_u = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $\alpha_f = 1 - (\text{Unconfined area})/(\text{total area})$

$\alpha_f = 0.43111111$

with Unconfined area =  $((b_{max}-2R)^2 + (h_{max}-2R)^2)/3 = 0.00$

$b_{max} = 400.00$

hmax = 400.00  
From EC8 A4.4.3(6),  $pf = 2tf/bw = 0.01016$   
bw = 200.00  
effective stress from (A.35),  $ff_e = 524.0792$

R = 40.00  
Effective FRP thickness,  $tf = NL*t*Cos(b1) = 1.016$   
 $f_{u,f} = 1055.00$   
 $E_f = 64828.00$   
 $u_{,f} = 0.015$

$ase = \text{Max}(((A_{conf,max} - A_{noConf}) / A_{conf,max}) * (A_{conf,min} / A_{conf,max}), 0) = 0.00$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988) "Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$psh_{,min} = \text{Min}(psh_x, psh_y) = 0.00165347$

Expression ((5.4d), TBDY) for  $psh_{,min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$psh_x \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$   
 $L_{stir}$  (Length of stirrups along Y) = 960.00  
 $A_{stir}$  (stirrups area) = 78.53982  
 $A_{sec}$  (section area) = 120000.00

$psh_y \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$   
 $L_{stir}$  (Length of stirrups along X) = 960.00  
 $A_{stir}$  (stirrups area) = 78.53982  
 $A_{sec}$  (section area) = 120000.00

s = 380.00  
 $f_{ywe} = 555.55$   
 $f_{ce} = 15.00$

From ((5.A5), TBDY), TBDY:  $cc = 0.00475778$   
c = confinement factor = 1.27578

$y1 = 0.0010562$   
 $sh1 = 0.00365026$

$ft1 = 304.185$   
 $fy1 = 253.4875$

$su1 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with

Shear\_factor = 1.00

$lo/lo_{,min} = lb/l_d = 0.22053887$

$su1 = 0.4 * esu1_{nominal} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu1_{nominal} = 0.08$ ,

For calculation of  $esu1_{nominal}$  and  $y1, sh1, ft1, fy1$ , it is considered characteristic value  $fsy1 = fs1/1.2$ , from table 5.1, TBDY.

$y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 * (lb/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.

with  $fs1 = fs = 253.4875$

with  $Es1 = Es = 200000.00$

$y2 = 0.0010562$   
 $sh2 = 0.00365026$

$ft2 = 304.185$   
 $fy2 = 253.4875$

$su2 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with

Shear\_factor = 1.00

$lo/lo_{,min} = lb/l_{b,min} = 0.22053887$

$su2 = 0.4 * esu2_{nominal} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $es_{u2\_nominal} = 0.08$ ,  
For calculation of  $es_{u2\_nominal}$  and  $y_2, sh_2, ft_2, fy_2$ , it is considered  
characteristic value  $fs_{y2} = fs_2/1.2$ , from table 5.1, TBDY.  
 $y_1, sh_1, ft_1, fy_1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
with  $fs_2 = fs = 253.4875$   
with  $Es_2 = Es = 200000.00$   
 $y_v = 0.0010562$   
 $sh_v = 0.00365026$   
 $ft_v = 304.185$   
 $fy_v = 253.4875$   
 $s_{uv} = 0.00365026$   
using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00  
 $lo/lo_{u,min} = lb/ld = 0.22053887$   
 $s_{uv} = 0.4 \cdot es_{uv\_nominal} ((5.5), TBDY) = 0.032$   
From table 5A.1, TBDY:  $es_{uv\_nominal} = 0.08$ ,  
considering characteristic value  $fs_{yv} = fs_v/1.2$ , from table 5.1, TBDY  
For calculation of  $es_{uv\_nominal}$  and  $y_v, sh_v, ft_v, fy_v$ , it is considered  
characteristic value  $fs_{yv} = fs_v/1.2$ , from table 5.1, TBDY.  
 $y_1, sh_1, ft_1, fy_1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
with  $fs_v = fs = 253.4875$   
with  $Es_v = Es = 200000.00$   
 $1 = A_{sl,ten}/(b \cdot d) \cdot (fs_1/f_c) = 0.53536441$   
 $2 = A_{sl,com}/(b \cdot d) \cdot (fs_2/f_c) = 0.19630028$   
 $v = A_{sl,mid}/(b \cdot d) \cdot (fs_v/f_c) = 0.48777647$   
and confined core properties:  
 $b = 140.00$   
 $d = 327.00$   
 $d' = 13.00$   
 $f_{cc} (5A.2, TBDY) = 19.13667$   
 $cc (5A.5, TBDY) = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $1 = A_{sl,ten}/(b \cdot d) \cdot (fs_1/f_c) = 0.83497202$   
 $2 = A_{sl,com}/(b \cdot d) \cdot (fs_2/f_c) = 0.30615641$   
 $v = A_{sl,mid}/(b \cdot d) \cdot (fs_v/f_c) = 0.76075229$   
Case/Assumption: Unconfined full section - Steel rupture  
' satisfies Eq. (4.3)  
--->  
 $v < v_{s,y2}$  - LHS eq.(4.5) is not satisfied  
--->  
 $v < v_{s,c}$  - RHS eq.(4.5) is not satisfied  
--->  
Case/Assumption Rejected.  
--->  
New Case/Assumption: Unconfined full section - Spalling of concrete cover  
' satisfies Eq. (4.4)  
--->  
 $v < s_{y1}$  - LHS eq.(4.7) is not satisfied  
--->  
 $v < v_{c,y1}$  - RHS eq.(4.6) is satisfied  
--->  
 $cu (4.10) = 0.46564051$   
 $M_{Rc} (4.17) = 2.0934E+008$   
--->  
New Case/Assumption: Ultimate curvature of confined core after spalling of concrete cover  
In expressions below, the following modifications have been made  
-  $b, d, d'$  replaced by geometric parameters of the core:  $b_o, d_o, d'_o$   
-  $N, 1, 2, v$  normalised to  $b_o \cdot d_o$ , instead of  $b \cdot d$   
- parameters of confined concrete,  $f_{cc}, cc$ , used in lieu of  $f_c, ec_u$   
--->  
Subcase: Rupture of tension steel  
--->  
 $v^* < v^*_{s,y2}$  - LHS eq.(4.5) is not satisfied  
--->  
 $v^* < v^*_{s,c}$  - LHS eq.(4.5) is not satisfied  
--->

Subcase rejected

--->

New Subcase: Failure of compression zone

--->

$v^* < v^*_{c,y2}$  - LHS eq.(4.6) is not satisfied

--->

$v^* < v^*_{c,y1}$  - RHS eq.(4.6) is satisfied

--->

$\mu_{cu}(4.10) = 0.55615794$

$M_{Ro}(4.17) = 2.4313E+008$

--->

$\mu_u = \mu_{cu}(4.2) = 2.6161250E-005$

$\mu_u = M_{Ro}$

Calculation of ratio  $l_b/l_d$

Lap Length:  $l_b/l_d = 0.22053887$

$l_b = 300.00$

$l_d = 1360.304$

Calculation of  $l_{b,min}$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.  
 $= 1$

$d_b = 18.00$

Mean strength value of all re-bars:  $f_y = 555.55$

$f'_c = 15.00$ , but  $f'_c^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$t = 1.00$

$s = 0.80$

$e = 1.00$

$c_b = 24.02082$

$K_{tr} = 0.82673491$

$A_{tr} = \min(A_{tr_x}, A_{tr_y}) = 157.0796$

where  $A_{tr_x}$ ,  $A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis

$s = 380.00$

$n = 20.00$

Calculation of  $\mu_{u1}$ -

Calculation of ultimate curvature  $\mu_u$  according to 4.1, Biskinis/Fardis 2013:

$\mu_u = 1.3353763E-005$

$\mu_u = 1.2706E+008$

with full section properties:

$b = 400.00$

$d = 357.00$

$d' = 43.00$

$v = 0.00221164$

$N = 4737.328$

$f'_c = 15.00$

$\alpha_{co}(5A.5, TBDY) = 0.002$

Final value of  $\mu_{cu}$ :  $\mu_{cu}^* = \text{shear\_factor} * \max(\mu_{cu}, \mu_{cc}) = 0.018$

The Shear\_factor is considered equal to 1 (pure moment strength)

From (5.4b), TBDY:  $\mu_{cu} = 0.018$

$\mu_{we}((5.4c), TBDY) = \alpha_{se} * \mu_{sh,min} * f_{ywe}/f_{ce} + \min(f_x, f_y) = 0.15303423$

where  $f = \alpha_f * p_f * f_{fe}/f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$f_x = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $\alpha_f = 1 - (\text{Unconfined area})/(\text{total area})$

$\alpha_f = 0.43111111$

with Unconfined area =  $((b_{max}-2R)^2 + (h_{max}-2R)^2)/3 = 51733.333$

$b_{max} = 400.00$

$h_{max} = 400.00$

From EC8 A.4.4.3(6),  $p_f = 2t_f/b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{f,e} = 524.0792$

$f_y = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area})/(\text{total area})$

$a_f = 0.43111111$

with Unconfined area =  $((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 0.00$

$b_{\max} = 400.00$

$h_{\max} = 400.00$

From EC8 A4.4.3(6),  $p_f = 2t_f/b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{f,e} = 524.0792$

$R = 40.00$

Effective FRP thickness,  $t_f = NL \cdot t \cdot \cos(\beta_1) = 1.016$

$f_{u,f} = 1055.00$

$E_f = 64828.00$

$u_f = 0.015$

$a_{se} = \text{Max}(((A_{\text{conf,max}} - A_{\text{noConf}})/A_{\text{conf,max}}) \cdot (A_{\text{conf,min}}/A_{\text{conf,max}}), 0) = 0.00$

The definitions of  $A_{\text{noConf}}$ ,  $A_{\text{conf,min}}$  and  $A_{\text{conf,max}}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{\text{conf,max}} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{\text{conf,min}} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{\text{conf,max}}$  by a length equal to half the clear spacing between hoops.

$A_{\text{noConf}} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$p_{sh,min} = \text{Min}(p_{sh,x}, p_{sh,y}) = 0.00165347$

Expression ((5.4d), TBDY) for  $p_{sh,min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$p_{sh,x} \text{ ((5.4d), TBDY)} = L_{\text{stir}} \cdot A_{\text{stir}} / (A_{\text{sec}} \cdot s) = 0.00165347$

$L_{\text{stir}}$  (Length of stirrups along Y) = 960.00

$A_{\text{stir}}$  (stirrups area) = 78.53982

$A_{\text{sec}}$  (section area) = 120000.00

$p_{sh,y} \text{ ((5.4d), TBDY)} = L_{\text{stir}} \cdot A_{\text{stir}} / (A_{\text{sec}} \cdot s) = 0.00165347$

$L_{\text{stir}}$  (Length of stirrups along X) = 960.00

$A_{\text{stir}}$  (stirrups area) = 78.53982

$A_{\text{sec}}$  (section area) = 120000.00

$s = 380.00$

$f_{ywe} = 555.55$

$f_{ce} = 15.00$

From ((5.A5), TBDY), TBDY:  $cc = 0.00475778$

$c$  = confinement factor = 1.27578

$y_1 = 0.0010562$

$sh_1 = 0.00365026$

$ft_1 = 304.185$

$fy_1 = 253.4875$

$su_1 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$l_o/l_{ou,min} = l_b/l_d = 0.22053887$

$su_1 = 0.4 \cdot esu_{1,nominal} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu_{1,nominal} = 0.08$ ,

For calculation of  $esu_{1,nominal}$  and  $y_1, sh_1, ft_1, fy_1$ , it is considered characteristic value  $fsy_1 = fs_1/1.2$ , from table 5.1, TBDY.

$y_1, sh_1, ft_1, fy_1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.

with  $fs_1 = fs = 253.4875$

with  $Es_1 = Es = 200000.00$

$y_2 = 0.0010562$

$sh_2 = 0.00365026$

$ft_2 = 304.185$

```

fy2 = 253.4875
su2 = 0.00365026
    using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
    and also multiplied by the shear_factor according to 15.7.1.4, with
    Shear_factor = 1.00
    lo/lou,min = lb/lb,min = 0.22053887
    su2 = 0.4*esu2_nominal ((5.5), TBDY) = 0.032
    From table 5A.1, TBDY: esu2_nominal = 0.08,
    For calculation of esu2_nominal and y2, sh2,ft2,fy2, it is considered
    characteristic value fsy2 = fs2/1.2, from table 5.1, TBDY.
    y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/ld)^ 2/3), from 10.3.5, ASCE 41-17.
    with fs2 = fs = 253.4875
    with Es2 = Es = 200000.00
    yv = 0.0010562
    shv = 0.00365026
ftv = 304.185
fyv = 253.4875
suv = 0.00365026
    using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
    and also multiplied by the shear_factor according to 15.7.1.4, with
    Shear_factor = 1.00
    lo/lou,min = lb/ld = 0.22053887
    suv = 0.4*esuv_nominal ((5.5), TBDY) = 0.032
    From table 5A.1, TBDY: esuv_nominal = 0.08,
    considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY
    For calculation of esuv_nominal and yv, shv,ftv,fyv, it is considered
    characteristic value fsyv = fsv/1.2, from table 5.1, TBDY.
    y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/ld)^ 2/3), from 10.3.5, ASCE 41-17.
    with fsv = fs = 253.4875
    with Esv = Es = 200000.00
    1 = Asl,ten/(b*d)*(fs1/fc) = 0.09815014
    2 = Asl,com/(b*d)*(fs2/fc) = 0.26768221
    v = Asl,mid/(b*d)*(fsv/fc) = 0.24388823
and confined core properties:
b = 340.00
d = 327.00
d' = 13.00
fcc (5A.2, TBDY) = 19.13667
cc (5A.5, TBDY) = 0.00475778
    c = confinement factor = 1.27578
    1 = Asl,ten/(b*d)*(fs1/fc) = 0.1260644
    2 = Asl,com/(b*d)*(fs2/fc) = 0.34381201
    v = Asl,mid/(b*d)*(fsv/fc) = 0.31325094

```

Case/Assumption: Unconfined full section - Steel rupture  
 ' satisfies Eq. (4.3)

```

--->
v < vs,y2 - LHS eq.(4.5) is satisfied
--->
su (4.9) = 0.23431248
Mu = MRc (4.14) = 1.2706E+008
u = su (4.1) = 1.3353763E-005

```

---

Calculation of ratio lb/ld

---

```

Lap Length: lb/ld = 0.22053887
lb = 300.00
ld = 1360.304
Calculation of lb,min according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.
= 1
db = 18.00
Mean strength value of all re-bars: fy = 555.55
fc' = 15.00, but fc'^0.5 <= 8.3 MPa (22.5.3.1, ACI 318-14)
t = 1.00
s = 0.80
e = 1.00
cb = 24.02082

```



$K_{tr} = 0.82673491$   
 $A_{tr} = \text{Min}(A_{tr\_x}, A_{tr\_y}) = 157.0796$   
 where  $A_{tr\_x}$ ,  $A_{tr\_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis  
 $s = 380.00$   
 $n = 20.00$

Calculation of  $\mu_{2+}$

Calculation of ultimate curvature  $\mu$  according to 4.1, Biskinis/Fardis 2013:

$\mu = 2.6161250E-005$

$\mu_{2+} = 2.4313E+008$

with full section properties:

$b = 200.00$

$d = 357.00$

$d' = 43.00$

$v = 0.00442328$

$N = 4737.328$

$f_c = 15.00$

$\alpha_{co} (5A.5, \text{TBDY}) = 0.002$

Final value of  $\mu_{cu}$ :  $\mu_{cu}^* = \text{shear\_factor} * \text{Max}(\mu_{cu}, \mu_{cc}) = 0.018$

The Shear\_factor is considered equal to 1 (pure moment strength)

From (5.4b), TBDY:  $\mu_{cu} = 0.018$

we ((5.4c), TBDY) =  $\alpha_{se} * \text{sh}_{\min} * f_{ywe} / f_{ce} + \text{Min}(f_x, f_y) = 0.15303423$

where  $f = \alpha_f * \rho_f * f_{fe} / f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$f_x = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $\alpha_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$\alpha_f = 0.43111111$

with Unconfined area =  $((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2) / 3 = 51733.333$

$b_{\max} = 400.00$

$h_{\max} = 400.00$

From EC8 A.4.4.3(6),  $\rho_f = 2t_f / b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

$f_y = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $\alpha_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$\alpha_f = 0.43111111$

with Unconfined area =  $((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2) / 3 = 0.00$

$b_{\max} = 400.00$

$h_{\max} = 400.00$

From EC8 A.4.4.3(6),  $\rho_f = 2t_f / b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

$R = 40.00$

Effective FRP thickness,  $t_f = N L * t * \cos(b_1) = 1.016$

$f_{u,f} = 1055.00$

$E_f = 64828.00$

$u_f = 0.015$

$\alpha_{se} = \text{Max}(((A_{\text{conf,max}} - A_{\text{noConf}}) / A_{\text{conf,max}}) * (A_{\text{conf,min}} / A_{\text{conf,max}}), 0) = 0.00$

The definitions of  $A_{\text{noConf}}$ ,  $A_{\text{conf,min}}$  and  $A_{\text{conf,max}}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{\text{conf,max}} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{\text{conf,min}} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{\text{conf,max}}$  by a length equal to half the clear spacing between hoops.

$A_{\text{noConf}} = 33066.667$  is the unconfined core area which is equal to  $b_i^2 / 6$  as defined at (A.2).

psh,min = Min(psh,x , psh,y) = 0.00165347  
 Expression ((5.4d), TBDY) for psh,min has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

---


$$psh,x \text{ ((5.4d), TBDY)} = Lstir * Astir / (Asec * s) = 0.00165347$$

Lstir (Length of stirrups along Y) = 960.00

Astir (stirrups area) = 78.53982

Asec (section area) = 120000.00

---


$$psh,y \text{ ((5.4d), TBDY)} = Lstir * Astir / (Asec * s) = 0.00165347$$

Lstir (Length of stirrups along X) = 960.00

Astir (stirrups area) = 78.53982

Asec (section area) = 120000.00

---

s = 380.00

fywe = 555.55

fce = 15.00

From ((5.A5), TBDY), TBDY: cc = 0.00475778

c = confinement factor = 1.27578

y1 = 0.0010562

sh1 = 0.00365026

ft1 = 304.185

fy1 = 253.4875

su1 = 0.00365026

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with

Shear\_factor = 1.00

lo/lou,min = lb/lb = 0.22053887

su1 = 0.4\*esu1\_nominal ((5.5), TBDY) = 0.032

From table 5A.1, TBDY: esu1\_nominal = 0.08,

For calculation of esu1\_nominal and y1, sh1,ft1,fy1, it is considered  
 characteristic value fsy1 = fs1/1.2, from table 5.1, TBDY.

y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25\*(lb/lb)^2/3), from 10.3.5, ASCE 41-17.

with fs1 = fs = 253.4875

with Es1 = Es = 200000.00

y2 = 0.0010562

sh2 = 0.00365026

ft2 = 304.185

fy2 = 253.4875

su2 = 0.00365026

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with

Shear\_factor = 1.00

lo/lou,min = lb/lb,min = 0.22053887

su2 = 0.4\*esu2\_nominal ((5.5), TBDY) = 0.032

From table 5A.1, TBDY: esu2\_nominal = 0.08,

For calculation of esu2\_nominal and y2, sh2,ft2,fy2, it is considered  
 characteristic value fsy2 = fs2/1.2, from table 5.1, TBDY.

y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25\*(lb/lb)^2/3), from 10.3.5, ASCE 41-17.

with fs2 = fs = 253.4875

with Es2 = Es = 200000.00

yv = 0.0010562

shv = 0.00365026

ftv = 304.185

fyv = 253.4875

suv = 0.00365026

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with

Shear\_factor = 1.00

lo/lou,min = lb/lb = 0.22053887

suv = 0.4\*esuv\_nominal ((5.5), TBDY) = 0.032

From table 5A.1, TBDY: esuv\_nominal = 0.08,

considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY  
 For calculation of esuv\_nominal and yv, shv,ftv,fyv, it is considered

characteristic value fsyv = fsv/1.2, from table 5.1, TBDY.

y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25\*(lb/lb)^2/3), from 10.3.5, ASCE 41-17.

with fsv = fs = 253.4875

```

with Esv = Es = 200000.00
1 = Asl,ten/(b*d)*(fs1/fc) = 0.53536441
2 = Asl,com/(b*d)*(fs2/fc) = 0.19630028
v = Asl,mid/(b*d)*(fsv/fc) = 0.48777647
and confined core properties:
b = 140.00
d = 327.00
d' = 13.00
fcc (5A.2, TBDY) = 19.13667
cc (5A.5, TBDY) = 0.00475778
c = confinement factor = 1.27578
1 = Asl,ten/(b*d)*(fs1/fc) = 0.83497202
2 = Asl,com/(b*d)*(fs2/fc) = 0.30615641
v = Asl,mid/(b*d)*(fsv/fc) = 0.76075229
Case/Assumption: Unconfined full section - Steel rupture
' satisfies Eq. (4.3)
---->
v < vs,y2 - LHS eq.(4.5) is not satisfied
---->
v < vs,c - RHS eq.(4.5) is not satisfied
---->
Case/Assumption Rejected.
---->
New Case/Assumption: Unconfined full section - Spalling of concrete cover
' satisfies Eq. (4.4)
---->
v < s,y1 - LHS eq.(4.7) is not satisfied
---->
v < vc,y1 - RHS eq.(4.6) is satisfied
---->
cu (4.10) = 0.46564051
MRc (4.17) = 2.0934E+008
---->
New Case/Assumption: Ultimate curvature of confined core after spalling of concrete cover
In expressions below, the following modifications have been made
- b, d, d' replaced by geometric parameters of the core: bo, do, d'o
- N, 1, 2, v normalised to bo*do, instead of b*d
- - parameters of confined concrete, fcc, cc, used in lieu of fc, ecu
---->
Subcase: Rupture of tension steel
---->
v* < v*s,y2 - LHS eq.(4.5) is not satisfied
---->
v* < v*s,c - LHS eq.(4.5) is not satisfied
---->
Subcase rejected
---->
New Subcase: Failure of compression zone
---->
v* < v*c,y2 - LHS eq.(4.6) is not satisfied
---->
v* < v*c,y1 - RHS eq.(4.6) is satisfied
---->
*cu (4.10) = 0.55615794
MRo (4.17) = 2.4313E+008
---->
u = cu (4.2) = 2.6161250E-005
Mu = MRo
-----

Calculation of ratio lb/lc
-----
Lap Length: lb/lc = 0.22053887
lb = 300.00
lc = 1360.304
Calculation of lb,min according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.
= 1

```

$db = 18.00$   
Mean strength value of all re-bars:  $f_y = 555.55$   
 $fc' = 15.00$ , but  $fc'^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)  
 $t = 1.00$   
 $s = 0.80$   
 $e = 1.00$   
 $cb = 24.02082$   
 $K_{tr} = 0.82673491$   
 $A_{tr} = \text{Min}(A_{tr_x}, A_{tr_y}) = 157.0796$   
where  $A_{tr_x}$ ,  $A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis  
 $s = 380.00$   
 $n = 20.00$

#### Calculation of $\mu_2$ -

Calculation of ultimate curvature  $\mu$  according to 4.1, Biskinis/Fardis 2013:

$\mu = 1.3353763E-005$   
 $\mu_u = 1.2706E+008$

with full section properties:

$b = 400.00$   
 $d = 357.00$   
 $d' = 43.00$   
 $v = 0.00221164$   
 $N = 4737.328$   
 $fc = 15.00$   
 $\alpha_1(5A.5, \text{TB DY}) = 0.002$   
Final value of  $\mu_u$ :  $\mu_u^* = \text{shear\_factor} * \text{Max}(\mu_u, \mu_c) = 0.018$   
The Shear\_factor is considered equal to 1 (pure moment strength)  
From (5.4b), TB DY:  $\mu_u = 0.018$   
 $\mu_u((5.4c), \text{TB DY}) = \alpha_1 * \mu_u^* * f_{ywe}/f_{ce} + \text{Min}(\mu_u, \mu_c) = 0.15303423$   
where  $f = \alpha_1 * \mu_u^* * f_{fe}/f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$\mu_u = 0.15303423$

Expression ((15B.6), TB DY) is modified as  $\alpha_1 = 1 - (\text{Unconfined area})/(\text{total area})$

$\alpha_1 = 0.43111111$

with Unconfined area =  $((b_{\text{max}} - 2R)^2 + (h_{\text{max}} - 2R)^2)/3 = 51733.333$

$b_{\text{max}} = 400.00$

$h_{\text{max}} = 400.00$

From EC8 A.4.4.3(6),  $\mu_u = 2t_f/b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

$\mu_u = 0.15303423$

Expression ((15B.6), TB DY) is modified as  $\alpha_1 = 1 - (\text{Unconfined area})/(\text{total area})$

$\alpha_1 = 0.43111111$

with Unconfined area =  $((b_{\text{max}} - 2R)^2 + (h_{\text{max}} - 2R)^2)/3 = 0.00$

$b_{\text{max}} = 400.00$

$h_{\text{max}} = 400.00$

From EC8 A.4.4.3(6),  $\mu_u = 2t_f/b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

$R = 40.00$

Effective FRP thickness,  $t_f = N L^* t \cos(b_1) = 1.016$

$f_{u,f} = 1055.00$

$E_f = 64828.00$

$\mu_u = 0.015$

$\alpha_1 = \text{Max}(((A_{\text{conf,max}} - A_{\text{noConf}})/A_{\text{conf,max}}) * (A_{\text{conf,min}}/A_{\text{conf,max}}), 0) = 0.00$

The definitions of  $A_{\text{noConf}}$ ,  $A_{\text{conf,min}}$  and  $A_{\text{conf,max}}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

Aconf,max = 75600.00 is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

Aconf,min = 0.00 is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area Aconf,max by a length equal to half the clear spacing between hoops.

AnoConf = 33066.667 is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

psh,min = Min(psh,x , psh,y) = 0.00165347

Expression ((5.4d), TBDY) for psh,min has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

psh,x ((5.4d), TBDY) = Lstir\*Astir/(Asec\*s) = 0.00165347

Lstir (Length of stirrups along Y) = 960.00

Astir (stirrups area) = 78.53982

Asec (section area) = 120000.00

psh,y ((5.4d), TBDY) = Lstir\*Astir/(Asec\*s) = 0.00165347

Lstir (Length of stirrups along X) = 960.00

Astir (stirrups area) = 78.53982

Asec (section area) = 120000.00

s = 380.00

fywe = 555.55

fce = 15.00

From ((5.A5), TBDY), TBDY: cc = 0.00475778

c = confinement factor = 1.27578

y1 = 0.0010562

sh1 = 0.00365026

ft1 = 304.185

fy1 = 253.4875

su1 = 0.00365026

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

lo/lou,min = lb/lb = 0.22053887

su1 = 0.4\*esu1\_nominal ((5.5), TBDY) = 0.032

From table 5A.1, TBDY: esu1\_nominal = 0.08,

For calculation of esu1\_nominal and y1, sh1,ft1,fy1, it is considered characteristic value fsy1 = fs1/1.2, from table 5.1, TBDY.

y1, sh1,ft1,fy1, are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/lb)^{2/3})$ , from 10.3.5, ASCE 41-17.

with fs1 = fs = 253.4875

with Es1 = Es = 200000.00

y2 = 0.0010562

sh2 = 0.00365026

ft2 = 304.185

fy2 = 253.4875

su2 = 0.00365026

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

lo/lou,min = lb/lb,min = 0.22053887

su2 = 0.4\*esu2\_nominal ((5.5), TBDY) = 0.032

From table 5A.1, TBDY: esu2\_nominal = 0.08,

For calculation of esu2\_nominal and y2, sh2,ft2,fy2, it is considered characteristic value fsy2 = fs2/1.2, from table 5.1, TBDY.

y1, sh1,ft1,fy1, are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/lb)^{2/3})$ , from 10.3.5, ASCE 41-17.

with fs2 = fs = 253.4875

with Es2 = Es = 200000.00

yv = 0.0010562

shv = 0.00365026

ftv = 304.185

fyv = 253.4875

suv = 0.00365026

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

lo/lou,min = lb/lb = 0.22053887

$suv = 0.4 * esuv\_nominal ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esuv\_nominal = 0.08$ ,  
 considering characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY  
 For calculation of  $esuv\_nominal$  and  $yv$ ,  $shv$ ,  $ftv$ ,  $fyv$ , it is considered  
 characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY.  
 $y1$ ,  $sh1$ ,  $ft1$ ,  $fy1$ , are also multiplied by  $Min(1, 1.25 * (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fsv = fs = 253.4875$   
 with  $Esv = Es = 200000.00$   
 $1 = Asl,ten/(b*d)*(fs1/fc) = 0.09815014$   
 $2 = Asl,com/(b*d)*(fs2/fc) = 0.26768221$   
 $v = Asl,mid/(b*d)*(fsv/fc) = 0.24388823$

and confined core properties:

$b = 340.00$   
 $d = 327.00$   
 $d' = 13.00$   
 $fcc (5A.2, TBDY) = 19.13667$   
 $cc (5A.5, TBDY) = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $1 = Asl,ten/(b*d)*(fs1/fc) = 0.1260644$   
 $2 = Asl,com/(b*d)*(fs2/fc) = 0.34381201$   
 $v = Asl,mid/(b*d)*(fsv/fc) = 0.31325094$

Case/Assumption: Unconfined full section - Steel rupture  
 ' satisfies Eq. (4.3)

--->  
 $v < vs,y2$  - LHS eq.(4.5) is satisfied  
 ---->  
 $su (4.9) = 0.23431248$   
 $Mu = MRc (4.14) = 1.2706E+008$   
 $u = su (4.1) = 1.3353763E-005$

Calculation of ratio  $lb/ld$

Lap Length:  $lb/ld = 0.22053887$   
 $lb = 300.00$   
 $ld = 1360.304$   
 Calculation of  $lb,min$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.  
 $= 1$   
 $db = 18.00$   
 Mean strength value of all re-bars:  $fy = 555.55$   
 $fc' = 15.00$ , but  $fc'^{0.5} \leq 8.3 \text{ MPa}$  (22.5.3.1, ACI 318-14)  
 $t = 1.00$   
 $s = 0.80$   
 $e = 1.00$   
 $cb = 24.02082$   
 $Ktr = 0.82673491$   
 $Atr = Min(Atr\_x, Atr\_y) = 157.0796$   
 where  $Atr\_x$ ,  $Atr\_y$  are the sum of the area of all stirrup legs along X and Y loxal axis  
 $s = 380.00$   
 $n = 20.00$

Calculation of Shear Strength  $Vr = Min(Vr1, Vr2) = 196005.816$

Calculation of Shear Strength at edge 1,  $Vr1 = 227350.021$   
 $Vr1 = VCol ((10.3), ASCE 41-17) = knl * VCol0$   
 $VCol0 = 227350.021$   
 $knl = 1$  (zero step-static loading)

NOTE: In expression (10-3) 'Vs' is replaced by 'Vs+ f\*Vf'  
 where Vf is the contribution of FRPs (11.3), ACI 440).

$= 1$  (normal-weight concrete)  
 $fc' = 15.00$ , but  $fc'^{0.5} \leq 8.3 \text{ MPa}$  (22.5.3.1, ACI 318-14)  
 $M/Vd = 2.00$

$\mu_u = 3.21769$   
 $\mu_v = 0.01054019$   
 $d = 0.8 \cdot h = 320.00$   
 $N_u = 4737.328$   
 $A_g = 80000.00$   
 From (11.5.4.8), ACI 318-14:  $V_s = V_{s1} + V_{s2} = 0.00$   
 where:  
 $V_{s1} = 0.00$  is calculated for section web, with:  
 $d = 320.00$   
 $A_v = 157079.633$   
 $f_y = 444.44$   
 $s = 380.00$   
 $V_{s1}$  is multiplied by  $\text{Col1} = 0.00$   
 $s/d = 1.1875$   
 $V_{s2} = 0.00$  is calculated for section flange, with:  
 $d = 160.00$   
 $A_v = 157079.633$   
 $f_y = 444.44$   
 $s = 380.00$   
 $V_{s2}$  is multiplied by  $\text{Col2} = 0.00$   
 $s/d = 2.375$   
 $V_f ((11-3)-(11.4), \text{ACI 440}) = 188111.148$   
 $f = 0.95$ , for fully-wrapped sections  
 $w_f/s_f = 1$  (FRP strips adjacent to one another).  
 In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot \alpha) \sin \alpha$  which is more a generalised expression,  
 where  $\alpha$  is the angle of the crack direction (see KANEPE).  
 This later relation, considered as a function  $V_f(\alpha)$ , is implemented for every different fiber orientation  $\alpha_i$ ,  
 as well as for 2 crack directions,  $\alpha = 45^\circ$  and  $\alpha = -45^\circ$  to take into consideration the cyclic seismic loading.  
 orientation 1:  $\alpha_1 = b_1 + 90^\circ = 90.00$   
 $V_f = \text{Min}(|V_f(45, \alpha_1)|, |V_f(-45, \alpha_1)|)$ , with:  
 total thickness per orientation,  $t_{f1} = N_L \cdot t / N_{oDir} = 1.016$   
 $d_{fv} = d$  (figure 11.2, ACI 440) = 357.00  
 $f_{fe} ((11-5), \text{ACI 440}) = 259.312$   
 $E_f = 64828.00$   
 $f_{e} = 0.004$ , from (11.6a), ACI 440  
 with  $f_u = 0.01$   
 From (11-11), ACI 440:  $V_s + V_f \leq 164661.611$   
 $b_w = 200.00$

Calculation of Shear Strength at edge 2,  $V_{r2} = 196005.816$   
 $V_{r2} = V_{Col} ((10.3), \text{ASCE 41-17}) = k_n l \cdot V_{Col0}$   
 $V_{Col0} = 196005.816$   
 $k_n l = 1$  (zero step-static loading)

NOTE: In expression (10-3) ' $V_s$ ' is replaced by ' $V_s + f \cdot V_f$ '  
 where  $V_f$  is the contribution of FRPs (11.3), ACI 440).

$\lambda = 1$  (normal-weight concrete)  
 $f_c' = 15.00$ , but  $f_c'^{0.5} \leq 8.3 \text{ MPa}$  (22.5.3.1, ACI 318-14)  
 $M/Vd = 4.00$   
 $\mu_u = 23.99609$   
 $\mu_v = 0.01054019$   
 $d = 0.8 \cdot h = 320.00$   
 $N_u = 4737.328$   
 $A_g = 80000.00$   
 From (11.5.4.8), ACI 318-14:  $V_s = V_{s1} + V_{s2} = 0.00$   
 where:  
 $V_{s1} = 0.00$  is calculated for section web, with:  
 $d = 320.00$   
 $A_v = 157079.633$   
 $f_y = 444.44$   
 $s = 380.00$   
 $V_{s1}$  is multiplied by  $\text{Col1} = 0.00$   
 $s/d = 1.1875$   
 $V_{s2} = 0.00$  is calculated for section flange, with:  
 $d = 160.00$

Av = 157079.633

fy = 444.44

s = 380.00

Vs2 is multiplied by Col2 = 0.00

s/d = 2.375

Vf ((11-3)-(11.4), ACI 440) = 188111.148

f = 0.95, for fully-wrapped sections

wf/sf = 1 (FRP strips adjacent to one another).

In (11.3)  $\sin \theta + \cos \theta$  is replaced with  $(\cot \theta + \cot \alpha) \sin \alpha$  which is more a generalised expression, where  $\theta$  is the angle of the crack direction (see KANEPE).

This later relation, considered as a function  $V_f(\theta, \alpha)$ , is implemented for every different fiber orientation  $\alpha_i$ , as well as for 2 crack directions,  $\theta = 45^\circ$  and  $\theta = -45^\circ$  to take into consideration the cyclic seismic loading.

orientation 1:  $\theta_1 = \theta_1 + 90^\circ = 90.00$

$V_f = \text{Min}(|V_f(45, \theta_1)|, |V_f(-45, \theta_1)|)$ , with:

total thickness per orientation,  $t_{f1} = N_L * t / N_{oDir} = 1.016$

$d_{fv} = d$  (figure 11.2, ACI 440) = 357.00

$f_{fe}((11-5), \text{ACI 440}) = 259.312$

$E_f = 64828.00$

$f_e = 0.004$ , from (11.6a), ACI 440

with  $f_u = 0.01$

From (11-11), ACI 440:  $V_s + V_f \leq 164661.611$

bw = 200.00

-----  
End Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1

At local axis: 3

-----  
Start Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1

At Shear local axis: 2

(Bending local axis: 3)

Section Type: rctcs

Constant Properties

-----  
Knowledge Factor,  $\phi = 0.90$

Mean strength values are used for both shear and moment calculations.

Consequently:

Existing material of Primary Member: Concrete Strength,  $f_c = f_{cm} = 15.00$

Existing material of Primary Member: Steel Strength,  $f_s = f_{sm} = 444.44$

Concrete Elasticity,  $E_c = 18203.022$

Steel Elasticity,  $E_s = 200000.00$

#####

Note: Especially for the calculation of moment strengths,

the above steel re-bar strengths are multiplied by 1.25 according to R18.6.5, ACI 318-14

Existing material: Steel Strength,  $f_s = 1.25 * f_{sm} = 555.55$

#####

Max Height,  $H_{max} = 400.00$

Min Height,  $H_{min} = 200.00$

Max Width,  $W_{max} = 400.00$

Min Width,  $W_{min} = 200.00$

Eccentricity,  $E_{cc} = 100.00$

Cover Thickness,  $c = 25.00$

Mean Confinement Factor overall section = 1.27578

Element Length,  $L = 3000.00$

Primary Member

Ribbed Bars

Ductile Steel

Without Detailing for Earthquake Resistance (including stirrups not closed at 135°)

Longitudinal Bars With Ends Lapped Starting at the End Sections

Lap Length  $l_o = 300.00$

FRP Wrapping Data

Type: Carbon

Cured laminate properties (design values)

Thickness,  $t = 1.016$



Tensile Strength,  $f_{fu} = 1055.00$   
Tensile Modulus,  $E_f = 64828.00$   
Elongation,  $\epsilon_{fu} = 0.01$   
Number of directions,  $NoDir = 1$   
Fiber orientations,  $b_i = 0.00^\circ$   
Number of layers,  $NL = 1$   
Radius of rounding corners,  $R = 40.00$

#### Stepwise Properties

At local axis: 2  
EDGE -A-  
Shear Force,  $V_a = 1.5456333E-009$   
EDGE -B-  
Shear Force,  $V_b = -1.5456333E-009$   
BOTH EDGES  
Axial Force,  $F = -4737.328$   
Longitudinal Reinforcement Area Distribution (in 2 divisions)  
-Tension:  $As_t = 0.00$   
-Compression:  $As_c = 5152.212$   
Longitudinal Reinforcement Area Distribution (in 3 divisions)  
-Tension:  $As_{t,ten} = 1231.504$   
-Compression:  $As_{l,com} = 1231.504$   
-Middle:  $As_{l,mid} = 2689.203$

Calculation of Shear Capacity ratio,  $V_e/V_r = 0.55718248$   
Member Controlled by Flexure ( $V_e/V_r < 1$ )  
Calculation of Shear Demand from fig. R18.6.5, ACI 318-14  $V_e = (M_{pr1} + M_{pr2})/l_n = 126675.449$   
with  
 $M_{pr1} = \max(\mu_{u1+}, \mu_{u1-}) = 1.9001E+008$   
 $\mu_{u1+} = 1.9001E+008$ , is the ultimate moment strength at the edge 1 of the member in the actual moment direction which is defined for the static loading combination  
 $\mu_{u1-} = 1.9001E+008$ , is the ultimate moment strength at the edge 1 of the member in the opposite moment direction which is defined for the static loading combination  
 $M_{pr2} = \max(\mu_{u2+}, \mu_{u2-}) = 1.9001E+008$   
 $\mu_{u2+} = 1.9001E+008$ , is the ultimate moment strength at the edge 2 of the member in the actual moment direction which is defined for the static loading combination  
 $\mu_{u2-} = 1.9001E+008$ , is the ultimate moment strength at the edge 2 of the member in the opposite moment direction which is defined for the static loading combination

#### Calculation of $\mu_{u1+}$

Calculation of ultimate curvature  $\mu_u$  according to 4.1, Biskinis/Fardis 2013:  
 $\mu_u = 1.7086748E-005$   
 $\mu_u = 1.9001E+008$

with full section properties:

$b = 200.00$   
 $d = 357.00$   
 $d' = 43.00$   
 $v = 0.00442328$   
 $N = 4737.328$   
 $f_c = 15.00$   
 $\phi_o (5A.5, TBDY) = 0.002$   
Final value of  $\phi_u$ :  $\phi_u^* = \text{shear\_factor} * \max(\phi_u, \phi_o) = 0.018$   
The Shear\_factor is considered equal to 1 (pure moment strength)  
From (5.4b), TBDY:  $\phi_u = 0.018$   
 $\phi_u ((5.4c), TBDY) = a_s e^* s_{h,min} * f_{ywe}/f_{ce} + \min(f_x, f_y) = 0.15303423$   
where  $f = a_f^* p_f^* f_{fe}/f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$$f_x = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area})/(\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 51733.333$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } p_f = 2t_f/b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{f,e} = 524.0792$$

$$f_y = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area})/(\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 0.00$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } p_f = 2t_f/b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{f,e} = 524.0792$$

$$R = 40.00$$

$$\text{Effective FRP thickness, } t_f = N_L * t * \cos(b_1) = 1.016$$

$$f_{u,f} = 1055.00$$

$$E_f = 64828.00$$

$$u_{f,f} = 0.015$$

$$a_{se} = \text{Max}(((A_{\text{conf,max}} - A_{\text{noConf}})/A_{\text{conf,max}}) * (A_{\text{conf,min}}/A_{\text{conf,max}}), 0) = 0.00$$

The definitions of  $A_{\text{noConf}}$ ,  $A_{\text{conf,min}}$  and  $A_{\text{conf,max}}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{\text{conf,max}} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{\text{conf,min}} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{\text{conf,max}}$  by a length equal to half the clear spacing between hoops.

$A_{\text{noConf}} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$$p_{sh,min} = \text{Min}(p_{sh,x}, p_{sh,y}) = 0.00165347$$

Expression ((5.4d), TBDY) for  $p_{sh,min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$$p_{sh,x} \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$$

$$L_{stir} \text{ (Length of stirrups along Y)} = 960.00$$

$$A_{stir} \text{ (stirrups area)} = 78.53982$$

$$A_{sec} \text{ (section area)} = 120000.00$$

$$p_{sh,y} \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$$

$$L_{stir} \text{ (Length of stirrups along X)} = 960.00$$

$$A_{stir} \text{ (stirrups area)} = 78.53982$$

$$A_{sec} \text{ (section area)} = 120000.00$$

$$s = 380.00$$

$$f_{ywe} = 555.55$$

$$f_{ce} = 15.00$$

$$\text{From ((5.A5), TBDY), TBDY: } c_c = 0.00475778$$

$$c = \text{confinement factor} = 1.27578$$

$$y_1 = 0.0010562$$

$$sh_1 = 0.00365026$$

$$ft_1 = 304.185$$

$$fy_1 = 253.4875$$

$$su_1 = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$$l_o/l_{ou,min} = l_b/l_d = 0.22053887$$

$$su_1 = 0.4 * esu_{1,nominal} \text{ ((5.5), TBDY)} = 0.032$$

$$\text{From table 5A.1, TBDY: } esu_{1,nominal} = 0.08,$$

For calculation of  $esu1\_nominal$  and  $y1, sh1, ft1, fy1$ , it is considered characteristic value  $fsy1 = fs1/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fs1 = fs = 253.4875$   
 with  $Es1 = Es = 200000.00$   
 $y2 = 0.0010562$   
 $sh2 = 0.00365026$   
 $ft2 = 304.185$   
 $fy2 = 253.4875$   
 $su2 = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $lo/lo_{u,min} = lb/lb_{min} = 0.22053887$   
 $su2 = 0.4 \cdot esu2\_nominal \cdot ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esu2\_nominal = 0.08$ ,  
 For calculation of  $esu2\_nominal$  and  $y2, sh2, ft2, fy2$ , it is considered characteristic value  $fsy2 = fs2/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fs2 = fs = 253.4875$   
 with  $Es2 = Es = 200000.00$   
 $yv = 0.0010562$   
 $shv = 0.00365026$   
 $ftv = 304.185$   
 $fyv = 253.4875$   
 $suv = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $lo/lo_{u,min} = lb/ld = 0.22053887$   
 $suv = 0.4 \cdot esuv\_nominal \cdot ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esuv\_nominal = 0.08$ ,  
 considering characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY  
 For calculation of  $esuv\_nominal$  and  $yv, shv, ftv, fyv$ , it is considered characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fsv = fs = 253.4875$   
 with  $Es_v = Es = 200000.00$   
 $1 = Asl_{ten}/(b \cdot d) \cdot (fs1/fc) = 0.29147618$   
 $2 = Asl_{com}/(b \cdot d) \cdot (fs2/fc) = 0.29147618$   
 $v = Asl_{mid}/(b \cdot d) \cdot (fsv/fc) = 0.6364888$

and confined core properties:

$b = 140.00$   
 $d = 327.00$   
 $d' = 13.00$   
 $f_{cc} (5A.2, TBDY) = 19.13667$   
 $cc (5A.5, TBDY) = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $1 = Asl_{ten}/(b \cdot d) \cdot (fs1/fc) = 0.45459588$   
 $2 = Asl_{com}/(b \cdot d) \cdot (fs2/fc) = 0.45459588$   
 $v = Asl_{mid}/(b \cdot d) \cdot (fsv/fc) = 0.99268896$

Case/Assumption: Unconfined full section - Steel rupture  
 ' satisfies Eq. (4.3)

--->  
 $v < v_{s,y2}$  - LHS eq.(4.5) is not satisfied  
 --->  
 $v < v_{s,c}$  - RHS eq.(4.5) is satisfied  
 --->  
 $su (4.8) = 0.40159417$   
 $Mu = MRc (4.15) = 1.9001E+008$   
 $u = su (4.1) = 1.7086748E-005$

Calculation of ratio  $lb/ld$

Lap Length:  $lb/ld = 0.22053887$   
 $lb = 300.00$

Id = 1360.304

Calculation of  $I_{b,min}$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.  
= 1

db = 18.00

Mean strength value of all re-bars:  $f_y = 555.55$

$f_c' = 15.00$ , but  $f_c^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

t = 1.00

s = 0.80

e = 1.00

cb = 24.02082

Ktr = 0.82673491

Atr = Min(Atr<sub>x</sub>, Atr<sub>y</sub>) = 157.0796

where Atr<sub>x</sub>, Atr<sub>y</sub> are the sum of the area of all stirrup legs along X and Y local axis

s = 380.00

n = 20.00

Calculation of Mu1-

Calculation of ultimate curvature  $\phi_u$  according to 4.1, Biskinis/Fardis 2013:

$\phi_u = 1.7086748E-005$

Mu = 1.9001E+008

with full section properties:

b = 200.00

d = 357.00

d' = 43.00

v = 0.00442328

N = 4737.328

$f_c = 15.00$

$\phi_0$  (5A.5, TBDY) = 0.002

Final value of  $\phi_u$ :  $\phi_u^* = \text{shear\_factor} * \text{Max}(\phi_u, \phi_c) = 0.018$

The Shear\_factor is considered equal to 1 (pure moment strength)

From (5.4b), TBDY:  $\phi_u = 0.018$

$\phi_u$  ((5.4c), TBDY) =  $a_s e^* \phi_{u,min} * f_{ywe} / f_{ce} + \text{Min}(\phi_{ux}, \phi_{uy}) = 0.15303423$

where  $\phi = a_f * \phi_f * f_{fe} / f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$\phi_{ux} = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$a_f = 0.43111111$

with Unconfined area =  $((b_{max} - 2R)^2 + (h_{max} - 2R)^2) / 3 = 51733.333$

$b_{max} = 400.00$

$h_{max} = 400.00$

From EC8 A.4.4.3(6),  $\phi_f = 2t_f / b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

$f_y = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$a_f = 0.43111111$

with Unconfined area =  $((b_{max} - 2R)^2 + (h_{max} - 2R)^2) / 3 = 0.00$

$b_{max} = 400.00$

$h_{max} = 400.00$

From EC8 A.4.4.3(6),  $\phi_f = 2t_f / b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

R = 40.00

Effective FRP thickness,  $t_f = N_L * t * \cos(b_1) = 1.016$

$f_{u,f} = 1055.00$

$E_f = 64828.00$

$\phi_{u,f} = 0.015$

$a_s e = \text{Max}(((A_{conf,max} - A_{noConf}) / A_{conf,max}) * (A_{conf,min} / A_{conf,max}), 0) = 0.00$

The definitions of A<sub>noConf</sub>, A<sub>conf,min</sub> and A<sub>conf,max</sub> are derived from generalization

of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$p_{sh,min} = \text{Min}(p_{sh,x}, p_{sh,y}) = 0.00165347$

Expression ((5.4d), TBDY) for  $p_{sh,min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$p_{sh,x} \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$

$L_{stir}$  (Length of stirrups along Y) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$p_{sh,y} \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$

$L_{stir}$  (Length of stirrups along X) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$s = 380.00$

$f_{ywe} = 555.55$

$f_{ce} = 15.00$

From ((5.A5), TBDY), TBDY:  $cc = 0.00475778$

$c$  = confinement factor = 1.27578

$y_1 = 0.0010562$

$sh_1 = 0.00365026$

$ft_1 = 304.185$

$fy_1 = 253.4875$

$su_1 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$lo/lou,min = lb/l_d = 0.22053887$

$su_1 = 0.4 * esu1_{nominal} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu1_{nominal} = 0.08$ ,

For calculation of  $esu1_{nominal}$  and  $y_1, sh_1, ft_1, fy_1$ , it is considered characteristic value  $fsy_1 = fs_1/1.2$ , from table 5.1, TBDY.

$y_1, sh_1, ft_1, fy_1$ , are also multiplied by  $\text{Min}(1, 1.25 * (lb/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.

with  $fs_1 = fs = 253.4875$

with  $Es_1 = Es = 200000.00$

$y_2 = 0.0010562$

$sh_2 = 0.00365026$

$ft_2 = 304.185$

$fy_2 = 253.4875$

$su_2 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$lo/lou,min = lb/l_{b,min} = 0.22053887$

$su_2 = 0.4 * esu2_{nominal} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu2_{nominal} = 0.08$ ,

For calculation of  $esu2_{nominal}$  and  $y_2, sh_2, ft_2, fy_2$ , it is considered characteristic value  $fsy_2 = fs_2/1.2$ , from table 5.1, TBDY.

$y_2, sh_2, ft_2, fy_2$ , are also multiplied by  $\text{Min}(1, 1.25 * (lb/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.

with  $fs_2 = fs = 253.4875$

with  $Es_2 = Es = 200000.00$

$y_v = 0.0010562$

$sh_v = 0.00365026$

$ft_v = 304.185$

$fy_v = 253.4875$

$su_v = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor

and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $l_o/l_{o,min} = l_b/l_d = 0.22053887$   
 $suv = 0.4 * esuv_{nominal} ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esuv_{nominal} = 0.08$ ,  
 considering characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY  
 For calculation of  $esuv_{nominal}$  and  $yv, shv, ftv, fyv$ , it is considered  
 characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $Min(1, 1.25 * (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fsv = fs = 253.4875$   
 with  $Esv = Es = 200000.00$   
 $1 = Asl_{ten}/(b*d) * (fs1/fc) = 0.29147618$   
 $2 = Asl_{com}/(b*d) * (fs2/fc) = 0.29147618$   
 $v = Asl_{mid}/(b*d) * (fsv/fc) = 0.6364888$

and confined core properties:

$b = 140.00$   
 $d = 327.00$   
 $d' = 13.00$   
 $fcc (5A.2, TBDY) = 19.13667$   
 $cc (5A.5, TBDY) = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $1 = Asl_{ten}/(b*d) * (fs1/fc) = 0.45459588$   
 $2 = Asl_{com}/(b*d) * (fs2/fc) = 0.45459588$   
 $v = Asl_{mid}/(b*d) * (fsv/fc) = 0.99268896$

Case/Assumption: Unconfined full section - Steel rupture

' satisfies Eq. (4.3)

--->  
 $v < vs_{y2}$  - LHS eq.(4.5) is not satisfied

--->  
 $v < vs_c$  - RHS eq.(4.5) is satisfied

--->  
 $su (4.8) = 0.40159417$   
 $Mu = MRc (4.15) = 1.9001E+008$   
 $u = su (4.1) = 1.7086748E-005$

Calculation of ratio  $l_b/l_d$

Lap Length:  $l_b/l_d = 0.22053887$

$l_b = 300.00$   
 $l_d = 1360.304$

Calculation of  $l_b,min$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$= 1$   
 $db = 18.00$   
 Mean strength value of all re-bars:  $fy = 555.55$   
 $fc' = 15.00$ , but  $fc^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)  
 $t = 1.00$   
 $s = 0.80$   
 $e = 1.00$   
 $cb = 24.02082$   
 $Ktr = 0.82673491$   
 $Atr = Min(Atr_x, Atr_y) = 157.0796$   
 where  $Atr_x, Atr_y$  are the sum of the area of all stirrup legs along X and Y loxal axis  
 $s = 380.00$   
 $n = 20.00$

Calculation of  $Mu_{2+}$

Calculation of ultimate curvature  $u$  according to 4.1, Biskinis/Fardis 2013:

$u = 1.7086748E-005$   
 $Mu = 1.9001E+008$

with full section properties:

$$b = 200.00$$

$$d = 357.00$$

$$d' = 43.00$$

$$v = 0.00442328$$

$$N = 4737.328$$

$$f_c = 15.00$$

$$\alpha (5A.5, \text{TB DY}) = 0.002$$

$$\text{Final value of } \alpha: \alpha^* = \text{shear\_factor} * \text{Max}(\alpha, \alpha_c) = 0.018$$

The Shear\_factor is considered equal to 1 (pure moment strength)

$$\text{From (5.4b), TB DY: } \alpha = 0.018$$

$$\alpha_e ((5.4c), \text{TB DY}) = \alpha * \min(f_{ywe}/f_c + \min(f_x, f_y)) = 0.15303423$$

where  $f = \alpha * \rho_f * f_{fe}/f_c$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$$f_x = 0.15303423$$

Expression ((15B.6), TB DY) is modified as  $\alpha_f = 1 - (\text{Unconfined area})/(\text{total area})$

$$\alpha_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 51733.333$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A4.4.3(6), } \rho_f = 2t_f/b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$f_y = 0.15303423$$

Expression ((15B.6), TB DY) is modified as  $\alpha_f = 1 - (\text{Unconfined area})/(\text{total area})$

$$\alpha_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 0.00$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A4.4.3(6), } \rho_f = 2t_f/b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$R = 40.00$$

$$\text{Effective FRP thickness, } t_f = N L^* t \cos(\beta_1) = 1.016$$

$$f_{u,f} = 1055.00$$

$$E_f = 64828.00$$

$$u_f = 0.015$$

$$\alpha_{se} = \text{Max}(((A_{\text{conf,max}} - A_{\text{noConf}})/A_{\text{conf,max}}) * (A_{\text{conf,min}}/A_{\text{conf,max}}), 0) = 0.00$$

The definitions of  $A_{\text{noConf}}$ ,  $A_{\text{conf,min}}$  and  $A_{\text{conf,max}}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{\text{conf,max}} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{\text{conf,min}} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{\text{conf,max}}$  by a length equal to half the clear spacing between hoops.

$A_{\text{noConf}} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$$\rho_{sh,min} = \text{Min}(\rho_{sh,x}, \rho_{sh,y}) = 0.00165347$$

Expression ((5.4d), TB DY) for  $\rho_{sh,min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$$\rho_{sh,x} ((5.4d), \text{TB DY}) = L_{\text{stir}} * A_{\text{stir}} / (A_{\text{sec}} * s) = 0.00165347$$

$$L_{\text{stir}} (\text{Length of stirrups along Y}) = 960.00$$

$$A_{\text{stir}} (\text{stirrups area}) = 78.53982$$

$$A_{\text{sec}} (\text{section area}) = 120000.00$$

$$\rho_{sh,y} ((5.4d), \text{TB DY}) = L_{\text{stir}} * A_{\text{stir}} / (A_{\text{sec}} * s) = 0.00165347$$

$$L_{\text{stir}} (\text{Length of stirrups along X}) = 960.00$$

$$A_{\text{stir}} (\text{stirrups area}) = 78.53982$$

$$A_{\text{sec}} (\text{section area}) = 120000.00$$

$$s = 380.00$$

$$f_{ywe} = 555.55$$

$$f_c = 15.00$$

From ((5.A.5), TBDY), TBDY:  $cc = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $y1 = 0.0010562$   
 $sh1 = 0.00365026$   
 $ft1 = 304.185$   
 $fy1 = 253.4875$   
 $su1 = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $lo/lou,min = lb/ld = 0.22053887$   
 $su1 = 0.4*esu1\_nominal ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esu1\_nominal = 0.08$ ,  
 For calculation of  $esu1\_nominal$  and  $y1, sh1, ft1, fy1$ , it is considered  
 characteristic value  $fsy1 = fs1/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25*(lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fs1 = fs = 253.4875$   
 with  $Es1 = Es = 200000.00$   
 $y2 = 0.0010562$   
 $sh2 = 0.00365026$   
 $ft2 = 304.185$   
 $fy2 = 253.4875$   
 $su2 = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $lo/lou,min = lb/lb,min = 0.22053887$   
 $su2 = 0.4*esu2\_nominal ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esu2\_nominal = 0.08$ ,  
 For calculation of  $esu2\_nominal$  and  $y2, sh2, ft2, fy2$ , it is considered  
 characteristic value  $fsy2 = fs2/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25*(lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fs2 = fs = 253.4875$   
 with  $Es2 = Es = 200000.00$   
 $yv = 0.0010562$   
 $shv = 0.00365026$   
 $ftv = 304.185$   
 $fyv = 253.4875$   
 $suv = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $lo/lou,min = lb/ld = 0.22053887$   
 $suv = 0.4*esuv\_nominal ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esuv\_nominal = 0.08$ ,  
 considering characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY  
 For calculation of  $esuv\_nominal$  and  $yv, shv, ftv, fyv$ , it is considered  
 characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25*(lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fsv = fs = 253.4875$   
 with  $Esv = Es = 200000.00$   
 $1 = Asl,ten/(b*d)*(fs1/fc) = 0.29147618$   
 $2 = Asl,com/(b*d)*(fs2/fc) = 0.29147618$   
 $v = Asl,mid/(b*d)*(fsv/fc) = 0.6364888$   
 and confined core properties:  
 $b = 140.00$   
 $d = 327.00$   
 $d' = 13.00$   
 $fcc (5A.2, TBDY) = 19.13667$   
 $cc (5A.5, TBDY) = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $1 = Asl,ten/(b*d)*(fs1/fc) = 0.45459588$   
 $2 = Asl,com/(b*d)*(fs2/fc) = 0.45459588$   
 $v = Asl,mid/(b*d)*(fsv/fc) = 0.99268896$   
 Case/Assumption: Unconfined full section - Steel rupture  
 ' satisfies Eq. (4.3)

--->



$v < v_{s,y2}$  - LHS eq.(4.5) is not satisfied

---->

$v < v_{s,c}$  - RHS eq.(4.5) is satisfied

---->

$\mu_u(4.8) = 0.40159417$

$\mu_u = M_{Rc}(4.15) = 1.9001E+008$

$u = \mu_u(4.1) = 1.7086748E-005$

Calculation of ratio  $I_b/I_d$

Lap Length:  $I_b/I_d = 0.22053887$

$I_b = 300.00$

$I_d = 1360.304$

Calculation of  $I_{b,min}$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.  
 $= 1$

$d_b = 18.00$

Mean strength value of all re-bars:  $f_y = 555.55$

$f_c' = 15.00$ , but  $f_c'^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$t = 1.00$

$s = 0.80$

$e = 1.00$

$c_b = 24.02082$

$K_{tr} = 0.82673491$

$A_{tr} = \text{Min}(A_{tr,x}, A_{tr,y}) = 157.0796$

where  $A_{tr,x}$ ,  $A_{tr,y}$  are the sum of the area of all stirrup legs along X and Y loxal axis

$s = 380.00$

$n = 20.00$

Calculation of  $\mu_u$

Calculation of ultimate curvature  $\mu_u$  according to 4.1, Biskinis/Fardis 2013:

$u = 1.7086748E-005$

$\mu_u = 1.9001E+008$

with full section properties:

$b = 200.00$

$d = 357.00$

$d' = 43.00$

$v = 0.00442328$

$N = 4737.328$

$f_c = 15.00$

$\alpha_c(5A.5, \text{TBDY}) = 0.002$

Final value of  $\alpha_c$ :  $\alpha_c^* = \text{shear\_factor} * \text{Max}(\alpha_c, \alpha_{cc}) = 0.018$

The Shear\_factor is considered equal to 1 (pure moment strength)

From (5.4b), TBDY:  $\alpha_c = 0.018$

we ((5.4c), TBDY) =  $\alpha_{se} * \text{sh}_{min} * f_{ywe}/f_{ce} + \text{Min}(f_x, f_y) = 0.15303423$

where  $f = \alpha_f * p_f * f_{fe}/f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$f_x = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $\alpha_f = 1 - (\text{Unconfined area})/(\text{total area})$

$\alpha_f = 0.43111111$

with Unconfined area =  $((b_{max}-2R)^2 + (h_{max}-2R)^2)/3 = 51733.333$

$b_{max} = 400.00$

$h_{max} = 400.00$

From EC8 A.4.4.3(6),  $p_f = 2t_f/b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

$f_y = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $\alpha_f = 1 - (\text{Unconfined area})/(\text{total area})$

$\alpha_f = 0.43111111$

with Unconfined area =  $((b_{max}-2R)^2 + (h_{max}-2R)^2)/3 = 0.00$

bmax = 400.00  
hmax = 400.00  
From EC8 A4.4.3(6),  $pf = 2tf/bw = 0.01016$   
bw = 200.00  
effective stress from (A.35),  $ff,e = 524.0792$

R = 40.00  
Effective FRP thickness,  $tf = NL*t*Cos(b1) = 1.016$   
 $f_{u,f} = 1055.00$   
 $E_f = 64828.00$   
 $u_{,f} = 0.015$

$ase = \text{Max}(((A_{conf,max} - A_{noConf})/A_{conf,max}) * (A_{conf,min}/A_{conf,max}), 0) = 0.00$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988) "Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$psh,min = \text{Min}(psh,x, psh,y) = 0.00165347$

Expression ((5.4d), TBDY) for  $psh,min$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$psh,x \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$   
 $L_{stir}$  (Length of stirrups along Y) = 960.00  
 $A_{stir}$  (stirrups area) = 78.53982  
 $A_{sec}$  (section area) = 120000.00

$psh,y \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$   
 $L_{stir}$  (Length of stirrups along X) = 960.00  
 $A_{stir}$  (stirrups area) = 78.53982  
 $A_{sec}$  (section area) = 120000.00

s = 380.00  
 $f_{ywe} = 555.55$   
 $f_{ce} = 15.00$

From ((5.A5), TBDY), TBDY:  $cc = 0.00475778$   
c = confinement factor = 1.27578

$y1 = 0.0010562$   
 $sh1 = 0.00365026$

$ft1 = 304.185$

$fy1 = 253.4875$

$su1 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$lo/lo_{u,min} = lb/ld = 0.22053887$

$su1 = 0.4 * esu1_{nominal} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu1_{nominal} = 0.08$ ,

For calculation of  $esu1_{nominal}$  and  $y1, sh1, ft1, fy1$ , it is considered characteristic value  $fsy1 = fs1/1.2$ , from table 5.1, TBDY.

$y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 * (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.

with  $fs1 = fs = 253.4875$

with  $Es1 = Es = 200000.00$

$y2 = 0.0010562$   
 $sh2 = 0.00365026$

$ft2 = 304.185$

$fy2 = 253.4875$

$su2 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$lo/lo_{u,min} = lb/lb_{,min} = 0.22053887$

```

su2 = 0.4*esu2_nominal ((5.5), TBDY) = 0.032
From table 5A.1, TBDY: esu2_nominal = 0.08,
For calculation of esu2_nominal and y2, sh2,ft2,fy2, it is considered
characteristic value fsy2 = fs2/1.2, from table 5.1, TBDY.
y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/ld)^ 2/3), from 10.3.5, ASCE 41-17.
with fs2 = fs = 253.4875
with Es2 = Es = 200000.00
yv = 0.0010562
shv = 0.00365026
ftv = 304.185
fyv = 253.4875
suv = 0.00365026
using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
and also multiplied by the shear_factor according to 15.7.1.4, with
Shear_factor = 1.00
lo/lou,min = lb/ld = 0.22053887
suv = 0.4*esuv_nominal ((5.5), TBDY) = 0.032
From table 5A.1, TBDY: esuv_nominal = 0.08,
considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY
For calculation of esuv_nominal and yv, shv,ftv,fyv, it is considered
characteristic value fsyv = fsv/1.2, from table 5.1, TBDY.
y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/ld)^ 2/3), from 10.3.5, ASCE 41-17.
with fsv = fs = 253.4875
with Esv = Es = 200000.00
1 = Asl,ten/(b*d)*(fs1/fc) = 0.29147618
2 = Asl,com/(b*d)*(fs2/fc) = 0.29147618
v = Asl,mid/(b*d)*(fsv/fc) = 0.6364888
and confined core properties:
b = 140.00
d = 327.00
d' = 13.00
fcc (5A.2, TBDY) = 19.13667
cc (5A.5, TBDY) = 0.00475778
c = confinement factor = 1.27578
1 = Asl,ten/(b*d)*(fs1/fc) = 0.45459588
2 = Asl,com/(b*d)*(fs2/fc) = 0.45459588
v = Asl,mid/(b*d)*(fsv/fc) = 0.99268896
Case/Assumption: Unconfined full section - Steel rupture
'satisfies Eq. (4.3)
--->
v < vs,y2 - LHS eq.(4.5) is not satisfied
--->
v < vs,c - RHS eq.(4.5) is satisfied
--->
su (4.8) = 0.40159417
Mu = MRc (4.15) = 1.9001E+008
u = su (4.1) = 1.7086748E-005

```

#### Calculation of ratio lb/ld

```

Lap Length: lb/ld = 0.22053887
lb = 300.00
ld = 1360.304
Calculation of lb,min according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.
= 1
db = 18.00
Mean strength value of all re-bars: fy = 555.55
fc' = 15.00, but fc'^0.5 <= 8.3 MPa (22.5.3.1, ACI 318-14)
t = 1.00
s = 0.80
e = 1.00
cb = 24.02082
Ktr = 0.82673491
Atr = Min(Atr_x,Atr_y) = 157.0796
where Atr_x, Atr_y are the sum of the area of all stirrup legs along X and Y loxal axis
s = 380.00

```

$$n = 20.00$$

$$\text{Calculation of Shear Strength } V_r = \text{Min}(V_{r1}, V_{r2}) = 227350.021$$

$$\text{Calculation of Shear Strength at edge 1, } V_{r1} = 227350.021$$

$$V_{r1} = V_{Col} \text{ ((10.3), ASCE 41-17)} = knl * V_{Col0}$$

$$V_{Col0} = 227350.021$$

$$knl = 1 \text{ (zero step-static loading)}$$

NOTE: In expression (10-3) 'Vs' is replaced by 'Vs+ f\*Vf' where Vf is the contribution of FRPs (11.3), ACI 440).

$$= 1 \text{ (normal-weight concrete)}$$

$$f_c' = 15.00, \text{ but } f_c'^{0.5} \leq 8.3 \text{ MPa (22.5.3.1, ACI 318-14)}$$

$$M/Vd = 2.00$$

$$\mu_u = 0.00988804$$

$$V_u = 1.5456333E-009$$

$$d = 0.8 * h = 320.00$$

$$N_u = 4737.328$$

$$A_g = 80000.00$$

$$\text{From (11.5.4.8), ACI 318-14: } V_s = V_{s1} + V_{s2} = 0.00$$

where:

Vs1 = 0.00 is calculated for section web, with:

$$d = 160.00$$

$$A_v = 157079.633$$

$$f_y = 444.44$$

$$s = 380.00$$

Vs1 is multiplied by Col1 = 0.00

$$s/d = 2.375$$

Vs2 = 0.00 is calculated for section flange, with:

$$d = 320.00$$

$$A_v = 157079.633$$

$$f_y = 444.44$$

$$s = 380.00$$

Vs2 is multiplied by Col2 = 0.00

$$s/d = 1.1875$$

$$V_f \text{ ((11-3)-(11.4), ACI 440)} = 188111.148$$

$$f = 0.95, \text{ for fully-wrapped sections}$$

wf/sf = 1 (FRP strips adjacent to one another).

In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot a) \sin a$  which is more a generalised expression,

where  $a$  is the angle of the crack direction (see KANEPE).

This later relation, considered as a function  $V_f(\theta)$ , is implemented for every different fiber orientation  $\theta_i$ , as well as for 2 crack directions,  $\theta = 45^\circ$  and  $\theta = -45^\circ$  to take into consideration the cyclic seismic loading.

$$\text{orientation 1: } \theta_1 = \theta_1 + 90^\circ = 90.00$$

$$V_f = \text{Min}(|V_f(45, \theta_1)|, |V_f(-45, \theta_1)|), \text{ with:}$$

$$\text{total thickness per orientation, } t_{f1} = NL * t / N_{oDir} = 1.016$$

$$d_{fv} = d \text{ (figure 11.2, ACI 440)} = 357.00$$

$$f_{fe} \text{ ((11-5), ACI 440)} = 259.312$$

$$E_f = 64828.00$$

$$f_e = 0.004, \text{ from (11.6a), ACI 440}$$

$$\text{with } f_u = 0.01$$

$$\text{From (11-11), ACI 440: } V_s + V_f \leq 164661.611$$

$$b_w = 200.00$$

$$\text{Calculation of Shear Strength at edge 2, } V_{r2} = 227350.021$$

$$V_{r2} = V_{Col} \text{ ((10.3), ASCE 41-17)} = knl * V_{Col0}$$

$$V_{Col0} = 227350.021$$

$$knl = 1 \text{ (zero step-static loading)}$$

NOTE: In expression (10-3) 'Vs' is replaced by 'Vs+ f\*Vf' where Vf is the contribution of FRPs (11.3), ACI 440).

$$= 1 \text{ (normal-weight concrete)}$$

$f_c' = 15.00$ , but  $f_c'^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$M/Vd = 2.00$

$\mu_u = 0.00525978$

$V_u = 1.5456333E-009$

$d = 0.8 \cdot h = 320.00$

$N_u = 4737.328$

$A_g = 80000.00$

From (11.5.4.8), ACI 318-14:  $V_s = V_{s1} + V_{s2} = 0.00$

where:

$V_{s1} = 0.00$  is calculated for section web, with:

$d = 160.00$

$A_v = 157079.633$

$f_y = 444.44$

$s = 380.00$

$V_{s1}$  is multiplied by  $\text{Col1} = 0.00$

$s/d = 2.375$

$V_{s2} = 0.00$  is calculated for section flange, with:

$d = 320.00$

$A_v = 157079.633$

$f_y = 444.44$

$s = 380.00$

$V_{s2}$  is multiplied by  $\text{Col2} = 0.00$

$s/d = 1.1875$

$V_f$  ((11-3)-(11.4), ACI 440) = 188111.148

$f = 0.95$ , for fully-wrapped sections

$w_f/s_f = 1$  (FRP strips adjacent to one another).

In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot a) \sin a$  which is more a generalised expression, where  $a$  is the angle of the crack direction (see KANEPE).

This later relation, considered as a function  $V_f(\theta, a)$ , is implemented for every different fiber orientation  $a_i$ , as well as for 2 crack directions,  $\theta = 45^\circ$  and  $\theta = -45^\circ$  to take into consideration the cyclic seismic loading.

orientation 1:  $\theta = b1 + 90^\circ = 90.00$

$V_f = \text{Min}(|V_f(45, \theta)|, |V_f(-45, a1)|)$ , with:

total thickness per orientation,  $t_{f1} = N_L \cdot t / N_{\text{Dir}} = 1.016$

$d_{fv} = d$  (figure 11.2, ACI 440) = 357.00

$f_{fe}$  ((11-5), ACI 440) = 259.312

$E_f = 64828.00$

$f_e = 0.004$ , from (11.6a), ACI 440

with  $f_u = 0.01$

From (11-11), ACI 440:  $V_s + V_f \leq 164661.611$

$b_w = 200.00$

End Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1

At local axis: 2

Start Of Calculation of Chord Rotation Capacity for element: column TC1 of floor 1

At local axis: 2

Integration Section: (b)

Section Type: rctcs

Constant Properties

Knowledge Factor,  $\phi = 0.90$

Chord Rotation is generally considered as Deformation-Controlled Action according to Table C7-1, ASCE 41-17.

Mean strengths are used for Deformation-Controlled Actions according to 7.5.1.3, ASCE 41-17

Consequently:

Existing material of Primary Member: Concrete Strength,  $f_c = f_{cm} = 15.00$

Existing material of Primary Member: Steel Strength,  $f_s = f_{sm} = 444.44$

Concrete Elasticity,  $E_c = 18203.022$

Steel Elasticity,  $E_s = 200000.00$

Max Height,  $H_{\text{max}} = 400.00$

Min Height,  $H_{\text{min}} = 200.00$

Max Width,  $W_{\text{max}} = 400.00$

Min Width,  $W_{\text{min}} = 200.00$

Eccentricity, Ecc = 100.00  
 Cover Thickness, c = 25.00  
 Element Length, L = 3000.00  
 Primary Member  
 Ribbed Bars  
 Ductile Steel  
 Without Detailing for Earthquake Resistance (including stirrups not closed at 135°)  
 Longitudinal Bars With Ends Lapped Starting at the End Sections  
 Lap Length lb = 300.00  
 FRP Wrapping Data  
 Type: Carbon  
 Cured laminate properties (design values)  
 Thickness, t = 1.016  
 Tensile Strength, ffu = 1055.00  
 Tensile Modulus, Ef = 64828.00  
 Elongation, efu = 0.01  
 Number of directions, NoDir = 1  
 Fiber orientations, bi: 0.00°  
 Number of layers, NL = 1  
 Radius of rounding corners, R = 40.00

#### Stepwise Properties

Bending Moment, M = 21.03175  
 Shear Force, V2 = 2811.342  
 Shear Force, V3 = 0.02136663  
 Axial Force, F = -4735.965  
 Longitudinal Reinforcement Area Distribution (in 2 divisions)  
   -Tension: Aslt = 0.00  
   -Compression: Aslc = 5152.212  
 Longitudinal Reinforcement Area Distribution (in 3 divisions)  
   -Tension: Asl,ten = 2261.947  
   -Compression: Asl,com = 829.3805  
   -Middle: Asl,mid = 2060.885  
 Mean Diameter of Tension Reinforcement, DbL = 17.77778

Existing component: From table 7-7, ASCE 41\_17: Final chord rotation Capacity  $u_R = \frac{u}{p} = 0.0070088$   
 $u = y + p = 0.00778756$

- Calculation of  $y$  -

$y = (M_y * L_s / 3) / E_{eff} = 0.00778756$  ((4.29), Biskinis Phd))  
 $M_y = 1.9010E+008$   
 $L_s = M/V$  (with  $L_s > 0.1 * L$  and  $L_s < 2 * L$ ) = 984.3271  
 From table 10.5, ASCE 41\_17:  $E_{eff} = factor * E_c * I_g = 8.0093E+012$   
 $factor = 0.30$   
 $A_g = 120000.00$   
 $f_c' = 15.00$   
 $N = 4735.965$   
 $E_c * I_g = 2.6698E+013$

Calculation of Yielding Moment  $M_y$

Calculation of  $y$  and  $M_y$  according to Annex 7 -

$y = \min(y_{ten}, y_{com})$   
 $y_{ten} = 6.8134937E-006$   
 with ((10.1), ASCE 41-17)  $f_y = \min(f_y, 1.25 * f_y * (l_b / d)^{2/3}) = 235.317$   
 $d = 357.00$   
 $y = 0.51628986$

```

A = 0.07244171
B = 0.04953119
with pt = 0.0075814
    pc = 0.01161597
    pv = 0.02886393
    N = 4735.965
    b = 200.00
    " = 0.12044818
y_comp = 8.6576330E-006
with fc* (12.3, (ACI 440)) = 16.12972
    fc = 15.00
    fl = 0.93147527
    b = bmax = 400.00
    h = hmax = 400.00
    Ag = 120000.00
        g = pt + pc + pv = 0.07215983
        rc = 40.00
        Ae/Ac = 0.38686758
        Effective FRP thickness, tf = NL*t*cos(b1) = 1.016
    effective strain from (12.5) and (12.12), efe = 0.004
    fu = 0.01
    Ef = 64828.00
    Ec = 18203.022
    y = 0.51604609
    A = 0.0719519
    B = 0.04924932
    with Es = 200000.00

```

#### Calculation of ratio lb/ld

```

Lap Length: ld/ld,min = 0.27567359
lb = 300.00
ld = 1088.244
Calculation of l according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.
= 1
db = 18.00
Mean strength value of all re-bars: fy = 444.44
fc' = 15.00, but fc^0.5 <= 8.3 MPa (22.5.3.1, ACI 318-14)
    t = 1.00
    s = 0.80
    e = 1.00
cb = 24.02082
Ktr = 0.82673491
Atr = Min(Atr_x, Atr_y) = 157.0796
    where Atr_x, Atr_y are the sum of the area of all stirrup legs along X and Y loxal axis
s = 380.00
n = 20.00

```

#### - Calculation of p -

```

From table 10-8: p = 0.00
with:
- Columns controlled by inadequate development or splicing along the clear height because lb/ld < 1
shear control ratio VyE/VColOE = 0.82694402
d = 357.00
s = 0.00
    t = Av/(bw*s) + 2*tf/bw*(ffe/fs) = Av*Lstir/(Ag*s) + 2*tf/bw*(ffe/fs) = 0.0075814
Av = 78.53982, is the area of every stirrup
Lstir = 960.00, is the total Length of all stirrups parallel to loading (shear) direction
The term 2*tf/bw*(ffe/fs) is implemented to account for FRP contribution
where f = 2*tf/bw is FRP ratio (EC8 - 3, A.4.4.3(6)) and ffe/fs normalises f to steel strength
All these variables have already been given in Shear control ratio calculation.
NUD = 4735.965
Ag = 120000.00

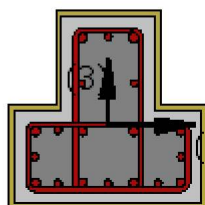
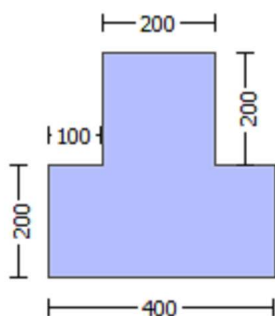
```

$f_{cE} = 15.00$   
 $f_{ytE} = f_{yIE} = 444.44$   
 $\rho_l = \text{Area\_Tot\_Long\_Rein}/(b*d) = 0.07215983$   
 $b = 200.00$   
 $d = 357.00$   
 $f_{cE} = 15.00$

-----  
 End Of Calculation of Chord Rotation Capacity for element: column TC1 of floor 1  
 At local axis: 2  
 Integration Section: (b)  
 -----

## Calculation No. 7

column C1, Floor 1  
 Limit State: Immediate Occupancy (data interpolation between analysis steps 1 and 2)  
 Analysis: Uniform +X  
 Check: Shear capacity VRd  
 Edge: End  
 Local Axis: (3)



Start Of Calculation of Shear Capacity for element: column TC1 of floor 1  
 At local axis: 3  
 Integration Section: (b)  
 Section Type: rctcs

Constant Properties

-----  
 Knowledge Factor,  $\gamma = 0.90$   
 Member Shear Force is generally considered as Force-Controlled Action according to Table C7-1, ASCE 41-17.  
 Lower-bound strengths are used for Force-Controlled Actions according to 7.5.1.3, ASCE 41-17  
 Consequently:  
 Existing material of Primary Member: Concrete Strength,  $f_c = f_{c\_lower\_bound} = 10.00$   
 Existing material of Primary Member: Steel Strength,  $f_s = f_{s\_lower\_bound} = 400.00$   
 Concrete Elasticity,  $E_c = 18203.022$



Steel Elasticity,  $E_s = 200000.00$   
 #####  
 Note: Especially for the calculation of  $\gamma$  for displacement ductility demand,  
 the expected (mean value) strengths are used (7.5.1.3, ASCE 41-17) because bending is considered as  
 Deformation-Controlled Action (Table C7-1, ASCE 41-17).  
 Existing material: Concrete Strength,  $f_c = f_{cm} = 15.00$   
 Existing material: Steel Strength,  $f_s = f_{sm} = 444.44$   
 #####  
 Max Height,  $H_{max} = 400.00$   
 Min Height,  $H_{min} = 200.00$   
 Max Width,  $W_{max} = 400.00$   
 Min Width,  $W_{min} = 200.00$   
 Eccentricity,  $Ecc = 100.00$   
 Cover Thickness,  $c = 25.00$   
 Element Length,  $L = 3000.00$   
 Primary Member  
 Ribbed Bars  
 Ductile Steel  
 Without Detailing for Earthquake Resistance (including stirrups not closed at 135°)  
 Longitudinal Bars With Ends Lapped Starting at the End Sections  
 Lap Length  $l_o = l_b = 300.00$   
 FRP Wrapping Data  
 Type: Carbon  
 Cured laminate properties (design values)  
 Thickness,  $t = 1.016$   
 Tensile Strength,  $f_{fu} = 1055.00$   
 Tensile Modulus,  $E_f = 64828.00$   
 Elongation,  $ef_u = 0.01$   
 Number of directions,  $NoDir = 1$   
 Fiber orientations,  $bi: 0.00^\circ$   
 Number of layers,  $NL = 1$   
 Radius of rounding corners,  $R = 40.00$

#### Stepwise Properties

EDGE -A-  
 Bending Moment,  $M_a = 47.67334$   
 Shear Force,  $V_a = -0.02136663$   
 EDGE -B-  
 Bending Moment,  $M_b = 21.03175$   
 Shear Force,  $V_b = 0.02136663$   
 BOTH EDGES  
 Axial Force,  $F = -4735.965$   
 Longitudinal Reinforcement Area Distribution (in 2 divisions)  
 -Tension:  $As_{lt} = 0.00$   
 -Compression:  $As_{lc} = 5152.212$   
 Longitudinal Reinforcement Area Distribution (in 3 divisions)  
 -Tension:  $As_{l,ten} = 2261.947$   
 -Compression:  $As_{l,com} = 829.3805$   
 -Middle:  $As_{l,mid} = 2060.885$   
 Mean Diameter of Tension Reinforcement,  $Db_{L,ten} = 17.77778$

Existing component: From table 7-7, ASCE 41\_17: Final Shear Capacity  $V_R = \phi V_n = 151052.888$   
 $V_n$  ((10.3), ASCE 41-17) =  $k_n \phi V_{CoI} = 167836.542$   
 $V_{CoI} = 167836.542$   
 $k_n = 1.00$   
 $displacement\_ductility\_demand = 3.9788798E-005$

NOTE: In expression (10-3) ' $V_s$ ' is replaced by ' $V_s + \phi V_f$ '  
 where  $V_f$  is the contribution of FRPs (11.3), ACI 440).

$\phi = 1$  (normal-weight concrete)  
 $f'_c = 10.00$ , but  $f'_c^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$M/Vd = 3.07602$   
 $\mu_u = 21.03175$   
 $\nu_u = 0.02136663$   
 $d = 0.8 \cdot h = 320.00$   
 $N_u = 4735.965$   
 $A_g = 80000.00$   
 From (11.5.4.8), ACI 318-14:  $V_s = V_{s1} + V_{s2} = 0.00$   
 where:  
 $V_{s1} = 0.00$  is calculated for section web, with:  
 $d = 320.00$   
 $A_v = 157079.633$   
 $f_y = 400.00$   
 $s = 380.00$   
 $V_{s1}$  is multiplied by  $\text{Col1} = 0.00$   
 $s/d = 1.1875$   
 $V_{s2} = 0.00$  is calculated for section flange, with:  
 $d = 160.00$   
 $A_v = 157079.633$   
 $f_y = 400.00$   
 $s = 380.00$   
 $V_{s2}$  is multiplied by  $\text{Col2} = 0.00$   
 $s/d = 2.375$   
 $V_f ((11-3)-(11.4), \text{ACI 440}) = 188111.148$   
 $f = 0.95$ , for fully-wrapped sections  
 $w_f/s_f = 1$  (FRP strips adjacent to one another).  
 In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot a) \sin a$  which is more a generalised expression,  
 where  $a$  is the angle of the crack direction (see KANEPE).  
 This later relation, considered as a function  $V_f(\theta, a)$ , is implemented for every different fiber orientation  $a_i$ ,  
 as well as for 2 crack directions,  $\theta = 45^\circ$  and  $\theta = -45^\circ$  to take into consideration the cyclic seismic loading.  
 orientation 1:  $\theta = b_1 + 90^\circ = 90.00$   
 $V_f = \text{Min}(|V_f(45, \theta)|, |V_f(-45, a_1)|)$ , with:  
 total thickness per orientation,  $t_{f1} = N_L \cdot t / N_{\text{Dir}} = 1.016$   
 $d_{fv} = d$  (figure 11.2, ACI 440) = 357.00  
 $f_{fe} ((11-5), \text{ACI 440}) = 259.312$   
 $E_f = 64828.00$   
 $f_e = 0.004$ , from (11.6a), ACI 440  
 with  $f_u = 0.01$   
 From (11-11), ACI 440:  $V_s + V_f \leq 134445.642$   
 $b_w = 200.00$

displacement\_ductility\_demand is calculated as  $\delta / y$

- Calculation of  $\delta / y$  for END B -  
 for rotation axis 2 and integ. section (b)

From analysis, chord rotation  $\theta = 3.0985757E-007$   
 $y = (M_y \cdot L_s / 3) / E_{\text{eff}} = 0.00778756$  ((4.29), Biskinis Phd))  
 $M_y = 1.9010E+008$   
 $L_s = M/V$  (with  $L_s > 0.1 \cdot L$  and  $L_s < 2 \cdot L$ ) = 984.3271  
 From table 10.5, ASCE 41\_17:  $E_{\text{eff}} = \text{factor} \cdot E_c \cdot I_g = 8.0093E+012$   
 factor = 0.30  
 $A_g = 120000.00$   
 $f_c' = 15.00$   
 $N = 4735.965$   
 $E_c \cdot I_g = 2.6698E+013$

Calculation of Yielding Moment  $M_y$

Calculation of  $\delta$  and  $M_y$  according to Annex 7 -

$y = \text{Min}(\delta_{\text{ten}}, \delta_{\text{com}})$   
 $\delta_{\text{ten}} = 6.8134937E-006$   
 with ((10.1), ASCE 41-17)  $f_y = \text{Min}(f_y, 1.25 \cdot f_y \cdot (I_b / d)^{2/3}) = 235.317$

```

d = 357.00
y = 0.51628986
A = 0.07244171
B = 0.04953119
with pt = 0.03167993
    pc = 0.01161597
    pv = 0.02886393
    N = 4735.965
    b = 200.00
    " = 0.12044818
y_comp = 8.6576330E-006
with fc* (12.3, (ACI 440)) = 16.12972
    fc = 15.00
    fl = 0.93147527
    b = bmax = 400.00
    h = hmax = 400.00
    Ag = 120000.00
    g = pt + pc + pv = 0.07215983
    rc = 40.00
    Ae/Ac = 0.38686758
    Effective FRP thickness, tf = NL*t*cos(b1) = 1.016
    effective strain from (12.5) and (12.12), efe = 0.004
    fu = 0.01
    Ef = 64828.00
    Ec = 18203.022
    y = 0.51604609
    A = 0.0719519
    B = 0.04924932
    with Es = 200000.00

```

Calculation of ratio lb/l<sub>d</sub>

Lap Length: l<sub>d</sub>/l<sub>d,min</sub> = 0.27567359

l<sub>b</sub> = 300.00

l<sub>d</sub> = 1088.244

Calculation of l according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.  
= 1

db = 18.00

Mean strength value of all re-bars: f<sub>y</sub> = 444.44

f<sub>c</sub>' = 15.00, but f<sub>c</sub>'<sup>0.5</sup> ≤ 8.3 MPa (22.5.3.1, ACI 318-14)

t = 1.00

s = 0.80

e = 1.00

cb = 24.02082

K<sub>tr</sub> = 0.82673491

A<sub>tr</sub> = Min(A<sub>tr\_x</sub>, A<sub>tr\_y</sub>) = 157.0796

where A<sub>tr\_x</sub>, A<sub>tr\_y</sub> are the sum of the area of all stirrup legs along X and Y local axis

s = 380.00

n = 20.00

End Of Calculation of Shear Capacity for element: column TC1 of floor 1

At local axis: 3

Integration Section: (b)

## Calculation No. 8

column C1, Floor 1

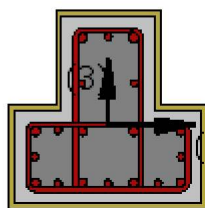
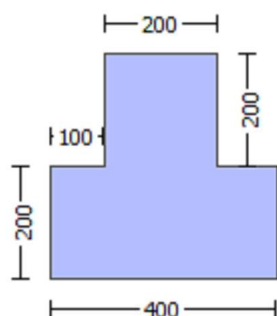
Limit State: Immediate Occupancy (data interpolation between analysis steps 1 and 2)

Analysis: Uniform +X

Check: Chord rotation capacity (  $\phi$  )

Edge: End

Local Axis: (3)



Start Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1

At Shear local axis: 3

(Bending local axis: 2)

Section Type: rctcs

Constant Properties

Knowledge Factor,  $\gamma = 0.90$

Mean strength values are used for both shear and moment calculations.

Consequently:

Existing material of Primary Member: Concrete Strength,  $f_c = f_{cm} = 15.00$

Existing material of Primary Member: Steel Strength,  $f_s = f_{sm} = 444.44$

Concrete Elasticity,  $E_c = 18203.022$

Steel Elasticity,  $E_s = 200000.00$

#####

Note: Especially for the calculation of moment strengths,

the above steel re-bar strengths are multiplied by 1.25 according to R18.6.5, ACI 318-14

Existing material: Steel Strength,  $f_s = 1.25 \cdot f_{sm} = 555.55$

#####

Max Height,  $H_{max} = 400.00$

Min Height,  $H_{min} = 200.00$

Max Width,  $W_{max} = 400.00$

Min Width,  $W_{min} = 200.00$

Eccentricity,  $E_{cc} = 100.00$

Cover Thickness,  $c = 25.00$

Mean Confinement Factor overall section = 1.27578

Element Length,  $L = 3000.00$

Primary Member

Ribbed Bars

Ductile Steel

Without Detailing for Earthquake Resistance (including stirrups not closed at 135°)

Longitudinal Bars With Ends Lapped Starting at the End Sections

Lap Length  $l_o = 300.00$

FRP Wrapping Data

Type: Carbon

Cured laminate properties (design values)

Thickness,  $t = 1.016$

Tensile Strength,  $f_{fu} = 1055.00$

Tensile Modulus,  $E_f = 64828.00$

Elongation,  $\epsilon_{fu} = 0.01$   
Number of directions,  $NoDir = 1$   
Fiber orientations,  $bi = 0.00^\circ$   
Number of layers,  $NL = 1$   
Radius of rounding corners,  $R = 40.00$

#### Stepwise Properties

At local axis: 3  
EDGE -A-  
Shear Force,  $V_a = 0.01054019$   
EDGE -B-  
Shear Force,  $V_b = -0.01054019$   
BOTH EDGES  
Axial Force,  $F = -4737.328$   
Longitudinal Reinforcement Area Distribution (in 2 divisions)  
-Tension:  $As_t = 0.00$   
-Compression:  $As_c = 5152.212$   
Longitudinal Reinforcement Area Distribution (in 3 divisions)  
-Tension:  $As_{ten} = 2261.947$   
-Compression:  $As_{com} = 829.3805$   
-Middle:  $As_{mid} = 2060.885$

Calculation of Shear Capacity ratio,  $V_e/V_r = 0.82694402$   
Member Controlled by Flexure ( $V_e/V_r < 1$ )  
Calculation of Shear Demand from fig. R18.6.5, ACI 318-14  $V_e = (M_{pr1} + M_{pr2})/l_n = 162085.836$   
with  
 $M_{pr1} = \max(\mu_{u1+}, \mu_{u1-}) = 2.4313E+008$   
 $\mu_{u1+} = 2.4313E+008$ , is the ultimate moment strength at the edge 1 of the member in the actual moment direction which is defined for the static loading combination  
 $\mu_{u1-} = 1.2706E+008$ , is the ultimate moment strength at the edge 1 of the member in the opposite moment direction which is defined for the static loading combination  
 $M_{pr2} = \max(\mu_{u2+}, \mu_{u2-}) = 2.4313E+008$   
 $\mu_{u2+} = 2.4313E+008$ , is the ultimate moment strength at the edge 2 of the member in the actual moment direction which is defined for the static loading combination  
 $\mu_{u2-} = 1.2706E+008$ , is the ultimate moment strength at the edge 2 of the member in the opposite moment direction which is defined for the static loading combination

#### Calculation of $\mu_{u1+}$

Calculation of ultimate curvature  $\mu_u$  according to 4.1, Biskinis/Fardis 2013:  
 $\mu_u = 2.6161250E-005$   
 $\mu_u = 2.4313E+008$

with full section properties:

$b = 200.00$   
 $d = 357.00$   
 $d' = 43.00$   
 $v = 0.00442328$   
 $N = 4737.328$   
 $f_c = 15.00$   
 $\alpha_1(5A.5, TBDY) = 0.002$   
Final value of  $\alpha_1$ :  $\alpha_1 = \text{shear\_factor} * \max(\alpha_c, \alpha_1) = 0.018$   
The Shear\_factor is considered equal to 1 (pure moment strength)  
From (5.4b), TBDY:  $\alpha_1 = 0.018$   
where  $\alpha_1 = \alpha_1 * \rho_f * f_{fe}/f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)  
 $\alpha_1 = 0.15303423$   
Expression ((15B.6), TBDY) is modified as  $\alpha_f = 1 - (\text{Unconfined area})/(\text{total area})$

$$af = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 51733.333$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A4.4.3(6), } pf = 2tf/bw = 0.01016$$

$$bw = 200.00$$

$$\text{effective stress from (A.35), } ff,e = 524.0792$$

$$fy = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $af = 1 - (\text{Unconfined area})/(\text{total area})$

$$af = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 0.00$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A4.4.3(6), } pf = 2tf/bw = 0.01016$$

$$bw = 200.00$$

$$\text{effective stress from (A.35), } ff,e = 524.0792$$

$$R = 40.00$$

$$\text{Effective FRP thickness, } tf = NL * t * \cos(b1) = 1.016$$

$$fu,f = 1055.00$$

$$Ef = 64828.00$$

$$u,f = 0.015$$

$$ase = \text{Max}(((A_{\text{conf,max}} - A_{\text{noConf}})/A_{\text{conf,max}}) * (A_{\text{conf,min}}/A_{\text{conf,max}}), 0) = 0.00$$

The definitions of  $A_{\text{noConf}}$ ,  $A_{\text{conf,min}}$  and  $A_{\text{conf,max}}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{\text{conf,max}} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{\text{conf,min}} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{\text{conf,max}}$  by a length equal to half the clear spacing between hoops.

$A_{\text{noConf}} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$$psh_{\min} = \text{Min}(psh_x, psh_y) = 0.00165347$$

Expression ((5.4d), TBDY) for  $psh_{\min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$$psh_x \text{ ((5.4d), TBDY)} = L_{\text{stir}} * A_{\text{stir}} / (A_{\text{sec}} * s) = 0.00165347$$

$$L_{\text{stir}} \text{ (Length of stirrups along Y)} = 960.00$$

$$A_{\text{stir}} \text{ (stirrups area)} = 78.53982$$

$$A_{\text{sec}} \text{ (section area)} = 120000.00$$

$$psh_y \text{ ((5.4d), TBDY)} = L_{\text{stir}} * A_{\text{stir}} / (A_{\text{sec}} * s) = 0.00165347$$

$$L_{\text{stir}} \text{ (Length of stirrups along X)} = 960.00$$

$$A_{\text{stir}} \text{ (stirrups area)} = 78.53982$$

$$A_{\text{sec}} \text{ (section area)} = 120000.00$$

$$s = 380.00$$

$$fy_{we} = 555.55$$

$$f_{ce} = 15.00$$

$$\text{From ((5.A5), TBDY), TBDY: } cc = 0.00475778$$

$$c = \text{confinement factor} = 1.27578$$

$$y1 = 0.0010562$$

$$sh1 = 0.00365026$$

$$ft1 = 304.185$$

$$fy1 = 253.4875$$

$$su1 = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$$lo/lou_{\min} = lb/ld = 0.22053887$$

$$su1 = 0.4 * esu1_{\text{nominal}} \text{ ((5.5), TBDY)} = 0.032$$

From table 5A.1, TBDY:  $esu1_{\text{nominal}} = 0.08$ ,

For calculation of  $esu1_{\text{nominal}}$  and  $y1$ ,  $sh1$ ,  $ft1$ ,  $fy1$ , it is considered characteristic value  $fsy1 = fs1/1.2$ , from table 5.1, TBDY.

$y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fs1 = fs = 253.4875$   
 with  $Es1 = Es = 200000.00$   
 $y2 = 0.0010562$   
 $sh2 = 0.00365026$   
 $ft2 = 304.185$   
 $fy2 = 253.4875$   
 $su2 = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $lo/lou, min = lb/lb, min = 0.22053887$   
 $su2 = 0.4 \cdot esu2\_nominal ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esu2\_nominal = 0.08$ ,  
 For calculation of  $esu2\_nominal$  and  $y2, sh2, ft2, fy2$ , it is considered  
 characteristic value  $fsy2 = fs2/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fs2 = fs = 253.4875$   
 with  $Es2 = Es = 200000.00$   
 $yv = 0.0010562$   
 $shv = 0.00365026$   
 $ftv = 304.185$   
 $fyv = 253.4875$   
 $suv = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $lo/lou, min = lb/ld = 0.22053887$   
 $suv = 0.4 \cdot esuv\_nominal ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esuv\_nominal = 0.08$ ,  
 considering characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY  
 For calculation of  $esuv\_nominal$  and  $yv, shv, ftv, fyv$ , it is considered  
 characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fsv = fs = 253.4875$   
 with  $Esv = Es = 200000.00$   
 $1 = Asl, ten / (b \cdot d) \cdot (fs1 / fc) = 0.53536441$   
 $2 = Asl, com / (b \cdot d) \cdot (fs2 / fc) = 0.19630028$   
 $v = Asl, mid / (b \cdot d) \cdot (fsv / fc) = 0.48777647$

and confined core properties:

$b = 140.00$   
 $d = 327.00$   
 $d' = 13.00$   
 $fcc (5A.2, TBDY) = 19.13667$   
 $cc (5A.5, TBDY) = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $1 = Asl, ten / (b \cdot d) \cdot (fs1 / fc) = 0.83497202$   
 $2 = Asl, com / (b \cdot d) \cdot (fs2 / fc) = 0.30615641$   
 $v = Asl, mid / (b \cdot d) \cdot (fsv / fc) = 0.76075229$

Case/Assumption: Unconfined full section - Steel rupture

' satisfies Eq. (4.3)

----

$v < vs, y2$  - LHS eq.(4.5) is not satisfied

----

$v < vs, c$  - RHS eq.(4.5) is not satisfied

----

Case/Assumption Rejected.

----

New Case/Assumption: Unconfined full section - Spalling of concrete cover

' satisfies Eq. (4.4)

----

$v < s, y1$  - LHS eq.(4.7) is not satisfied

----

$v < vc, y1$  - RHS eq.(4.6) is satisfied

----

$cu (4.10) = 0.46564051$

$MRC (4.17) = 2.0934E+008$

```

--->
New Case/Assumption: Ultimate curvature of confined core after spalling of concrete cover
In expressions below, the following modifications have been made
- b, d, d' replaced by geometric parameters of the core: bo, do, d'o
- N,  $\epsilon_s$ ,  $\epsilon_c$  v normalised to bo*do, instead of b*d
-  $\epsilon_{cc}$ ,  $\epsilon_{cc}$  parameters of confined concrete,  $\epsilon_{cc}$ ,  $\epsilon_{cc}$  used in lieu of  $\epsilon_c$ ,  $\epsilon_{cc}$ 
--->
Subcase: Rupture of tension steel
--->
 $\epsilon_s^* < \epsilon_{sy}$  - LHS eq.(4.5) is not satisfied
--->
 $\epsilon_s^* < \epsilon_{sc}$  - LHS eq.(4.5) is not satisfied
--->
Subcase rejected
--->
New Subcase: Failure of compression zone
--->
 $\epsilon_s^* < \epsilon_{sc}$  - LHS eq.(4.6) is not satisfied
--->
 $\epsilon_s^* < \epsilon_{sc}$  - RHS eq.(4.6) is satisfied
--->
 $\epsilon_{cu}$  (4.10) = 0.55615794
MRo (4.17) = 2.4313E+008
--->
 $\epsilon_u = \epsilon_{cu}$  (4.2) = 2.6161250E-005
Mu = MRo
-----

Calculation of ratio lb/ld
-----
Lap Length: lb/ld = 0.22053887
lb = 300.00
ld = 1360.304
Calculation of lb,min according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.
= 1
db = 18.00
Mean strength value of all re-bars: fy = 555.55
fc' = 15.00, but  $f_c^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)
t = 1.00
s = 0.80
e = 1.00
cb = 24.02082
Ktr = 0.82673491
Atr = Min(Atr_x, Atr_y) = 157.0796
where Atr_x, Atr_y are the sum of the area of all stirrup legs along X and Y loxal axis
s = 380.00
n = 20.00
-----
-----
-----

Calculation of Mu1-
-----
-----

Calculation of ultimate curvature  $\epsilon_u$  according to 4.1, Biskinis/Fardis 2013:
 $\epsilon_u = 1.3353763E-005$ 
Mu = 1.2706E+008
-----

with full section properties:
b = 400.00
d = 357.00
d' = 43.00
v = 0.00221164
N = 4737.328
fc = 15.00
 $\epsilon_{co}$  (5A.5, TBDY) = 0.002
Final value of  $\epsilon_{cu}$ :  $\epsilon_{cu}^* = \text{shear\_factor} * \text{Max}(\epsilon_{cu}, \epsilon_{cc}) = 0.018$ 

```



The Shear\_factor is considered equal to 1 (pure moment strength)

From (5.4b), TBDY:  $c_u = 0.018$

we ((5.4c), TBDY) =  $ase * sh_{min} * fy_{we} / f_{ce} + \min(f_x, f_y) = 0.15303423$

where  $f = af * pf * f_{fe} / f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$f_x = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $af = 1 - (\text{Unconfined area}) / (\text{total area})$

$af = 0.43111111$

with Unconfined area =  $((b_{max} - 2R)^2 + (h_{max} - 2R)^2) / 3 = 51733.333$

$b_{max} = 400.00$

$h_{max} = 400.00$

From EC8 A4.4.3(6),  $pf = 2tf/bw = 0.01016$

$bw = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

$f_y = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $af = 1 - (\text{Unconfined area}) / (\text{total area})$

$af = 0.43111111$

with Unconfined area =  $((b_{max} - 2R)^2 + (h_{max} - 2R)^2) / 3 = 0.00$

$b_{max} = 400.00$

$h_{max} = 400.00$

From EC8 A4.4.3(6),  $pf = 2tf/bw = 0.01016$

$bw = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

$R = 40.00$

Effective FRP thickness,  $tf = NL * t * \cos(b1) = 1.016$

$f_{u,f} = 1055.00$

$E_f = 64828.00$

$u_{f} = 0.015$

$ase = \max((A_{conf,max} - A_{noConf}) / A_{conf,max}) * (A_{conf,min} / A_{conf,max}, 0) = 0.00$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$psh_{min} = \min(psh_x, psh_y) = 0.00165347$

Expression ((5.4d), TBDY) for  $psh_{min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$psh_x$  ((5.4d), TBDY) =  $L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$

$L_{stir}$  (Length of stirrups along Y) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$psh_y$  ((5.4d), TBDY) =  $L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$

$L_{stir}$  (Length of stirrups along X) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$s = 380.00$

$fy_{we} = 555.55$

$f_{ce} = 15.00$

From ((5.A5), TBDY), TBDY:  $cc = 0.00475778$

$c$  = confinement factor = 1.27578

$y1 = 0.0010562$

$sh1 = 0.00365026$

$ft1 = 304.185$

$fy1 = 253.4875$

$su1 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor

and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $l_o/l_{ou,min} = l_b/l_d = 0.22053887$   
 $su_1 = 0.4 * esu_{1,nominal} ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esu_{1,nominal} = 0.08$ ,  
 For calculation of  $esu_{1,nominal}$  and  $y_1, sh_1, ft_1, fy_1$ , it is considered  
 characteristic value  $fsy_1 = fs_1/1.2$ , from table 5.1, TBDY.  
 $y_1, sh_1, ft_1, fy_1$ , are also multiplied by  $Min(1, 1.25 * (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fs_1 = fs = 253.4875$   
 with  $Es_1 = Es = 200000.00$   
 $y_2 = 0.0010562$   
 $sh_2 = 0.00365026$   
 $ft_2 = 304.185$   
 $fy_2 = 253.4875$   
 $su_2 = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $l_o/l_{ou,min} = l_b/l_{b,min} = 0.22053887$   
 $su_2 = 0.4 * esu_{2,nominal} ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esu_{2,nominal} = 0.08$ ,  
 For calculation of  $esu_{2,nominal}$  and  $y_2, sh_2, ft_2, fy_2$ , it is considered  
 characteristic value  $fsy_2 = fs_2/1.2$ , from table 5.1, TBDY.  
 $y_1, sh_1, ft_1, fy_1$ , are also multiplied by  $Min(1, 1.25 * (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fs_2 = fs = 253.4875$   
 with  $Es_2 = Es = 200000.00$   
 $y_v = 0.0010562$   
 $sh_v = 0.00365026$   
 $ft_v = 304.185$   
 $fy_v = 253.4875$   
 $suv = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $l_o/l_{ou,min} = l_b/l_d = 0.22053887$   
 $suv = 0.4 * esuv_{nominal} ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esuv_{nominal} = 0.08$ ,  
 considering characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY  
 For calculation of  $esuv_{nominal}$  and  $y_v, sh_v, ft_v, fy_v$ , it is considered  
 characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY.  
 $y_1, sh_1, ft_1, fy_1$ , are also multiplied by  $Min(1, 1.25 * (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fsv = fs = 253.4875$   
 with  $Esv = Es = 200000.00$   
 $1 = Asl_{ten}/(b*d) * (fs_1/fc) = 0.09815014$   
 $2 = Asl_{com}/(b*d) * (fs_2/fc) = 0.26768221$   
 $v = Asl_{mid}/(b*d) * (fsv/fc) = 0.24388823$   
 and confined core properties:  
 $b = 340.00$   
 $d = 327.00$   
 $d' = 13.00$   
 $f_{cc} (5A.2, TBDY) = 19.13667$   
 $cc (5A.5, TBDY) = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $1 = Asl_{ten}/(b*d) * (fs_1/fc) = 0.1260644$   
 $2 = Asl_{com}/(b*d) * (fs_2/fc) = 0.34381201$   
 $v = Asl_{mid}/(b*d) * (fsv/fc) = 0.31325094$   
 Case/Assumption: Unconfined full section - Steel rupture  
 ' satisfies Eq. (4.3)  
 --->  
 $v < v_{s,y2}$  - LHS eq.(4.5) is satisfied  
 --->  
 $su (4.9) = 0.23431248$   
 $Mu = MRc (4.14) = 1.2706E+008$   
 $u = su (4.1) = 1.3353763E-005$

-----  
 Calculation of ratio  $l_b/l_d$

Lap Length:  $l_b/l_d = 0.22053887$

$l_b = 300.00$

$l_d = 1360.304$

Calculation of  $l_b$ , min according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$= 1$

$d_b = 18.00$

Mean strength value of all re-bars:  $f_y = 555.55$

$f_c' = 15.00$ , but  $f_c'^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$t = 1.00$

$s = 0.80$

$e = 1.00$

$c_b = 24.02082$

$K_{tr} = 0.82673491$

$A_{tr} = \text{Min}(A_{tr_x}, A_{tr_y}) = 157.0796$

where  $A_{tr_x}$ ,  $A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis

$s = 380.00$

$n = 20.00$

Calculation of  $\mu_{2+}$

Calculation of ultimate curvature  $\mu$  according to 4.1, Biskinis/Fardis 2013:

$\mu = 2.6161250E-005$

$\mu = 2.4313E+008$

with full section properties:

$b = 200.00$

$d = 357.00$

$d' = 43.00$

$v = 0.00442328$

$N = 4737.328$

$f_c = 15.00$

$c_o$  (5A.5, TBDY) = 0.002

Final value of  $\mu$ :  $\mu^* = \text{shear\_factor} * \text{Max}(\mu, c_o) = 0.018$

The Shear\_factor is considered equal to 1 (pure moment strength)

From (5.4b), TBDY:  $\mu = 0.018$

we ((5.4c), TBDY) =  $a_s * \text{sh}_{\min} * f_{ywe}/f_{ce} + \text{Min}(f_x, f_y) = 0.15303423$

where  $f = a_f * p_f * f_{fe}/f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$f_x = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area})/(\text{total area})$

$a_f = 0.43111111$

with Unconfined area =  $((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 51733.333$

$b_{\max} = 400.00$

$h_{\max} = 400.00$

From EC8 A.4.4.3(6),  $p_f = 2t_f/b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

$f_y = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area})/(\text{total area})$

$a_f = 0.43111111$

with Unconfined area =  $((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 0.00$

$b_{\max} = 400.00$

$h_{\max} = 400.00$

From EC8 A.4.4.3(6),  $p_f = 2t_f/b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

$R = 40.00$

Effective FRP thickness,  $t_f = N L^* t \cos(b_1) = 1.016$

$f_{u,f} = 1055.00$

$E_f = 64828.00$

$$u,f = 0.015$$

$$ase = \text{Max}(((A_{conf,max} - A_{noConf}) / A_{conf,max}) * (A_{conf,min} / A_{conf,max}), 0) = 0.00$$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$$psh,min = \text{Min}(psh,x, psh,y) = 0.00165347$$

Expression ((5.4d), TBDY) for  $psh,min$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$$psh,x \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$$

$$L_{stir} \text{ (Length of stirrups along Y)} = 960.00$$

$$A_{stir} \text{ (stirrups area)} = 78.53982$$

$$A_{sec} \text{ (section area)} = 120000.00$$

$$psh,y \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$$

$$L_{stir} \text{ (Length of stirrups along X)} = 960.00$$

$$A_{stir} \text{ (stirrups area)} = 78.53982$$

$$A_{sec} \text{ (section area)} = 120000.00$$

$$s = 380.00$$

$$f_{ywe} = 555.55$$

$$f_{ce} = 15.00$$

$$\text{From ((5.A5), TBDY), TBDY: } cc = 0.00475778$$

$$c = \text{confinement factor} = 1.27578$$

$$y_1 = 0.0010562$$

$$sh_1 = 0.00365026$$

$$ft_1 = 304.185$$

$$fy_1 = 253.4875$$

$$su_1 = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$$l_o/l_{ou,min} = l_b/l_d = 0.22053887$$

$$su_1 = 0.4 * esu_{1,nominal} \text{ ((5.5), TBDY)} = 0.032$$

From table 5A.1, TBDY:  $esu_{1,nominal} = 0.08$ ,

For calculation of  $esu_{1,nominal}$  and  $y_1$ ,  $sh_1$ ,  $ft_1$ ,  $fy_1$ , it is considered characteristic value  $fsy_1 = fs_1/1.2$ , from table 5.1, TBDY.

$y_1$ ,  $sh_1$ ,  $ft_1$ ,  $fy_1$ , are also multiplied by  $\text{Min}(1, 1.25 * (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.

$$\text{with } fs_1 = fs = 253.4875$$

$$\text{with } Es_1 = Es = 200000.00$$

$$y_2 = 0.0010562$$

$$sh_2 = 0.00365026$$

$$ft_2 = 304.185$$

$$fy_2 = 253.4875$$

$$su_2 = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$$l_o/l_{ou,min} = l_b/l_{b,min} = 0.22053887$$

$$su_2 = 0.4 * esu_{2,nominal} \text{ ((5.5), TBDY)} = 0.032$$

From table 5A.1, TBDY:  $esu_{2,nominal} = 0.08$ ,

For calculation of  $esu_{2,nominal}$  and  $y_2$ ,  $sh_2$ ,  $ft_2$ ,  $fy_2$ , it is considered characteristic value  $fsy_2 = fs_2/1.2$ , from table 5.1, TBDY.

$y_1$ ,  $sh_1$ ,  $ft_1$ ,  $fy_1$ , are also multiplied by  $\text{Min}(1, 1.25 * (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.

$$\text{with } fs_2 = fs = 253.4875$$

$$\text{with } Es_2 = Es = 200000.00$$

$$y_v = 0.0010562$$

$$sh_v = 0.00365026$$

$$ft_v = 304.185$$

```

fyv = 253.4875
suv = 0.00365026
    using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
    and also multiplied by the shear_factor according to 15.7.1.4, with
    Shear_factor = 1.00
    lo/lo,min = lb/ld = 0.22053887
    suv = 0.4*esuv_nominal ((5.5), TBDY) = 0.032
    From table 5A.1, TBDY: esuv_nominal = 0.08,
    considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY
    For calculation of esuv_nominal and yv, shv,ftv,fyv, it is considered
    characteristic value fsyv = fsv/1.2, from table 5.1, TBDY.
    y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/ld)^ 2/3), from 10.3.5, ASCE 41-17.
    with fsv = fs = 253.4875
    with Esv = Es = 200000.00
    1 = Asl,ten/(b*d)*(fs1/fc) = 0.53536441
    2 = Asl,com/(b*d)*(fs2/fc) = 0.19630028
    v = Asl,mid/(b*d)*(fsv/fc) = 0.48777647
and confined core properties:
b = 140.00
d = 327.00
d' = 13.00
fcc (5A.2, TBDY) = 19.13667
cc (5A.5, TBDY) = 0.00475778
    c = confinement factor = 1.27578
    1 = Asl,ten/(b*d)*(fs1/fc) = 0.83497202
    2 = Asl,com/(b*d)*(fs2/fc) = 0.30615641
    v = Asl,mid/(b*d)*(fsv/fc) = 0.76075229
Case/Assumption: Unconfined full section - Steel rupture
' satisfies Eq. (4.3)
--->
v < vs,y2 - LHS eq.(4.5) is not satisfied
--->
v < vs,c - RHS eq.(4.5) is not satisfied
--->
Case/Assumption Rejected.
--->
New Case/Assumption: Unconfined full section - Spalling of concrete cover
' satisfies Eq. (4.4)
--->
v < s,y1 - LHS eq.(4.7) is not satisfied
--->
v < vc,y1 - RHS eq.(4.6) is satisfied
--->
    cu (4.10) = 0.46564051
    MRc (4.17) = 2.0934E+008
--->
New Case/Assumption: Ultimate curvature of confined core after spalling of concrete cover
In expressions below, the following modifications have been made
- b, d, d' replaced by geometric parameters of the core: bo, do, d'o
- N, 1, 2, v normalised to bo*do, instead of b*d
- - parameters of confined concrete, fcc, cc, used in lieu of fc, ecu
--->
Subcase: Rupture of tension steel
--->
v* < v*s,y2 - LHS eq.(4.5) is not satisfied
--->
v* < v*s,c - LHS eq.(4.5) is not satisfied
--->
Subcase rejected
--->
New Subcase: Failure of compression zone
--->
v* < v*c,y2 - LHS eq.(4.6) is not satisfied
--->
v* < v*c,y1 - RHS eq.(4.6) is satisfied
--->
    *cu (4.10) = 0.55615794

```

$$M_{Ro} (4.17) = 2.4313E+008$$

---->

$$u = cu (4.2) = 2.6161250E-005$$

$$\mu = M_{Ro}$$

Calculation of ratio  $l_b/l_d$

$$\text{Lap Length: } l_b/l_d = 0.22053887$$

$$l_b = 300.00$$

$$l_d = 1360.304$$

Calculation of  $l_b, \min$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$$= 1$$

$$d_b = 18.00$$

Mean strength value of all re-bars:  $f_y = 555.55$

$$f'_c = 15.00, \text{ but } f'_c^{0.5} \leq 8.3 \text{ MPa (22.5.3.1, ACI 318-14)}$$

$$t = 1.00$$

$$s = 0.80$$

$$e = 1.00$$

$$c_b = 24.02082$$

$$K_{tr} = 0.82673491$$

$$A_{tr} = \min(A_{tr_x}, A_{tr_y}) = 157.0796$$

where  $A_{tr_x}, A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis

$$s = 380.00$$

$$n = 20.00$$

Calculation of  $\mu_2$ -

Calculation of ultimate curvature  $\mu$  according to 4.1, Biskinis/Fardis 2013:

$$u = 1.3353763E-005$$

$$\mu = 1.2706E+008$$

with full section properties:

$$b = 400.00$$

$$d = 357.00$$

$$d' = 43.00$$

$$v = 0.00221164$$

$$N = 4737.328$$

$$f'_c = 15.00$$

$$c_o (5A.5, \text{ TBDY}) = 0.002$$

$$\text{Final value of } c_u: c_u^* = \text{shear\_factor} * \max(c_u, c_c) = 0.018$$

The Shear\_factor is considered equal to 1 (pure moment strength)

$$\text{From (5.4b), TBDY: } c_u = 0.018$$

$$w_e ((5.4c), \text{ TBDY}) = a_{se} * s_{h, \min} * f_{ywe} / f_{ce} + \min(f_x, f_y) = 0.15303423$$

where  $f = a_f * p_f * f_{fe} / f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$$f_x = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2) / 3 = 51733.333$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } p_f = 2t_f / b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$f_y = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2) / 3 = 0.00$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } p_f = 2t_f / b_w = 0.01016$$

bw = 200.00  
effective stress from (A.35),  $f_{f,e} = 524.0792$

R = 40.00  
Effective FRP thickness,  $t_f = N_L * t * \cos(b_1) = 1.016$   
 $f_{u,f} = 1055.00$   
 $E_f = 64828.00$   
 $u_{,f} = 0.015$

$a_{se} = \text{Max}(((A_{conf,max} - A_{noConf}) / A_{conf,max}) * (A_{conf,min} / A_{conf,max}), 0) = 0.00$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988) "Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$p_{sh,min} = \text{Min}(p_{sh,x}, p_{sh,y}) = 0.00165347$

Expression ((5.4d), TBDY) for  $p_{sh,min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$p_{sh,x} \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$

$L_{stir}$  (Length of stirrups along Y) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$p_{sh,y} \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$

$L_{stir}$  (Length of stirrups along X) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

s = 380.00

$f_{ywe} = 555.55$

$f_{ce} = 15.00$

From ((5.A5), TBDY), TBDY:  $cc = 0.00475778$

c = confinement factor = 1.27578

$y_1 = 0.0010562$

$sh_1 = 0.00365026$

$ft_1 = 304.185$

$fy_1 = 253.4875$

$su_1 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$l_o/l_{ou,min} = l_b/l_d = 0.22053887$

$su_1 = 0.4 * esu1_{nominal} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu1_{nominal} = 0.08$ ,

For calculation of  $esu1_{nominal}$  and  $y_1$ ,  $sh_1$ ,  $ft_1$ ,  $fy_1$ , it is considered characteristic value  $fsy_1 = fs_1/1.2$ , from table 5.1, TBDY.

$y_1$ ,  $sh_1$ ,  $ft_1$ ,  $fy_1$ , are also multiplied by  $\text{Min}(1, 1.25 * (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.

with  $fs_1 = fs = 253.4875$

with  $Es_1 = Es = 200000.00$

$y_2 = 0.0010562$

$sh_2 = 0.00365026$

$ft_2 = 304.185$

$fy_2 = 253.4875$

$su_2 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$l_o/l_{ou,min} = l_b/l_{b,min} = 0.22053887$

$su_2 = 0.4 * esu2_{nominal} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu2_{nominal} = 0.08$ ,

For calculation of  $esu2_{nominal}$  and  $y_2$ ,  $sh_2$ ,  $ft_2$ ,  $fy_2$ , it is considered

characteristic value  $f_{sy2} = f_{s2}/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $f_{s2} = f_s = 253.4875$   
 with  $E_{s2} = E_s = 200000.00$   
 $y_v = 0.0010562$   
 $sh_v = 0.00365026$   
 $ft_v = 304.185$   
 $fy_v = 253.4875$   
 $suv = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $l_o/l_{ou,min} = l_b/l_d = 0.22053887$   
 $suv = 0.4 \cdot esuv_{nominal} ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esuv_{nominal} = 0.08$ ,  
 considering characteristic value  $f_{syv} = f_{sv}/1.2$ , from table 5.1, TBDY  
 For calculation of  $esuv_{nominal}$  and  $y_v, sh_v, ft_v, fy_v$ , it is considered  
 characteristic value  $f_{syv} = f_{sv}/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $f_{sv} = f_s = 253.4875$   
 with  $E_{sv} = E_s = 200000.00$   
 $1 = A_{sl,ten}/(b \cdot d) \cdot (f_{s1}/f_c) = 0.09815014$   
 $2 = A_{sl,com}/(b \cdot d) \cdot (f_{s2}/f_c) = 0.26768221$   
 $v = A_{sl,mid}/(b \cdot d) \cdot (f_{sv}/f_c) = 0.24388823$   
 and confined core properties:  
 $b = 340.00$   
 $d = 327.00$   
 $d' = 13.00$   
 $f_{cc} (5A.2, TBDY) = 19.13667$   
 $cc (5A.5, TBDY) = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $1 = A_{sl,ten}/(b \cdot d) \cdot (f_{s1}/f_c) = 0.1260644$   
 $2 = A_{sl,com}/(b \cdot d) \cdot (f_{s2}/f_c) = 0.34381201$   
 $v = A_{sl,mid}/(b \cdot d) \cdot (f_{sv}/f_c) = 0.31325094$   
 Case/Assumption: Unconfined full section - Steel rupture  
 ' satisfies Eq. (4.3)  
 --->  
 $v < v_{s,y2}$  - LHS eq.(4.5) is satisfied  
 --->  
 $su (4.9) = 0.23431248$   
 $Mu = MR_c (4.14) = 1.2706E+008$   
 $u = su (4.1) = 1.3353763E-005$

#### Calculation of ratio $l_b/l_d$

Lap Length:  $l_b/l_d = 0.22053887$   
 $l_b = 300.00$   
 $l_d = 1360.304$   
 Calculation of  $l_{b,min}$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.  
 $= 1$   
 $db = 18.00$   
 Mean strength value of all re-bars:  $fy = 555.55$   
 $f_c' = 15.00$ , but  $f_c'^{0.5} \leq 8.3 \text{ MPa}$  (22.5.3.1, ACI 318-14)  
 $t = 1.00$   
 $s = 0.80$   
 $e = 1.00$   
 $cb = 24.02082$   
 $K_{tr} = 0.82673491$   
 $A_{tr} = \text{Min}(A_{tr_x}, A_{tr_y}) = 157.0796$   
 where  $A_{tr_x}, A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis  
 $s = 380.00$   
 $n = 20.00$



Calculation of Shear Strength  $V_r = \min(V_{r1}, V_{r2}) = 196005.816$

Calculation of Shear Strength at edge 1,  $V_{r1} = 227350.021$

$V_{r1} = V_{Col} \text{ ((10.3), ASCE 41-17)} = k_{nl} * V_{Col0}$

$V_{Col0} = 227350.021$

$k_{nl} = 1$  (zero step-static loading)

NOTE: In expression (10-3) ' $V_s$ ' is replaced by ' $V_s + f * V_f$ ' where  $V_f$  is the contribution of FRPs (11.3), ACI 440).

$\lambda = 1$  (normal-weight concrete)

$f'_c = 15.00$ , but  $f'_c^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$M/Vd = 2.00$

$\mu_u = 3.21769$

$\nu_u = 0.01054019$

$d = 0.8 * h = 320.00$

$N_u = 4737.328$

$A_g = 80000.00$

From (11.5.4.8), ACI 318-14:  $V_s = V_{s1} + V_{s2} = 0.00$

where:

$V_{s1} = 0.00$  is calculated for section web, with:

$d = 320.00$

$A_v = 157079.633$

$f_y = 444.44$

$s = 380.00$

$V_{s1}$  is multiplied by  $Col1 = 0.00$

$s/d = 1.1875$

$V_{s2} = 0.00$  is calculated for section flange, with:

$d = 160.00$

$A_v = 157079.633$

$f_y = 444.44$

$s = 380.00$

$V_{s2}$  is multiplied by  $Col2 = 0.00$

$s/d = 2.375$

$V_f \text{ ((11-3)-(11.4), ACI 440)} = 188111.148$

$f = 0.95$ , for fully-wrapped sections

$w_f/s_f = 1$  (FRP strips adjacent to one another).

In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot_a) \sin \alpha$  which is more a generalised expression, where  $\alpha$  is the angle of the crack direction (see KANEPE).

This later relation, considered as a function  $V_f(\alpha, \theta)$ , is implemented for every different fiber orientation  $\alpha_i$ , as well as for 2 crack directions,  $\theta = 45^\circ$  and  $\theta = -45^\circ$  to take into consideration the cyclic seismic loading.

orientation 1:  $\theta = b1 + 90^\circ = 90.00$

$V_f = \min(|V_f(45, \theta)|, |V_f(-45, \theta)|)$ , with:

total thickness per orientation,  $t_{f1} = N_L * t / N_{oDir} = 1.016$

$d_{fv} = d$  (figure 11.2, ACI 440) = 357.00

$f_{fe} \text{ ((11-5), ACI 440)} = 259.312$

$E_f = 64828.00$

$f_e = 0.004$ , from (11.6a), ACI 440

with  $f_u = 0.01$

From (11-11), ACI 440:  $V_s + V_f \leq 164661.611$

$b_w = 200.00$

Calculation of Shear Strength at edge 2,  $V_{r2} = 196005.816$

$V_{r2} = V_{Col} \text{ ((10.3), ASCE 41-17)} = k_{nl} * V_{Col0}$

$V_{Col0} = 196005.816$

$k_{nl} = 1$  (zero step-static loading)

NOTE: In expression (10-3) ' $V_s$ ' is replaced by ' $V_s + f * V_f$ ' where  $V_f$  is the contribution of FRPs (11.3), ACI 440).

$\lambda = 1$  (normal-weight concrete)

$f'_c = 15.00$ , but  $f'_c^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$M/Vd = 4.00$

$\mu_u = 23.99609$

$\nu_u = 0.01054019$

$d = 0.8 * h = 320.00$

$N_u = 4737.328$   
 $A_g = 80000.00$   
 From (11.5.4.8), ACI 318-14:  $V_s = V_{s1} + V_{s2} = 0.00$   
 where:  
 $V_{s1} = 0.00$  is calculated for section web, with:  
 $d = 320.00$   
 $A_v = 157079.633$   
 $f_y = 444.44$   
 $s = 380.00$   
 $V_{s1}$  is multiplied by  $Col1 = 0.00$   
 $s/d = 1.1875$   
 $V_{s2} = 0.00$  is calculated for section flange, with:  
 $d = 160.00$   
 $A_v = 157079.633$   
 $f_y = 444.44$   
 $s = 380.00$   
 $V_{s2}$  is multiplied by  $Col2 = 0.00$   
 $s/d = 2.375$   
 $V_f ((11-3)-(11.4), ACI 440) = 188111.148$   
 $f = 0.95$ , for fully-wrapped sections  
 $wf/sf = 1$  (FRP strips adjacent to one another).  
 In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot a) \sin a$  which is more a generalised expression,  
 where  $a$  is the angle of the crack direction (see KANEPE).  
 This later relation, considered as a function  $V_f( , )$ , is implemented for every different fiber orientation  $a_i$ ,  
 as well as for 2 crack directions,  $a = 45^\circ$  and  $a = -45^\circ$  to take into consideration the cyclic seismic loading.  
 orientation 1:  $a_1 = b_1 + 90^\circ = 90.00$   
 $V_f = \text{Min}(|V_f(45, 1)|, |V_f(-45, a_1)|)$ , with:  
 total thickness per orientation,  $t_{f1} = N_L * t / N_{oDir} = 1.016$   
 $d_{fv} = d$  (figure 11.2, ACI 440) = 357.00  
 $f_{fe} ((11-5), ACI 440) = 259.312$   
 $E_f = 64828.00$   
 $f_e = 0.004$ , from (11.6a), ACI 440  
 with  $f_u = 0.01$   
 From (11-11), ACI 440:  $V_s + V_f \leq 164661.611$   
 $b_w = 200.00$

-----  
 End Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1  
 At local axis: 3  
 -----

-----  
 Start Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1  
 At Shear local axis: 2  
 (Bending local axis: 3)  
 Section Type: rctcs

Constant Properties

-----  
 Knowledge Factor,  $\phi = 0.90$   
 Mean strength values are used for both shear and moment calculations.  
 Consequently:  
 Existing material of Primary Member: Concrete Strength,  $f_c = f_{cm} = 15.00$   
 Existing material of Primary Member: Steel Strength,  $f_s = f_{sm} = 444.44$   
 Concrete Elasticity,  $E_c = 18203.022$   
 Steel Elasticity,  $E_s = 200000.00$   
 #####  
 Note: Especially for the calculation of moment strengths,  
 the above steel re-bar strengths are multiplied by 1.25 according to R18.6.5, ACI 318-14  
 Existing material: Steel Strength,  $f_s = 1.25 * f_{sm} = 555.55$   
 #####  
 Max Height,  $H_{max} = 400.00$   
 Min Height,  $H_{min} = 200.00$   
 Max Width,  $W_{max} = 400.00$   
 Min Width,  $W_{min} = 200.00$   
 Eccentricity,  $Ecc = 100.00$

```

Cover Thickness, c = 25.00
Mean Confinement Factor overall section = 1.27578
Element Length, L = 3000.00
Primary Member
Ribbed Bars
Ductile Steel
Without Detailing for Earthquake Resistance (including stirrups not closed at 135°)
Longitudinal Bars With Ends Lapped Starting at the End Sections
Lap Length lo = 300.00
FRP Wrapping Data
Type: Carbon
Cured laminate properties (design values)
Thickness, t = 1.016
Tensile Strength, ffu = 1055.00
Tensile Modulus, Ef = 64828.00
Elongation, efu = 0.01
Number of directions, NoDir = 1
Fiber orientations, bi: 0.00°
Number of layers, NL = 1
Radius of rounding corners, R = 40.00
-----

Stepwise Properties
-----
At local axis: 2
EDGE -A-
Shear Force, Va = 1.5456333E-009
EDGE -B-
Shear Force, Vb = -1.5456333E-009
BOTH EDGES
Axial Force, F = -4737.328
Longitudinal Reinforcement Area Distribution (in 2 divisions)
  -Tension: Aslt = 0.00
  -Compression: Aslc = 5152.212
Longitudinal Reinforcement Area Distribution (in 3 divisions)
  -Tension: Asl,ten = 1231.504
  -Compression: Asl,com = 1231.504
  -Middle: Asl,mid = 2689.203
-----
-----

Calculation of Shear Capacity ratio , Ve/Vr = 0.55718248
Member Controlled by Flexure (Ve/Vr < 1)
Calculation of Shear Demand from fig. R18.6.5, ACI 318-14 Ve = (Mpr1 + Mpr2)/ln = 126675.449
with
Mpr1 = Max(Mu1+ , Mu1-) = 1.9001E+008
  Mu1+ = 1.9001E+008, is the ultimate moment strength at the edge 1 of the member in the actual moment direction
  which is defined for the static loading combination
  Mu1- = 1.9001E+008, is the ultimate moment strength at the edge 1 of the member in the opposite moment
  direction which is defined for the static loading combination
Mpr2 = Max(Mu2+ , Mu2-) = 1.9001E+008
  Mu2+ = 1.9001E+008, is the ultimate moment strength at the edge 2 of the member in the actual moment direction
  which is defined for the the static loading combination
  Mu2- = 1.9001E+008, is the ultimate moment strength at the edge 2 of the member in the opposite moment
  direction which is defined for the the static loading combination
-----

Calculation of Mu1+
-----

Calculation of ultimate curvature u according to 4.1, Biskinis/Fardis 2013:
u = 1.7086748E-005
Mu = 1.9001E+008
-----

with full section properties:

```

$$b = 200.00$$

$$d = 357.00$$

$$d' = 43.00$$

$$v = 0.00442328$$

$$N = 4737.328$$

$$f_c = 15.00$$

$$\alpha (5A.5, \text{TB DY}) = 0.002$$

$$\text{Final value of } \alpha: \alpha^* = \text{shear\_factor} * \text{Max}(\alpha, \alpha_c) = 0.018$$

The Shear\_factor is considered equal to 1 (pure moment strength)

$$\text{From (5.4b), TB DY: } \alpha = 0.018$$

$$\alpha_e \text{ ((5.4c), TB DY)} = \alpha_e * \text{sh}_{\min} * f_{ywe} / f_{ce} + \text{Min}(f_x, f_y) = 0.15303423$$

where  $f = \alpha * \rho_f * f_{fe} / f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$$f_x = 0.15303423$$

Expression ((15B.6), TB DY) is modified as  $\alpha_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$$\alpha_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2) / 3 = 51733.333$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A4.4.3(6), } \rho_f = 2t_f / b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$f_y = 0.15303423$$

Expression ((15B.6), TB DY) is modified as  $\alpha_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$$\alpha_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2) / 3 = 0.00$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A4.4.3(6), } \rho_f = 2t_f / b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$R = 40.00$$

$$\text{Effective FRP thickness, } t_f = N L * t * \cos(b_1) = 1.016$$

$$f_{u,f} = 1055.00$$

$$E_f = 64828.00$$

$$u_{f,f} = 0.015$$

$$\alpha_{se} = \text{Max}(((A_{\text{conf,max}} - A_{\text{noConf}}) / A_{\text{conf,max}}) * (A_{\text{conf,min}} / A_{\text{conf,max}}), 0) = 0.00$$

The definitions of  $A_{\text{noConf}}$ ,  $A_{\text{conf,min}}$  and  $A_{\text{conf,max}}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{\text{conf,max}} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{\text{conf,min}} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{\text{conf,max}}$  by a length equal to half the clear spacing between hoops.

$A_{\text{noConf}} = 33066.667$  is the unconfined core area which is equal to  $b_i^2 / 6$  as defined at (A.2).

$$\rho_{sh,\min} = \text{Min}(\rho_{sh,x}, \rho_{sh,y}) = 0.00165347$$

Expression ((5.4d), TB DY) for  $\rho_{sh,\min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$$\rho_{sh,x} \text{ ((5.4d), TB DY)} = L_{\text{stir}} * A_{\text{stir}} / (A_{\text{sec}} * s) = 0.00165347$$

$$L_{\text{stir}} \text{ (Length of stirrups along Y)} = 960.00$$

$$A_{\text{stir}} \text{ (stirrups area)} = 78.53982$$

$$A_{\text{sec}} \text{ (section area)} = 120000.00$$

$$\rho_{sh,y} \text{ ((5.4d), TB DY)} = L_{\text{stir}} * A_{\text{stir}} / (A_{\text{sec}} * s) = 0.00165347$$

$$L_{\text{stir}} \text{ (Length of stirrups along X)} = 960.00$$

$$A_{\text{stir}} \text{ (stirrups area)} = 78.53982$$

$$A_{\text{sec}} \text{ (section area)} = 120000.00$$

$$s = 380.00$$

$$f_{ywe} = 555.55$$

$$f_{ce} = 15.00$$

From ((5.A.5), TBDY), TBDY:  $cc = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $y1 = 0.0010562$   
 $sh1 = 0.00365026$   
 $ft1 = 304.185$   
 $fy1 = 253.4875$   
 $su1 = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $lo/lou,min = lb/ld = 0.22053887$   
 $su1 = 0.4 * esu1\_nominal ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esu1\_nominal = 0.08$ ,  
 For calculation of  $esu1\_nominal$  and  $y1, sh1, ft1, fy1$ , it is considered  
 characteristic value  $fsy1 = fs1/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 * (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fs1 = fs = 253.4875$   
 with  $Es1 = Es = 200000.00$   
 $y2 = 0.0010562$   
 $sh2 = 0.00365026$   
 $ft2 = 304.185$   
 $fy2 = 253.4875$   
 $su2 = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $lo/lou,min = lb/lb,min = 0.22053887$   
 $su2 = 0.4 * esu2\_nominal ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esu2\_nominal = 0.08$ ,  
 For calculation of  $esu2\_nominal$  and  $y2, sh2, ft2, fy2$ , it is considered  
 characteristic value  $fsy2 = fs2/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 * (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fs2 = fs = 253.4875$   
 with  $Es2 = Es = 200000.00$   
 $yv = 0.0010562$   
 $shv = 0.00365026$   
 $ftv = 304.185$   
 $fyv = 253.4875$   
 $suv = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $lo/lou,min = lb/ld = 0.22053887$   
 $suv = 0.4 * esuv\_nominal ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esuv\_nominal = 0.08$ ,  
 considering characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY  
 For calculation of  $esuv\_nominal$  and  $yv, shv, ftv, fyv$ , it is considered  
 characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 * (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fsv = fs = 253.4875$   
 with  $Esv = Es = 200000.00$   
 $1 = Asl,ten/(b*d)*(fs1/fc) = 0.29147618$   
 $2 = Asl,com/(b*d)*(fs2/fc) = 0.29147618$   
 $v = Asl,mid/(b*d)*(fsv/fc) = 0.6364888$   
 and confined core properties:  
 $b = 140.00$   
 $d = 327.00$   
 $d' = 13.00$   
 $fcc (5A.2, TBDY) = 19.13667$   
 $cc (5A.5, TBDY) = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $1 = Asl,ten/(b*d)*(fs1/fc) = 0.45459588$   
 $2 = Asl,com/(b*d)*(fs2/fc) = 0.45459588$   
 $v = Asl,mid/(b*d)*(fsv/fc) = 0.99268896$   
 Case/Assumption: Unconfined full section - Steel rupture  
 ' satisfies Eq. (4.3)

--->

$v < v_{s,y2}$  - LHS eq.(4.5) is not satisfied

---->

$v < v_{s,c}$  - RHS eq.(4.5) is satisfied

---->

$\mu_u (4.8) = 0.40159417$

$\mu_u = M_{Rc} (4.15) = 1.9001E+008$

$u = \mu_u (4.1) = 1.7086748E-005$

Calculation of ratio  $I_b/I_d$

Lap Length:  $I_b/I_d = 0.22053887$

$I_b = 300.00$

$I_d = 1360.304$

Calculation of  $I_b$ ,min according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.  
= 1

$d_b = 18.00$

Mean strength value of all re-bars:  $f_y = 555.55$

$f_c' = 15.00$ , but  $f_c'^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$t = 1.00$

$s = 0.80$

$e = 1.00$

$c_b = 24.02082$

$K_{tr} = 0.82673491$

$A_{tr} = \text{Min}(A_{tr,x}, A_{tr,y}) = 157.0796$

where  $A_{tr,x}$ ,  $A_{tr,y}$  are the sum of the area of all stirrup legs along X and Y loxal axis

$s = 380.00$

$n = 20.00$

Calculation of  $\mu_{u1}$ -

Calculation of ultimate curvature  $\mu_u$  according to 4.1, Biskinis/Fardis 2013:

$u = 1.7086748E-005$

$\mu_u = 1.9001E+008$

with full section properties:

$b = 200.00$

$d = 357.00$

$d' = 43.00$

$v = 0.00442328$

$N = 4737.328$

$f_c = 15.00$

$\alpha (5A.5, \text{TB DY}) = 0.002$

Final value of  $\mu_u$ :  $\mu_u^* = \text{shear\_factor} * \text{Max}(\mu_u, \alpha) = 0.018$

The Shear\_factor is considered equal to 1 (pure moment strength)

From (5.4b), TB DY:  $\mu_u = 0.018$

we ((5.4c), TB DY) =  $\alpha_{se} * \frac{sh_{min} * f_{ywe}}{f_{ce}} + \text{Min}(f_x, f_y) = 0.15303423$

where  $f = \alpha_f * p_f * f_{fe} / f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$f_x = 0.15303423$

Expression ((15B.6), TB DY) is modified as  $\alpha_f = 1 - (\text{Unconfined area})/(\text{total area})$

$\alpha_f = 0.43111111$

with Unconfined area =  $((b_{max}-2R)^2 + (h_{max}-2R)^2)/3 = 51733.333$

$b_{max} = 400.00$

$h_{max} = 400.00$

From EC8 A.4.4.3(6),  $p_f = 2t_f/b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

$f_y = 0.15303423$

Expression ((15B.6), TB DY) is modified as  $\alpha_f = 1 - (\text{Unconfined area})/(\text{total area})$

$\alpha_f = 0.43111111$

with Unconfined area =  $((b_{max}-2R)^2 + (h_{max}-2R)^2)/3 = 0.00$

bmax = 400.00  
hmax = 400.00  
From EC8 A4.4.3(6),  $pf = 2tf/bw = 0.01016$   
bw = 200.00  
effective stress from (A.35),  $ff,e = 524.0792$

R = 40.00  
Effective FRP thickness,  $tf = NL*t*Cos(b1) = 1.016$   
 $f_{u,f} = 1055.00$   
 $E_f = 64828.00$   
 $u_{,f} = 0.015$

$ase = \text{Max}(((A_{conf,max} - A_{noConf}) / A_{conf,max}) * (A_{conf,min} / A_{conf,max}), 0) = 0.00$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988) "Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$psh,min = \text{Min}(psh,x, psh,y) = 0.00165347$

Expression ((5.4d), TBDY) for  $psh,min$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$psh,x \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$   
 $L_{stir}$  (Length of stirrups along Y) = 960.00  
 $A_{stir}$  (stirrups area) = 78.53982  
 $A_{sec}$  (section area) = 120000.00

$psh,y \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$   
 $L_{stir}$  (Length of stirrups along X) = 960.00  
 $A_{stir}$  (stirrups area) = 78.53982  
 $A_{sec}$  (section area) = 120000.00

s = 380.00  
 $f_{ywe} = 555.55$   
 $f_{ce} = 15.00$

From ((5.A5), TBDY), TBDY:  $cc = 0.00475778$   
c = confinement factor = 1.27578

$y1 = 0.0010562$   
 $sh1 = 0.00365026$

$ft1 = 304.185$

$fy1 = 253.4875$

$su1 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$lo/lo_{u,min} = lb/ld = 0.22053887$

$su1 = 0.4 * esu1_{nominal} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu1_{nominal} = 0.08$ ,

For calculation of  $esu1_{nominal}$  and  $y1, sh1, ft1, fy1$ , it is considered characteristic value  $fsy1 = fs1/1.2$ , from table 5.1, TBDY.

$y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 * (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.

with  $fs1 = fs = 253.4875$

with  $Es1 = Es = 200000.00$

$y2 = 0.0010562$   
 $sh2 = 0.00365026$

$ft2 = 304.185$

$fy2 = 253.4875$

$su2 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$lo/lo_{u,min} = lb/lb_{,min} = 0.22053887$

```

su2 = 0.4*esu2_nominal ((5.5), TBDY) = 0.032
From table 5A.1, TBDY: esu2_nominal = 0.08,
For calculation of esu2_nominal and y2, sh2,ft2,fy2, it is considered
characteristic value fsy2 = fs2/1.2, from table 5.1, TBDY.
y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/d)^ 2/3), from 10.3.5, ASCE 41-17.
with fs2 = fs = 253.4875
with Es2 = Es = 200000.00
yv = 0.0010562
shv = 0.00365026
ftv = 304.185
fyv = 253.4875
suv = 0.00365026
using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
and also multiplied by the shear_factor according to 15.7.1.4, with
Shear_factor = 1.00
lo/lou,min = lb/d = 0.22053887
suv = 0.4*esuv_nominal ((5.5), TBDY) = 0.032
From table 5A.1, TBDY: esuv_nominal = 0.08,
considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY
For calculation of esuv_nominal and yv, shv,ftv,fyv, it is considered
characteristic value fsyv = fsv/1.2, from table 5.1, TBDY.
y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/d)^ 2/3), from 10.3.5, ASCE 41-17.
with fsv = fs = 253.4875
with Esv = Es = 200000.00
1 = Asl,ten/(b*d)*(fs1/fc) = 0.29147618
2 = Asl,com/(b*d)*(fs2/fc) = 0.29147618
v = Asl,mid/(b*d)*(fsv/fc) = 0.6364888
and confined core properties:
b = 140.00
d = 327.00
d' = 13.00
fcc (5A.2, TBDY) = 19.13667
cc (5A.5, TBDY) = 0.00475778
c = confinement factor = 1.27578
1 = Asl,ten/(b*d)*(fs1/fc) = 0.45459588
2 = Asl,com/(b*d)*(fs2/fc) = 0.45459588
v = Asl,mid/(b*d)*(fsv/fc) = 0.99268896
Case/Assumption: Unconfined full section - Steel rupture
'satisfies Eq. (4.3)
--->
v < vs,y2 - LHS eq.(4.5) is not satisfied
--->
v < vs,c - RHS eq.(4.5) is satisfied
--->
su (4.8) = 0.40159417
Mu = MRc (4.15) = 1.9001E+008
u = su (4.1) = 1.7086748E-005

```

#### Calculation of ratio lb/d

```

Lap Length: lb/d = 0.22053887
lb = 300.00
ld = 1360.304
Calculation of lb,min according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.
= 1
db = 18.00
Mean strength value of all re-bars: fy = 555.55
fc' = 15.00, but fc^0.5 <= 8.3 MPa (22.5.3.1, ACI 318-14)
t = 1.00
s = 0.80
e = 1.00
cb = 24.02082
Ktr = 0.82673491
Atr = Min(Atr_x,Atr_y) = 157.0796
where Atr_x, Atr_y are the sum of the area of all stirrup legs along X and Y loxal axis
s = 380.00

```



n = 20.00

Calculation of  $\mu_{2+}$

Calculation of ultimate curvature  $\mu$  according to 4.1, Biskinis/Fardis 2013:

$\mu = 1.7086748E-005$

$\mu_u = 1.9001E+008$

with full section properties:

b = 200.00

d = 357.00

d' = 43.00

v = 0.00442328

N = 4737.328

$f_c = 15.00$

$\mu_c$  (5A.5, TBDY) = 0.002

Final value of  $\mu_c$ :  $\mu_c^* = \text{shear\_factor} * \text{Max}(\mu_c, \mu_c) = 0.018$

The Shear\_factor is considered equal to 1 (pure moment strength)

From (5.4b), TBDY:  $\mu_c = 0.018$

where ((5.4c), TBDY) =  $\mu_c^* * \mu_{c, \min} * f_{ywe} / f_{ce} + \text{Min}(\mu_c, \mu_c) = 0.15303423$

where  $\mu_c = \mu_c^* * \mu_{c, \min} * f_{ywe} / f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$\mu_c = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $\mu_c = 1 - (\text{Unconfined area}) / (\text{total area})$

$\mu_c = 0.43111111$

with Unconfined area =  $((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2) / 3 = 51733.333$

$b_{\max} = 400.00$

$h_{\max} = 400.00$

From EC8 A4.4.3(6),  $\mu_c = 2t_f / b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

$\mu_c = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $\mu_c = 1 - (\text{Unconfined area}) / (\text{total area})$

$\mu_c = 0.43111111$

with Unconfined area =  $((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2) / 3 = 0.00$

$b_{\max} = 400.00$

$h_{\max} = 400.00$

From EC8 A4.4.3(6),  $\mu_c = 2t_f / b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

R = 40.00

Effective FRP thickness,  $t_f = N L^* t \cos(b_1) = 1.016$

$f_{u,f} = 1055.00$

$E_f = 64828.00$

$\mu_{u,f} = 0.015$

$\mu_{ase} = \text{Max}(((A_{\text{conf,max}} - A_{\text{noConf}}) / A_{\text{conf,max}}) * (A_{\text{conf,min}} / A_{\text{conf,max}}), 0) = 0.00$

The definitions of  $A_{\text{noConf}}$ ,  $A_{\text{conf,min}}$  and  $A_{\text{conf,max}}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{\text{conf,max}} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{\text{conf,min}} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{\text{conf,max}}$  by a length equal to half the clear spacing between hoops.

$A_{\text{noConf}} = 33066.667$  is the unconfined core area which is equal to  $b_i^2 / 6$  as defined at (A.2).

$\mu_{psh,min} = \text{Min}(\mu_{psh,x}, \mu_{psh,y}) = 0.00165347$

Expression ((5.4d), TBDY) for  $\mu_{psh,min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$$psh,x ((5.4d), TBDY) = Lstir * Astir / (Asec * s) = 0.00165347$$

$$Lstir \text{ (Length of stirrups along Y)} = 960.00$$

$$Astir \text{ (stirrups area)} = 78.53982$$

$$Asec \text{ (section area)} = 120000.00$$

$$psh,y ((5.4d), TBDY) = Lstir * Astir / (Asec * s) = 0.00165347$$

$$Lstir \text{ (Length of stirrups along X)} = 960.00$$

$$Astir \text{ (stirrups area)} = 78.53982$$

$$Asec \text{ (section area)} = 120000.00$$

$$s = 380.00$$

$$fywe = 555.55$$

$$fce = 15.00$$

$$\text{From } ((5.A5), TBDY), TBDY: cc = 0.00475778$$

$$c = \text{confinement factor} = 1.27578$$

$$y1 = 0.0010562$$

$$sh1 = 0.00365026$$

$$ft1 = 304.185$$

$$fy1 = 253.4875$$

$$su1 = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00

$$lo/lou,min = lb/ld = 0.22053887$$

$$su1 = 0.4 * esu1\_nominal ((5.5), TBDY) = 0.032$$

$$\text{From table 5A.1, TBDY: } esu1\_nominal = 0.08,$$

For calculation of esu1\_nominal and y1, sh1,ft1,fy1, it is considered  
characteristic value fsy1 = fs1/1.2, from table 5.1, TBDY.

$$y1, sh1,ft1,fy1, \text{ are also multiplied by } \text{Min}(1, 1.25 * (lb/ld)^{2/3}), \text{ from 10.3.5, ASCE 41-17.}$$

$$\text{with } fs1 = fs = 253.4875$$

$$\text{with } Es1 = Es = 200000.00$$

$$y2 = 0.0010562$$

$$sh2 = 0.00365026$$

$$ft2 = 304.185$$

$$fy2 = 253.4875$$

$$su2 = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00

$$lo/lou,min = lb/lb,min = 0.22053887$$

$$su2 = 0.4 * esu2\_nominal ((5.5), TBDY) = 0.032$$

$$\text{From table 5A.1, TBDY: } esu2\_nominal = 0.08,$$

For calculation of esu2\_nominal and y2, sh2,ft2,fy2, it is considered  
characteristic value fsy2 = fs2/1.2, from table 5.1, TBDY.

$$y1, sh1,ft1,fy1, \text{ are also multiplied by } \text{Min}(1, 1.25 * (lb/ld)^{2/3}), \text{ from 10.3.5, ASCE 41-17.}$$

$$\text{with } fs2 = fs = 253.4875$$

$$\text{with } Es2 = Es = 200000.00$$

$$yv = 0.0010562$$

$$shv = 0.00365026$$

$$ftv = 304.185$$

$$fyv = 253.4875$$

$$suv = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00

$$lo/lou,min = lb/ld = 0.22053887$$

$$suv = 0.4 * esuv\_nominal ((5.5), TBDY) = 0.032$$

$$\text{From table 5A.1, TBDY: } esuv\_nominal = 0.08,$$

considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY

For calculation of esuv\_nominal and yv, shv,ftv,fyv, it is considered  
characteristic value fsyv = fsv/1.2, from table 5.1, TBDY.

$$y1, sh1,ft1,fy1, \text{ are also multiplied by } \text{Min}(1, 1.25 * (lb/ld)^{2/3}), \text{ from 10.3.5, ASCE 41-17.}$$

$$\text{with } fsv = fs = 253.4875$$

$$\text{with } Esv = Es = 200000.00$$

$$1 = Asl,ten / (b * d) * (fs1 / fc) = 0.29147618$$

$$2 = Asl,com / (b * d) * (fs2 / fc) = 0.29147618$$

$$v = Asl,mid / (b * d) * (fsv / fc) = 0.6364888$$

and confined core properties:

$$b = 140.00$$

$$d = 327.00$$

$$d' = 13.00$$

$$fcc(5A.2, TBDY) = 19.13667$$

$$cc(5A.5, TBDY) = 0.00475778$$

$$c = \text{confinement factor} = 1.27578$$

$$1 = A_{s1,ten}/(b*d)*(f_{s1}/f_c) = 0.45459588$$

$$2 = A_{s2,com}/(b*d)*(f_{s2}/f_c) = 0.45459588$$

$$v = A_{s,mid}/(b*d)*(f_{sv}/f_c) = 0.99268896$$

Case/Assumption: Unconfined full section - Steel rupture

' satisfies Eq. (4.3)

--->

$v < v_{s,y2}$  - LHS eq.(4.5) is not satisfied

--->

$v < v_{s,c}$  - RHS eq.(4.5) is satisfied

--->

$$su(4.8) = 0.40159417$$

$$Mu = MRc(4.15) = 1.9001E+008$$

$$u = su(4.1) = 1.7086748E-005$$

Calculation of ratio  $l_b/l_d$

Lap Length:  $l_b/l_d = 0.22053887$

$$l_b = 300.00$$

$$l_d = 1360.304$$

Calculation of  $l_b, \min$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$$= 1$$

$$d_b = 18.00$$

Mean strength value of all re-bars:  $f_y = 555.55$

$$f_c' = 15.00, \text{ but } f_c'^{0.5} \leq 8.3 \text{ MPa (22.5.3.1, ACI 318-14)}$$

$$t = 1.00$$

$$s = 0.80$$

$$e = 1.00$$

$$c_b = 24.02082$$

$$K_{tr} = 0.82673491$$

$$A_{tr} = \min(A_{tr_x}, A_{tr_y}) = 157.0796$$

where  $A_{tr_x}$ ,  $A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis

$$s = 380.00$$

$$n = 20.00$$

Calculation of  $Mu_2$ -

Calculation of ultimate curvature  $u$  according to 4.1, Biskinis/Fardis 2013:

$$u = 1.7086748E-005$$

$$Mu = 1.9001E+008$$

with full section properties:

$$b = 200.00$$

$$d = 357.00$$

$$d' = 43.00$$

$$v = 0.00442328$$

$$N = 4737.328$$

$$f_c = 15.00$$

$$co(5A.5, TBDY) = 0.002$$

$$\text{Final value of } cu: cu^* = \text{shear\_factor} * \max(cu, cc) = 0.018$$

The Shear\_factor is considered equal to 1 (pure moment strength)

$$\text{From (5.4b), TBDY: } cu = 0.018$$

$$we((5.4c), TBDY) = a_{se} * sh_{min} * f_{ywe}/f_{ce} + \min(f_x, f_y) = 0.15303423$$

where  $f = a_f * p_f * f_{fe}/f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$$f_x = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $af = 1 - (\text{Unconfined area})/(\text{total area})$

$af = 0.43111111$

with Unconfined area =  $((b_{max}-2R)^2 + (h_{max}-2R)^2)/3 = 51733.333$

$b_{max} = 400.00$

$h_{max} = 400.00$

From EC8 A.4.4.3(6),  $pf = 2tf/bw = 0.01016$

$bw = 200.00$

effective stress from (A.35),  $ff,e = 524.0792$

$f_y = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $af = 1 - (\text{Unconfined area})/(\text{total area})$

$af = 0.43111111$

with Unconfined area =  $((b_{max}-2R)^2 + (h_{max}-2R)^2)/3 = 0.00$

$b_{max} = 400.00$

$h_{max} = 400.00$

From EC8 A.4.4.3(6),  $pf = 2tf/bw = 0.01016$

$bw = 200.00$

effective stress from (A.35),  $ff,e = 524.0792$

$R = 40.00$

Effective FRP thickness,  $tf = NL \cdot t \cdot \cos(b_1) = 1.016$

$f_{u,f} = 1055.00$

$E_f = 64828.00$

$u_f = 0.015$

$ase = \text{Max}(((A_{conf,max} - A_{noConf})/A_{conf,max}) \cdot (A_{conf,min}/A_{conf,max}), 0) = 0.00$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

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J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$p_{sh,min} = \text{Min}(p_{sh,x}, p_{sh,y}) = 0.00165347$

Expression ((5.4d), TBDY) for  $p_{sh,min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$p_{sh,x} \text{ ((5.4d), TBDY)} = L_{stir} \cdot A_{stir} / (A_{sec} \cdot s) = 0.00165347$

$L_{stir}$  (Length of stirrups along Y) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$p_{sh,y} \text{ ((5.4d), TBDY)} = L_{stir} \cdot A_{stir} / (A_{sec} \cdot s) = 0.00165347$

$L_{stir}$  (Length of stirrups along X) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$s = 380.00$

$f_{ywe} = 555.55$

$f_{ce} = 15.00$

From ((5.A5), TBDY), TBDY:  $cc = 0.00475778$

$c$  = confinement factor = 1.27578

$y_1 = 0.0010562$

$sh_1 = 0.00365026$

$ft_1 = 304.185$

$fy_1 = 253.4875$

$su_1 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$lo/lo_{u,min} = lb/ld = 0.22053887$

$su_1 = 0.4 \cdot esu_{1,nominal} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu_{1,nominal} = 0.08$ ,

For calculation of  $esu_{1,nominal}$  and  $y_1$ ,  $sh_1$ ,  $ft_1$ ,  $fy_1$ , it is considered

characteristic value  $f_{sy1} = f_{s1}/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $f_{s1} = f_s = 253.4875$   
 with  $E_{s1} = E_s = 200000.00$   
 $y2 = 0.0010562$   
 $sh2 = 0.00365026$   
 $ft2 = 304.185$   
 $fy2 = 253.4875$   
 $su2 = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $l_o/l_{o,min} = l_b/l_{b,min} = 0.22053887$   
 $su2 = 0.4 \cdot esu2\_nominal \cdot ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esu2\_nominal = 0.08$ ,  
 For calculation of  $esu2\_nominal$  and  $y2, sh2, ft2, fy2$ , it is considered  
 characteristic value  $f_{sy2} = f_{s2}/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $f_{s2} = f_s = 253.4875$   
 with  $E_{s2} = E_s = 200000.00$   
 $yv = 0.0010562$   
 $shv = 0.00365026$   
 $ftv = 304.185$   
 $fyv = 253.4875$   
 $suv = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $l_o/l_{o,min} = l_b/l_d = 0.22053887$   
 $suv = 0.4 \cdot esuv\_nominal \cdot ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esuv\_nominal = 0.08$ ,  
 considering characteristic value  $f_{syv} = f_{sv}/1.2$ , from table 5.1, TBDY  
 For calculation of  $esuv\_nominal$  and  $yv, shv, ftv, fyv$ , it is considered  
 characteristic value  $f_{syv} = f_{sv}/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $f_{sv} = f_s = 253.4875$   
 with  $E_{sv} = E_s = 200000.00$   
 $1 = A_{sl,ten}/(b \cdot d) \cdot (f_{s1}/f_c) = 0.29147618$   
 $2 = A_{sl,com}/(b \cdot d) \cdot (f_{s2}/f_c) = 0.29147618$   
 $v = A_{sl,mid}/(b \cdot d) \cdot (f_{sv}/f_c) = 0.6364888$

and confined core properties:

$b = 140.00$   
 $d = 327.00$   
 $d' = 13.00$   
 $f_{cc} \text{ (5A.2, TBDY)} = 19.13667$   
 $cc \text{ (5A.5, TBDY)} = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $1 = A_{sl,ten}/(b \cdot d) \cdot (f_{s1}/f_c) = 0.45459588$   
 $2 = A_{sl,com}/(b \cdot d) \cdot (f_{s2}/f_c) = 0.45459588$   
 $v = A_{sl,mid}/(b \cdot d) \cdot (f_{sv}/f_c) = 0.99268896$

Case/Assumption: Unconfined full section - Steel rupture

' satisfies Eq. (4.3)

---->

$v < v_{s,y2}$  - LHS eq.(4.5) is not satisfied

---->

$v < v_{s,c}$  - RHS eq.(4.5) is satisfied

---->

$su \text{ (4.8)} = 0.40159417$

$Mu = MRc \text{ (4.15)} = 1.9001E+008$

$u = su \text{ (4.1)} = 1.7086748E-005$

Calculation of ratio  $l_b/l_d$

Lap Length:  $l_b/l_d = 0.22053887$

$l_b = 300.00$

$l_d = 1360.304$

Calculation of  $l_{b,min}$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$$= 1$$

$$d_b = 18.00$$

Mean strength value of all re-bars:  $f_y = 555.55$

$$f'_c = 15.00, \text{ but } f_c^{0.5} \leq 8.3 \text{ MPa (22.5.3.1, ACI 318-14)}$$

$$t = 1.00$$

$$s = 0.80$$

$$e = 1.00$$

$$c_b = 24.02082$$

$$K_{tr} = 0.82673491$$

$$A_{tr} = \min(A_{tr_x}, A_{tr_y}) = 157.0796$$

where  $A_{tr_x}$ ,  $A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis

$$s = 380.00$$

$$n = 20.00$$

Calculation of Shear Strength  $V_r = \min(V_{r1}, V_{r2}) = 227350.021$

Calculation of Shear Strength at edge 1,  $V_{r1} = 227350.021$

$$V_{r1} = V_{Col} \text{ ((10.3), ASCE 41-17)} = k_n l^* V_{Col0}$$

$$V_{Col0} = 227350.021$$

$$k_n l = 1 \text{ (zero step-static loading)}$$

NOTE: In expression (10-3) ' $V_s$ ' is replaced by ' $V_{s+} + f^* V_f$ '

where  $V_f$  is the contribution of FRPs (11.3), ACI 440).

$$= 1 \text{ (normal-weight concrete)}$$

$$f'_c = 15.00, \text{ but } f_c^{0.5} \leq 8.3 \text{ MPa (22.5.3.1, ACI 318-14)}$$

$$M/Vd = 2.00$$

$$\mu_u = 0.00988804$$

$$V_u = 1.5456333E-009$$

$$d = 0.8^*h = 320.00$$

$$N_u = 4737.328$$

$$A_g = 80000.00$$

$$\text{From (11.5.4.8), ACI 318-14: } V_s = V_{s1} + V_{s2} = 0.00$$

where:

$V_{s1} = 0.00$  is calculated for section web, with:

$$d = 160.00$$

$$A_v = 157079.633$$

$$f_y = 444.44$$

$$s = 380.00$$

$V_{s1}$  is multiplied by  $Col1 = 0.00$

$$s/d = 2.375$$

$V_{s2} = 0.00$  is calculated for section flange, with:

$$d = 320.00$$

$$A_v = 157079.633$$

$$f_y = 444.44$$

$$s = 380.00$$

$V_{s2}$  is multiplied by  $Col2 = 0.00$

$$s/d = 1.1875$$

$$V_f \text{ ((11-3)-(11.4), ACI 440)} = 188111.148$$

$$f = 0.95, \text{ for fully-wrapped sections}$$

$w_f/s_f = 1$  (FRP strips adjacent to one another).

In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot a) \sin a$  which is more a generalised expression,

where  $a$  is the angle of the crack direction (see KANEPE).

This later relation, considered as a function  $V_f(, )$ , is implemented for every different fiber orientation  $a_i$ , as well as for 2 crack directions,  $a = 45^\circ$  and  $a = -45^\circ$  to take into consideration the cyclic seismic loading.

$$\text{orientation 1: } \theta_1 = \theta_1 + 90^\circ = 90.00$$

$$V_f = \min(|V_f(45, \theta_1)|, |V_f(-45, \theta_1)|), \text{ with:}$$

$$\text{total thickness per orientation, } t_{f1} = N_L^* t / N_{oDir} = 1.016$$

$$d_{fv} = d \text{ (figure 11.2, ACI 440)} = 357.00$$

$$f_{fe} \text{ ((11-5), ACI 440)} = 259.312$$

$$E_f = 64828.00$$

$$f_e = 0.004, \text{ from (11.6a), ACI 440}$$

$$\text{with } f_u = 0.01$$

From (11-11), ACI 440:  $V_s + V_f \leq 164661.611$   
 $bw = 200.00$

Calculation of Shear Strength at edge 2,  $V_{r2} = 227350.021$   
 $V_{r2} = V_{Col} ((10.3), ASCE 41-17) = knl * V_{Col0}$   
 $V_{Col0} = 227350.021$   
 $knl = 1$  (zero step-static loading)

NOTE: In expression (10-3) ' $V_s$ ' is replaced by ' $V_s + f * V_f$ '  
where  $V_f$  is the contribution of FRPs (11.3), ACI 440).

$= 1$  (normal-weight concrete)  
 $f'_c = 15.00$ , but  $f'_c^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$M/Vd = 2.00$

$\mu_u = 0.00525978$

$V_u = 1.5456333E-009$

$d = 0.8 * h = 320.00$

$N_u = 4737.328$

$A_g = 80000.00$

From (11.5.4.8), ACI 318-14:  $V_s = V_{s1} + V_{s2} = 0.00$

where:

$V_{s1} = 0.00$  is calculated for section web, with:

$d = 160.00$

$A_v = 157079.633$

$f_y = 444.44$

$s = 380.00$

$V_{s1}$  is multiplied by  $Col1 = 0.00$

$s/d = 2.375$

$V_{s2} = 0.00$  is calculated for section flange, with:

$d = 320.00$

$A_v = 157079.633$

$f_y = 444.44$

$s = 380.00$

$V_{s2}$  is multiplied by  $Col2 = 0.00$

$s/d = 1.1875$

$V_f ((11-3)-(11.4), ACI 440) = 188111.148$

$f = 0.95$ , for fully-wrapped sections

$w_f/s_f = 1$  (FRP strips adjacent to one another).

In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot a) \sin a$  which is more a generalised expression,  
where  $a$  is the angle of the crack direction (see KANEPE).

This later relation, considered as a function  $V_f(, )$ , is implemented for every different fiber orientation  $a_i$ ,  
as well as for 2 crack directions,  $a = 45^\circ$  and  $a = -45^\circ$  to take into consideration the cyclic seismic loading.

orientation 1:  $a_1 = b_1 + 90^\circ = 90.00$

$V_f = \text{Min}(|V_f(45, 1)|, |V_f(-45, a_1)|)$ , with:

total thickness per orientation,  $t_{f1} = NL * t / NoDir = 1.016$

$d_{fv} = d$  (figure 11.2, ACI 440) = 357.00

$f_{fe} ((11-5), ACI 440) = 259.312$

$E_f = 64828.00$

$f_e = 0.004$ , from (11.6a), ACI 440

with  $f_u = 0.01$

From (11-11), ACI 440:  $V_s + V_f \leq 164661.611$

$bw = 200.00$

End Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1  
At local axis: 2

Start Of Calculation of Chord Rotation Capacity for element: column TC1 of floor 1  
At local axis: 3  
Integration Section: (b)  
Section Type: rctcs

Constant Properties

Knowledge Factor,  $\phi = 0.90$   
Chord Rotation is generally considered as Deformation-Controlled Action according to Table C7-1, ASCE 41-17.  
Mean strengths are used for Deformation-Controlled Actions according to 7.5.1.3, ASCE 41-17  
Consequently:  
Existing material of Primary Member: Concrete Strength,  $f_c = f_{cm} = 15.00$   
Existing material of Primary Member: Steel Strength,  $f_s = f_{sm} = 444.44$   
Concrete Elasticity,  $E_c = 18203.022$   
Steel Elasticity,  $E_s = 200000.00$   
Max Height,  $H_{max} = 400.00$   
Min Height,  $H_{min} = 200.00$   
Max Width,  $W_{max} = 400.00$   
Min Width,  $W_{min} = 200.00$   
Eccentricity,  $Ecc = 100.00$   
Cover Thickness,  $c = 25.00$   
Element Length,  $L = 3000.00$   
Primary Member  
Ribbed Bars  
Ductile Steel  
Without Detailing for Earthquake Resistance (including stirrups not closed at 135°)  
Longitudinal Bars With Ends Lapped Starting at the End Sections  
Lap Length  $l_b = 300.00$   
FRP Wrapping Data  
Type: Carbon  
Cured laminate properties (design values)  
Thickness,  $t = 1.016$   
Tensile Strength,  $f_{fu} = 1055.00$   
Tensile Modulus,  $E_f = 64828.00$   
Elongation,  $\epsilon_{fu} = 0.01$   
Number of directions,  $N_{oDir} = 1$   
Fiber orientations,  $b_i: 0.00^\circ$   
Number of layers,  $N_L = 1$   
Radius of rounding corners,  $R = 40.00$

#### Stepwise Properties

Bending Moment,  $M = -136.3192$   
Shear Force,  $V_2 = 2811.342$   
Shear Force,  $V_3 = 0.02136663$   
Axial Force,  $F = -4735.965$   
Longitudinal Reinforcement Area Distribution (in 2 divisions)  
-Tension:  $A_{sl,t} = 0.00$   
-Compression:  $A_{sl,c} = 5152.212$   
Longitudinal Reinforcement Area Distribution (in 3 divisions)  
-Tension:  $A_{sl,ten} = 1231.504$   
-Compression:  $A_{sl,com} = 1231.504$   
-Middle:  $A_{sl,mid} = 2689.203$   
Mean Diameter of Tension Reinforcement,  $Db_L = 17.60$

Existing component: From table 7-7, ASCE 41\_17: Final chord rotation Capacity  $u_{,R} = \phi \cdot u = 0.00187569$   
 $u = y + p = 0.0020841$

#### - Calculation of $y$ -

$y = (M_y \cdot L_s / 3) / E_{eff} = 0.0020841$  ((4.29), Biskinis Phd))  
 $M_y = 1.3657E+008$   
 $L_s = M/V$  (with  $L_s > 0.1 \cdot L$  and  $L_s < 2 \cdot L$ ) = 300.00  
From table 10.5, ASCE 41\_17:  $E_{eff} = factor \cdot E_c \cdot I_g = 6.5531E+012$   
factor = 0.30  
 $A_g = 120000.00$   
 $f_c' = 15.00$   
 $N = 4735.965$



$$E_c I_g = 2.1844E+013$$

Calculation of Yielding Moment  $M_y$

Calculation of  $y$  and  $M_y$  according to Annex 7 -

$$\begin{aligned}
 y &= \text{Min}(y_{\text{ten}}, y_{\text{com}}) \\
 y_{\text{ten}} &= 5.8874222E-006 \\
 \text{with } ((10.1), \text{ASCE 41-17}) \quad f_y &= \text{Min}(f_y, 1.25 \cdot f_y \cdot (l_b/d)^{2/3}) = 235.317 \\
 d &= 357.00 \\
 y &= 0.44020389 \\
 A &= 0.07244171 \\
 B &= 0.04070755 \\
 \text{with } p_t &= 0.0075814 \\
 p_c &= 0.01724796 \\
 p_v &= 0.03766391 \\
 N &= 4735.965 \\
 b &= 200.00 \\
 " &= 0.12044818 \\
 y_{\text{comp}} &= 1.0162905E-005 \\
 \text{with } f_c' &= (12.3, (\text{ACI 440})) = 16.12972 \\
 f_c &= 15.00 \\
 f_l &= 0.93147527 \\
 b &= b_{\text{max}} = 400.00 \\
 h &= h_{\text{max}} = 400.00 \\
 A_g &= 120000.00 \\
 g &= p_t + p_c + p_v = 0.07215983 \\
 r_c &= 40.00 \\
 A_e/A_c &= 0.38686758 \\
 \text{Effective FRP thickness, } t_f &= N L \cdot t \cdot \cos(b_1) = 1.016 \\
 \text{effective strain from (12.5) and (12.12), } e_{fe} &= 0.004 \\
 f_u &= 0.01 \\
 E_f &= 64828.00 \\
 E_c &= 18203.022 \\
 y &= 0.43961224 \\
 A &= 0.0719519 \\
 B &= 0.04042568 \\
 \text{with } E_s &= 200000.00
 \end{aligned}$$

Calculation of ratio  $l_b/d$

$$\text{Lap Length: } l_d/d, \text{min} = 0.27567359$$

$$l_b = 300.00$$

$$l_d = 1088.244$$

Calculation of  $I$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$$= 1$$

$$d_b = 18.00$$

$$\text{Mean strength value of all re-bars: } f_y = 444.44$$

$$f_c' = 15.00, \text{ but } f_c'^{0.5} \leq 8.3 \text{ MPa (22.5.3.1, ACI 318-14)}$$

$$t = 1.00$$

$$s = 0.80$$

$$e = 1.00$$

$$c_b = 24.02082$$

$$K_{tr} = 0.82673491$$

$$A_{tr} = \text{Min}(A_{tr_x}, A_{tr_y}) = 157.0796$$

where  $A_{tr_x}$ ,  $A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis

$$s = 380.00$$

$$n = 20.00$$

- Calculation of  $p$  -

From table 10-8:  $p = 0.00$

with:

- Columns controlled by inadequate development or splicing along the clear height because  $l_b/l_d < 1$

shear control ratio  $V_{yE}/V_{ColOE} = 0.55718248$

$d = 357.00$

$s = 0.00$

$t = A_v/(b_w*s) + 2*t_f/b_w*(f_{fe}/f_s) = A_v*L_{stir}/(A_g*s) + 2*t_f/b_w*(f_{fe}/f_s) = 0.0075814$

$A_v = 78.53982$ , is the area of every stirrup

$L_{stir} = 960.00$ , is the total Length of all stirrups parallel to loading (shear) direction

The term  $2*t_f/b_w*(f_{fe}/f_s)$  is implemented to account for FRP contribution

where  $f = 2*t_f/b_w$  is FRP ratio (EC8 - 3, A.4.4.3(6)) and  $f_{fe}/f_s$  normalises  $f$  to steel strength

All these variables have already been given in Shear control ratio calculation.

$NUD = 4735.965$

$A_g = 120000.00$

$f_{cE} = 15.00$

$f_{ytE} = f_{ylE} = 444.44$

$\rho_l = \text{Area\_Tot\_Long\_Rein}/(b*d) = 0.07215983$

$b = 200.00$

$d = 357.00$

$f_{cE} = 15.00$

-----  
End Of Calculation of Chord Rotation Capacity for element: column TC1 of floor 1

At local axis: 3

Integration Section: (b)

-----

## Calculation No. 9

column C1, Floor 1

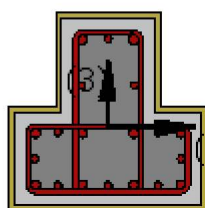
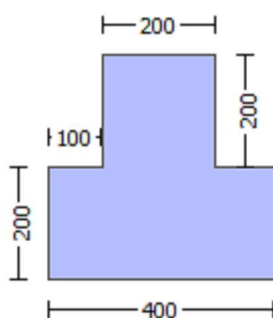
Limit State: Collapse Prevention (data interpolation between analysis steps 2 and 3)

Analysis: Uniform +X

Check: Shear capacity  $V_{Rd}$

Edge: Start

Local Axis: (2)



Start Of Calculation of Shear Capacity for element: column TC1 of floor 1

At local axis: 2  
Integration Section: (a)  
Section Type: rctcs

#### Constant Properties

-----  
Knowledge Factor,  $\gamma = 0.90$   
Member Shear Force is generally considered as Force-Controlled Action according to Table C7-1, ASCE 41-17.  
Lower-bound strengths are used for Force-Controlled Actions according to 7.5.1.3, ASCE 41-17  
Consequently:  
Existing material of Primary Member: Concrete Strength,  $f_c = f_{c\_lower\_bound} = 10.00$   
Existing material of Primary Member: Steel Strength,  $f_s = f_{s\_lower\_bound} = 400.00$   
Concrete Elasticity,  $E_c = 18203.022$   
Steel Elasticity,  $E_s = 200000.00$   
#####  
Note: Especially for the calculation of  $\gamma$  for displacement ductility demand,  
the expected (mean value) strengths are used (7.5.1.3, ASCE 41-17) because bending is considered as  
Deformation-Controlled Action (Table C7-1, ASCE 41-17).  
Existing material: Concrete Strength,  $f_c = f_{cm} = 15.00$   
Existing material: Steel Strength,  $f_s = f_{sm} = 444.44$   
#####  
Max Height,  $H_{max} = 400.00$   
Min Height,  $H_{min} = 200.00$   
Max Width,  $W_{max} = 400.00$   
Min Width,  $W_{min} = 200.00$   
Eccentricity,  $E_{cc} = 100.00$   
Cover Thickness,  $c = 25.00$   
Element Length,  $L = 3000.00$   
Primary Member  
Ribbed Bars  
Ductile Steel  
Without Detailing for Earthquake Resistance (including stirrups not closed at 135°)  
Longitudinal Bars With Ends Lapped Starting at the End Sections  
Lap Length  $l_o = l_b = 300.00$   
FRP Wrapping Data  
Type: Carbon  
Cured laminate properties (design values)  
Thickness,  $t = 1.016$   
Tensile Strength,  $f_{fu} = 1055.00$   
Tensile Modulus,  $E_f = 64828.00$   
Elongation,  $e_{fu} = 0.01$   
Number of directions,  $N_{oDir} = 1$   
Fiber orientations,  $b_i: 0.00^\circ$   
Number of layers,  $N_L = 1$   
Radius of rounding corners,  $R = 40.00$   
-----

#### Stepwise Properties

-----  
EDGE -A-  
Bending Moment,  $M_a = -1.1892E+007$   
Shear Force,  $V_a = -3961.043$   
EDGE -B-  
Bending Moment,  $M_b = 1473.353$   
Shear Force,  $V_b = 3961.043$   
BOTH EDGES  
Axial Force,  $F = -4742.638$   
Longitudinal Reinforcement Area Distribution (in 2 divisions)  
-Tension:  $As_{lt} = 2375.044$   
-Compression:  $As_{lc} = 2777.168$   
Longitudinal Reinforcement Area Distribution (in 3 divisions)  
-Tension:  $As_{l,ten} = 1231.504$   
-Compression:  $As_{l,com} = 1231.504$   
-Middle:  $As_{l,mid} = 2689.203$   
Mean Diameter of Tension Reinforcement,  $Db_{L,ten} = 17.60$   
-----  
-----

Existing component: From table 7-7, ASCE 41\_17: Final Shear Capacity  $V_R = V_n = 144111.676$   
 $V_n$  ((10.3), ASCE 41-17) =  $k_n \cdot V_{CoI0} = 160124.085$   
 $V_{CoI} = 160124.085$   
 $k_n = 1.00$   
 $displacement\_ductility\_demand = 0.02386949$

NOTE: In expression (10-3) ' $V_s$ ' is replaced by ' $V_s + f \cdot V_f$ '  
 where  $V_f$  is the contribution of FRPs (11.3), ACI 440).

$= 1$  (normal-weight concrete)  
 $f'_c = 10.00$ , but  $f'_c^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)  
 $M/Vd = 4.00$   
 $M_u = 1.1892E+007$   
 $V_u = 3961.043$   
 $d = 0.8 \cdot h = 320.00$   
 $N_u = 4742.638$   
 $A_g = 80000.00$   
 From (11.5.4.8), ACI 318-14:  $V_s = V_{s1} + V_{s2} = 0.00$   
 where:  
 $V_{s1} = 0.00$  is calculated for section web, with:  
 $d = 160.00$   
 $A_v = 157079.633$   
 $f_y = 400.00$   
 $s = 380.00$   
 $V_{s1}$  is multiplied by  $Col1 = 0.00$   
 $s/d = 2.375$   
 $V_{s2} = 0.00$  is calculated for section flange, with:  
 $d = 320.00$   
 $A_v = 157079.633$   
 $f_y = 400.00$   
 $s = 380.00$   
 $V_{s2}$  is multiplied by  $Col2 = 0.00$   
 $s/d = 1.1875$   
 $V_f$  ((11-3)-(11.4), ACI 440) =  $188111.148$   
 $f = 0.95$ , for fully-wrapped sections  
 $w_f/s_f = 1$  (FRP strips adjacent to one another).  
 In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot a) \sin a$  which is more a generalised expression,  
 where  $a$  is the angle of the crack direction (see KANEPE).  
 This later relation, considered as a function  $V_f(\theta, a)$ , is implemented for every different fiber orientation  $a_i$ ,  
 as well as for 2 crack directions,  $\theta = 45^\circ$  and  $\theta = -45^\circ$  to take into consideration the cyclic seismic loading.  
 orientation 1:  $\theta = b1 + 90^\circ = 90.00$   
 $V_f = \min(|V_f(45, 1)|, |V_f(-45, a1)|)$ , with:  
 total thickness per orientation,  $t_{f1} = N_L \cdot t / N_{oDir} = 1.016$   
 $d_{fv} = d$  (figure 11.2, ACI 440) =  $357.00$   
 $f_{fe}$  ((11-5), ACI 440) =  $259.312$   
 $E_f = 64828.00$   
 $f_e = 0.004$ , from (11.6a), ACI 440  
 with  $f_u = 0.01$   
 From (11-11), ACI 440:  $V_s + V_f \leq 134445.642$   
 $b_w = 200.00$

$displacement\_ductility\_demand$  is calculated as  $\delta / y$

- Calculation of  $\delta / y$  for END A -  
 for rotation axis 3 and integ. section (a)

From analysis, chord rotation  $\phi = 0.00049783$   
 $y = (M_y \cdot L_s / 3) / E_{eff} = 0.02085615$  ((4.29), Biskinis Phd))  
 $M_y = 1.3657E+008$   
 $L_s = M/V$  (with  $L_s > 0.1 \cdot L$  and  $L_s < 2 \cdot L$ ) =  $3002.161$   
 From table 10.5, ASCE 41\_17:  $E_{eff} = factor \cdot E_c \cdot I_g = 6.5531E+012$   
 $factor = 0.30$   
 $A_g = 120000.00$

$f_c' = 15.00$   
 $N = 4742.638$   
 $E_c \cdot I_g = 2.1844E+013$

#### Calculation of Yielding Moment $M_y$

Calculation of  $y$  and  $M_y$  according to Annex 7 -

$y = \text{Min}(y_{\text{ten}}, y_{\text{com}})$   
 $y_{\text{ten}} = 5.8874430E-006$   
with  $((10.1), \text{ASCE } 41-17)$   $f_y = \text{Min}(f_y, 1.25 \cdot f_y \cdot (l_b/d)^{2/3}) = 235.317$   
 $d = 357.00$   
 $y = 0.44020587$   
 $A = 0.0724421$   
 $B = 0.04070795$   
with  $pt = 0.01724796$   
 $pc = 0.01724796$   
 $pv = 0.03766391$   
 $N = 4742.638$   
 $b = 200.00$   
 $" = 0.12044818$   
 $y_{\text{comp}} = 1.0162879E-005$   
with  $f_c' (12.3, (\text{ACI } 440)) = 16.12972$   
 $f_c = 15.00$   
 $fl = 0.93147527$   
 $b = b_{\text{max}} = 400.00$   
 $h = h_{\text{max}} = 400.00$   
 $Ag = 120000.00$   
 $g = pt + pc + pv = 0.07215983$   
 $rc = 40.00$   
 $A_e/A_c = 0.38686758$   
Effective FRP thickness,  $t_f = NL \cdot t \cdot \cos(b1) = 1.016$   
effective strain from (12.5) and (12.12),  $\epsilon_{fe} = 0.004$   
 $f_u = 0.01$   
 $E_f = 64828.00$   
 $E_c = 18203.022$   
 $y = 0.43961339$   
 $A = 0.0719516$   
 $B = 0.04042568$   
with  $E_s = 200000.00$

#### Calculation of ratio $l_b/d$

Lap Length:  $l_d/d, \text{min} = 0.27567359$

$l_b = 300.00$   
 $l_d = 1088.244$

Calculation of  $I$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$= 1$   
 $db = 18.00$   
Mean strength value of all re-bars:  $f_y = 444.44$   
 $f_c' = 15.00$ , but  $f_c'^{0.5} \leq 8.3 \text{ MPa}$  (22.5.3.1, ACI 318-14)  
 $t = 1.00$   
 $s = 0.80$   
 $e = 1.00$   
 $cb = 24.02082$   
 $K_{tr} = 0.82673491$   
 $A_{tr} = \text{Min}(A_{tr\_x}, A_{tr\_y}) = 157.0796$   
where  $A_{tr\_x}, A_{tr\_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis  
 $s = 380.00$   
 $n = 20.00$

End Of Calculation of Shear Capacity for element: column TC1 of floor 1  
At local axis: 2

## Calculation No. 10

column C1, Floor 1

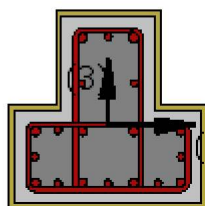
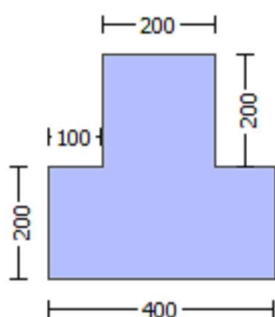
Limit State: Collapse Prevention (data interpolation between analysis steps 2 and 3)

Analysis: Uniform +X

Check: Chord rotation capacity (  $\mu$  )

Edge: Start

Local Axis: (2)



Start Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1

At Shear local axis: 3

(Bending local axis: 2)

Section Type: rctcs

Constant Properties

Knowledge Factor,  $\gamma = 0.90$

Mean strength values are used for both shear and moment calculations.

Consequently:

Existing material of Primary Member: Concrete Strength,  $f_c = f_{cm} = 15.00$

Existing material of Primary Member: Steel Strength,  $f_s = f_{sm} = 444.44$

Concrete Elasticity,  $E_c = 18203.022$

Steel Elasticity,  $E_s = 200000.00$

#####

Note: Especially for the calculation of moment strengths,

the above steel re-bar strengths are multiplied by 1.25 according to R18.6.5, ACI 318-14

Existing material: Steel Strength,  $f_s = 1.25 \cdot f_{sm} = 555.55$

#####

Max Height,  $H_{max} = 400.00$

Min Height,  $H_{min} = 200.00$

Max Width,  $W_{max} = 400.00$

Min Width,  $W_{min} = 200.00$

Eccentricity,  $E_{cc} = 100.00$

Cover Thickness,  $c = 25.00$

Mean Confinement Factor overall section = 1.27578

Element Length,  $L = 3000.00$   
 Primary Member  
 Ribbed Bars  
 Ductile Steel  
 Without Detailing for Earthquake Resistance (including stirrups not closed at  $135^\circ$ )  
 Longitudinal Bars With Ends Lapped Starting at the End Sections  
 Lap Length  $l_o = 300.00$   
 FRP Wrapping Data  
 Type: Carbon  
 Cured laminate properties (design values)  
 Thickness,  $t = 1.016$   
 Tensile Strength,  $f_{fu} = 1055.00$   
 Tensile Modulus,  $E_f = 64828.00$   
 Elongation,  $\epsilon_{fu} = 0.01$   
 Number of directions,  $NoDir = 1$   
 Fiber orientations,  $b_i: 0.00^\circ$   
 Number of layers,  $NL = 1$   
 Radius of rounding corners,  $R = 40.00$

#### Stepwise Properties

At local axis: 3  
 EDGE -A-  
 Shear Force,  $V_a = 0.01054019$   
 EDGE -B-  
 Shear Force,  $V_b = -0.01054019$   
 BOTH EDGES  
 Axial Force,  $F = -4737.328$   
 Longitudinal Reinforcement Area Distribution (in 2 divisions)  
   -Tension:  $As_t = 0.00$   
   -Compression:  $As_c = 5152.212$   
 Longitudinal Reinforcement Area Distribution (in 3 divisions)  
   -Tension:  $As_{t,ten} = 2261.947$   
   -Compression:  $As_{l,com} = 829.3805$   
   -Middle:  $As_{l,mid} = 2060.885$

Calculation of Shear Capacity ratio,  $V_e/V_r = 0.82694402$   
 Member Controlled by Flexure ( $V_e/V_r < 1$ )  
 Calculation of Shear Demand from fig. R18.6.5, ACI 318-14  $V_e = (M_{pr1} + M_{pr2})/l_n = 162085.836$   
 with  
 $M_{pr1} = \text{Max}(\mu_{u1+}, \mu_{u1-}) = 2.4313E+008$   
 $\mu_{u1+} = 2.4313E+008$ , is the ultimate moment strength at the edge 1 of the member in the actual moment direction which is defined for the static loading combination  
 $\mu_{u1-} = 1.2706E+008$ , is the ultimate moment strength at the edge 1 of the member in the opposite moment direction which is defined for the static loading combination  
 $M_{pr2} = \text{Max}(\mu_{u2+}, \mu_{u2-}) = 2.4313E+008$   
 $\mu_{u2+} = 2.4313E+008$ , is the ultimate moment strength at the edge 2 of the member in the actual moment direction which is defined for the the static loading combination  
 $\mu_{u2-} = 1.2706E+008$ , is the ultimate moment strength at the edge 2 of the member in the opposite moment direction which is defined for the the static loading combination

#### Calculation of $\mu_{u1+}$

Calculation of ultimate curvature  $\phi_u$  according to 4.1, Biskinis/Fardis 2013:  
 $\phi_u = 2.6161250E-005$   
 $M_u = 2.4313E+008$

with full section properties:  
 $b = 200.00$   
 $d = 357.00$

$d' = 43.00$   
 $v = 0.00442328$   
 $N = 4737.328$   
 $f_c = 15.00$   
 $\alpha (5A.5, TBDY) = 0.002$   
 Final value of  $\alpha$ :  $\alpha^* = \text{shear\_factor} * \text{Max}(\alpha, \alpha_c) = 0.018$   
 The Shear\_factor is considered equal to 1 (pure moment strength)  
 From (5.4b), TBDY:  $\alpha = 0.018$   
 $\alpha_e (5.4c, TBDY) = \alpha * \text{sh,min} * f_{ywe}/f_{ce} + \text{Min}(f_x, f_y) = 0.15303423$   
 where  $f = \alpha * \rho_f * f_{fe}/f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

---

$f_x = 0.15303423$   
 Expression ((15B.6), TBDY) is modified as  $\alpha_f = 1 - (\text{Unconfined area})/(\text{total area})$   
 $\alpha_f = 0.43111111$   
 with Unconfined area =  $((b_{\text{max}} - 2R)^2 + (h_{\text{max}} - 2R)^2)/3 = 51733.333$   
 $b_{\text{max}} = 400.00$   
 $h_{\text{max}} = 400.00$   
 From EC8 A.4.4.3(6),  $\rho_f = 2t_f/b_w = 0.01016$   
 $b_w = 200.00$   
 effective stress from (A.35),  $f_{fe} = 524.0792$

---

$f_y = 0.15303423$   
 Expression ((15B.6), TBDY) is modified as  $\alpha_f = 1 - (\text{Unconfined area})/(\text{total area})$   
 $\alpha_f = 0.43111111$   
 with Unconfined area =  $((b_{\text{max}} - 2R)^2 + (h_{\text{max}} - 2R)^2)/3 = 0.00$   
 $b_{\text{max}} = 400.00$   
 $h_{\text{max}} = 400.00$   
 From EC8 A.4.4.3(6),  $\rho_f = 2t_f/b_w = 0.01016$   
 $b_w = 200.00$   
 effective stress from (A.35),  $f_{fe} = 524.0792$

---

$R = 40.00$   
 Effective FRP thickness,  $t_f = N L^* t \cos(b_1) = 1.016$   
 $f_{u,f} = 1055.00$   
 $E_f = 64828.00$   
 $u_f = 0.015$   
 $\alpha_{se} = \text{Max}(((A_{\text{conf,max}} - A_{\text{noConf}})/A_{\text{conf,max}}) * (A_{\text{conf,min}}/A_{\text{conf,max}}), 0) = 0.00$   
 The definitions of  $A_{\text{noConf}}$ ,  $A_{\text{conf,min}}$  and  $A_{\text{conf,max}}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).  
 The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988) "Theoretical Stress-Strain Model for Confined Concrete."  
 J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.  
 $A_{\text{conf,max}} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.  
 $A_{\text{conf,min}} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{\text{conf,max}}$  by a length equal to half the clear spacing between hoops.  
 $A_{\text{noConf}} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).  
 $\rho_{sh,min} = \text{Min}(\rho_{sh,x}, \rho_{sh,y}) = 0.00165347$   
 Expression ((5.4d), TBDY) for  $\rho_{sh,min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

---

$\rho_{sh,x} (5.4d, TBDY) = L_{\text{stir}} * A_{\text{stir}} / (A_{\text{sec}} * s) = 0.00165347$   
 $L_{\text{stir}}$  (Length of stirrups along Y) = 960.00  
 $A_{\text{stir}}$  (stirrups area) = 78.53982  
 $A_{\text{sec}}$  (section area) = 120000.00

---

$\rho_{sh,y} (5.4d, TBDY) = L_{\text{stir}} * A_{\text{stir}} / (A_{\text{sec}} * s) = 0.00165347$   
 $L_{\text{stir}}$  (Length of stirrups along X) = 960.00  
 $A_{\text{stir}}$  (stirrups area) = 78.53982  
 $A_{\text{sec}}$  (section area) = 120000.00

---

$s = 380.00$   
 $f_{ywe} = 555.55$   
 $f_{ce} = 15.00$   
 From ((5A.5), TBDY), TBDY:  $\alpha_c = 0.00475778$   
 $\alpha_c$  = confinement factor = 1.27578



```

y1 = 0.0010562
sh1 = 0.00365026
ft1 = 304.185
fy1 = 253.4875
su1 = 0.00365026
    using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
    and also multiplied by the shear_factor according to 15.7.1.4, with
    Shear_factor = 1.00
    lo/lou,min = lb/lb = 0.22053887
    su1 = 0.4*esu1_nominal ((5.5), TBDY) = 0.032
    From table 5A.1, TBDY: esu1_nominal = 0.08,
    For calculation of esu1_nominal and y1, sh1,ft1,fy1, it is considered
    characteristic value fsy1 = fs1/1.2, from table 5.1, TBDY.
    y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/lb)^ 2/3), from 10.3.5, ASCE 41-17.
    with fs1 = fs = 253.4875
    with Es1 = Es = 200000.00
y2 = 0.0010562
sh2 = 0.00365026
ft2 = 304.185
fy2 = 253.4875
su2 = 0.00365026
    using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
    and also multiplied by the shear_factor according to 15.7.1.4, with
    Shear_factor = 1.00
    lo/lou,min = lb/lb,min = 0.22053887
    su2 = 0.4*esu2_nominal ((5.5), TBDY) = 0.032
    From table 5A.1, TBDY: esu2_nominal = 0.08,
    For calculation of esu2_nominal and y2, sh2,ft2,fy2, it is considered
    characteristic value fsy2 = fs2/1.2, from table 5.1, TBDY.
    y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/lb)^ 2/3), from 10.3.5, ASCE 41-17.
    with fs2 = fs = 253.4875
    with Es2 = Es = 200000.00
yv = 0.0010562
shv = 0.00365026
ftv = 304.185
fyv = 253.4875
suv = 0.00365026
    using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
    and also multiplied by the shear_factor according to 15.7.1.4, with
    Shear_factor = 1.00
    lo/lou,min = lb/lb = 0.22053887
    suv = 0.4*esuv_nominal ((5.5), TBDY) = 0.032
    From table 5A.1, TBDY: esuv_nominal = 0.08,
    considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY
    For calculation of esuv_nominal and yv, shv,ftv,fyv, it is considered
    characteristic value fsyv = fsv/1.2, from table 5.1, TBDY.
    y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/lb)^ 2/3), from 10.3.5, ASCE 41-17.
    with fsv = fs = 253.4875
    with Esv = Es = 200000.00
1 = Asl,ten/(b*d)*(fs1/fc) = 0.53536441
2 = Asl,com/(b*d)*(fs2/fc) = 0.19630028
v = Asl,mid/(b*d)*(fsv/fc) = 0.48777647
and confined core properties:
b = 140.00
d = 327.00
d' = 13.00
fcc (5A.2, TBDY) = 19.13667
cc (5A.5, TBDY) = 0.00475778
c = confinement factor = 1.27578
1 = Asl,ten/(b*d)*(fs1/fc) = 0.83497202
2 = Asl,com/(b*d)*(fs2/fc) = 0.30615641
v = Asl,mid/(b*d)*(fsv/fc) = 0.76075229
Case/Assumption: Unconfined full section - Steel rupture
' satisfies Eq. (4.3)
---->
v < vs,y2 - LHS eq.(4.5) is not satisfied
---->

```

$v < v_{s,c}$  - RHS eq.(4.5) is not satisfied

---->

Case/Assumption Rejected.

---->

New Case/Assumption: Unconfined full section - Spalling of concrete cover

' satisfies Eq. (4.4)

---->

$v < s_y1$  - LHS eq.(4.7) is not satisfied

---->

$v < v_{c,y1}$  - RHS eq.(4.6) is satisfied

---->

$\phi_{cu}$  (4.10) = 0.46564051

$M_{Rc}$  (4.17) = 2.0934E+008

---->

New Case/Assumption: Ultimate curvature of confined core after spalling of concrete cover

In expressions below, the following modifications have been made

- $b, d, d'$  replaced by geometric parameters of the core:  $b_o, d_o, d'_o$
- $N_1, N_2, v$  normalised to  $b_o d_o$ , instead of  $b d$
- $f_{cc}, \phi_{cc}$  parameters of confined concrete,  $f_{cc}, \phi_{cc}$  used in lieu of  $f_c, \phi_{cu}$

---->

Subcase: Rupture of tension steel

---->

$v^* < v^*_{s,y2}$  - LHS eq.(4.5) is not satisfied

---->

$v^* < v^*_{s,c}$  - LHS eq.(4.5) is not satisfied

---->

Subcase rejected

---->

New Subcase: Failure of compression zone

---->

$v^* < v^*_{c,y2}$  - LHS eq.(4.6) is not satisfied

---->

$v^* < v^*_{c,y1}$  - RHS eq.(4.6) is satisfied

---->

$\phi^*_{cu}$  (4.10) = 0.55615794

$M_{Ro}$  (4.17) = 2.4313E+008

---->

$u = \phi_{cu}$  (4.2) = 2.6161250E-005

$M_u = M_{Ro}$

-----  
Calculation of ratio  $l_b/l_d$

-----  
Lap Length:  $l_b/l_d = 0.22053887$

$l_b = 300.00$

$l_d = 1360.304$

Calculation of  $l_{b,min}$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$\lambda = 1$

$d_b = 18.00$

Mean strength value of all re-bars:  $f_y = 555.55$

$f'_c = 15.00$ , but  $f_c^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$t = 1.00$

$s = 0.80$

$e = 1.00$

$c_b = 24.02082$

$K_{tr} = 0.82673491$

$A_{tr} = \min(A_{tr_x}, A_{tr_y}) = 157.0796$

where  $A_{tr_x}, A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y local axis

$s = 380.00$

$n = 20.00$

-----  
Calculation of  $M_{u1}$ -  
-----  
-----

Calculation of ultimate curvature  $\phi_u$  according to 4.1, Biskinis/Fardis 2013:

$$u = 1.3353763E-005$$

$$Mu = 1.2706E+008$$

with full section properties:

$$b = 400.00$$

$$d = 357.00$$

$$d' = 43.00$$

$$v = 0.00221164$$

$$N = 4737.328$$

$$f_c = 15.00$$

$$\omega (5A.5, \text{TBDY}) = 0.002$$

$$\text{Final value of } \phi_u^* = \text{shear\_factor} * \text{Max}(\phi_u, \phi_c) = 0.018$$

The Shear\_factor is considered equal to 1 (pure moment strength)

$$\text{From (5.4b), TBDY: } \phi_u = 0.018$$

$$\omega_e ((5.4c), \text{TBDY}) = a_s e * \phi_{u, \min} * f_{ywe} / f_{ce} + \text{Min}(\phi_{ux}, \phi_{uy}) = 0.15303423$$

where  $\phi = a_f * \phi_f * f_{fe} / f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$$\phi_{ux} = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2) / 3 = 51733.333$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } \phi_f = 2t_f / b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$\phi_{uy} = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2) / 3 = 0.00$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } \phi_f = 2t_f / b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$R = 40.00$$

$$\text{Effective FRP thickness, } t_f = N L * t * \cos(b_1) = 1.016$$

$$f_{u,f} = 1055.00$$

$$E_f = 64828.00$$

$$u_{f} = 0.015$$

$$a_s e = \text{Max}(((A_{\text{conf,max}} - A_{\text{noConf}}) / A_{\text{conf,max}}) * (A_{\text{conf,min}} / A_{\text{conf,max}}), 0) = 0.00$$

The definitions of  $A_{\text{noConf}}$ ,  $A_{\text{conf,min}}$  and  $A_{\text{conf,max}}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{\text{conf,max}} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{\text{conf,min}} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{\text{conf,max}}$  by a length equal to half the clear spacing between hoops.

$A_{\text{noConf}} = 33066.667$  is the unconfined core area which is equal to  $b_i^2 / 6$  as defined at (A.2).

$$\phi_{sh, \min} = \text{Min}(\phi_{sh,x}, \phi_{sh,y}) = 0.00165347$$

Expression ((5.4d), TBDY) for  $\phi_{sh, \min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$$\phi_{sh,x} ((5.4d), \text{TBDY}) = L_{\text{stir}} * A_{\text{stir}} / (A_{\text{sec}} * s) = 0.00165347$$

$$L_{\text{stir}} (\text{Length of stirrups along Y}) = 960.00$$

$$A_{\text{stir}} (\text{stirrups area}) = 78.53982$$

$$A_{\text{sec}} (\text{section area}) = 120000.00$$

$$\phi_{sh,y} ((5.4d), \text{TBDY}) = L_{\text{stir}} * A_{\text{stir}} / (A_{\text{sec}} * s) = 0.00165347$$

$$L_{\text{stir}} (\text{Length of stirrups along X}) = 960.00$$

$$A_{\text{stir}} (\text{stirrups area}) = 78.53982$$

Asec (section area) = 120000.00

s = 380.00

fywe = 555.55

fce = 15.00

From ((5.A.5), TBDY), TBDY: cc = 0.00475778

c = confinement factor = 1.27578

y1 = 0.0010562

sh1 = 0.00365026

ft1 = 304.185

fy1 = 253.4875

su1 = 0.00365026

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00

lo/lou,min = lb/lb = 0.22053887

su1 = 0.4\*esu1\_nominal ((5.5), TBDY) = 0.032

From table 5A.1, TBDY: esu1\_nominal = 0.08,

For calculation of esu1\_nominal and y1, sh1,ft1,fy1, it is considered  
characteristic value fsy1 = fs1/1.2, from table 5.1, TBDY.

y1, sh1,ft1,fy1, are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/lb)^{2/3})$ , from 10.3.5, ASCE 41-17.

with fs1 = fs = 253.4875

with Es1 = Es = 200000.00

y2 = 0.0010562

sh2 = 0.00365026

ft2 = 304.185

fy2 = 253.4875

su2 = 0.00365026

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00

lo/lou,min = lb/lb,min = 0.22053887

su2 = 0.4\*esu2\_nominal ((5.5), TBDY) = 0.032

From table 5A.1, TBDY: esu2\_nominal = 0.08,

For calculation of esu2\_nominal and y2, sh2,ft2,fy2, it is considered  
characteristic value fsy2 = fs2/1.2, from table 5.1, TBDY.

y1, sh1,ft1,fy1, are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/lb)^{2/3})$ , from 10.3.5, ASCE 41-17.

with fs2 = fs = 253.4875

with Es2 = Es = 200000.00

yv = 0.0010562

shv = 0.00365026

ftv = 304.185

fyv = 253.4875

suv = 0.00365026

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00

lo/lou,min = lb/lb = 0.22053887

suv = 0.4\*esuv\_nominal ((5.5), TBDY) = 0.032

From table 5A.1, TBDY: esuv\_nominal = 0.08,

considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY

For calculation of esuv\_nominal and yv, shv,ftv,fyv, it is considered  
characteristic value fsyv = fsv/1.2, from table 5.1, TBDY.

y1, sh1,ft1,fy1, are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/lb)^{2/3})$ , from 10.3.5, ASCE 41-17.

with fsv = fs = 253.4875

with Esv = Es = 200000.00

1 = Asl,ten/(b\*d)\*(fs1/fc) = 0.09815014

2 = Asl,com/(b\*d)\*(fs2/fc) = 0.26768221

v = Asl,mid/(b\*d)\*(fsv/fc) = 0.24388823

and confined core properties:

b = 340.00

d = 327.00

d' = 13.00

fcc (5A.2, TBDY) = 19.13667

cc (5A.5, TBDY) = 0.00475778

c = confinement factor = 1.27578

1 = Asl,ten/(b\*d)\*(fs1/fc) = 0.1260644

$$2 = A_{sl,com}/(b*d)*(f_{s2}/f_c) = 0.34381201$$

$$v = A_{sl,mid}/(b*d)*(f_{sv}/f_c) = 0.31325094$$

Case/Assumption: Unconfined full section - Steel rupture

' satisfies Eq. (4.3)

---->

$v < v_{s,y2}$  - LHS eq.(4.5) is satisfied

---->

$$s_u(4.9) = 0.23431248$$

$$M_u = M_{Rc}(4.14) = 1.2706E+008$$

$$u = s_u(4.1) = 1.3353763E-005$$

Calculation of ratio  $l_b/l_d$

Lap Length:  $l_b/l_d = 0.22053887$

$$l_b = 300.00$$

$$l_d = 1360.304$$

Calculation of  $l_b, \min$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$$= 1$$

$$d_b = 18.00$$

Mean strength value of all re-bars:  $f_y = 555.55$

$f'_c = 15.00$ , but  $f_c^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$$t = 1.00$$

$$s = 0.80$$

$$e = 1.00$$

$$c_b = 24.02082$$

$$K_{tr} = 0.82673491$$

$$A_{tr} = \min(A_{tr_x}, A_{tr_y}) = 157.0796$$

where  $A_{tr_x}$ ,  $A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis

$$s = 380.00$$

$$n = 20.00$$

Calculation of  $M_{u2+}$

Calculation of ultimate curvature  $u$  according to 4.1, Biskinis/Fardis 2013:

$$u = 2.6161250E-005$$

$$M_u = 2.4313E+008$$

with full section properties:

$$b = 200.00$$

$$d = 357.00$$

$$d' = 43.00$$

$$v = 0.00442328$$

$$N = 4737.328$$

$$f_c = 15.00$$

$$c_o(5A.5, \text{TB DY}) = 0.002$$

$$\text{Final value of } c_u: c_u^* = \text{shear\_factor} * \max(c_u, c_c) = 0.018$$

The Shear\_factor is considered equal to 1 (pure moment strength)

$$\text{From (5.4b), TB DY: } c_u = 0.018$$

$$w_e((5.4c), \text{TB DY}) = a_{se} * s_{h, \min} * f_{ywe}/f_{ce} + \min(f_x, f_y) = 0.15303423$$

where  $f = a_f * p_f * f_{fe}/f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$$f_x = 0.15303423$$

Expression ((15B.6), TB DY) is modified as  $a_f = 1 - (\text{Unconfined area})/(\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 51733.333$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } p_f = 2t_f/b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$f_y = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $af = 1 - (\text{Unconfined area})/(\text{total area})$

$af = 0.43111111$

with  $\text{Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 0.00$

$b_{\max} = 400.00$

$h_{\max} = 400.00$

From EC8 A.4.4.3(6),  $pf = 2tf/bw = 0.01016$

$bw = 200.00$

effective stress from (A.35),  $ff,e = 524.0792$

$R = 40.00$

Effective FRP thickness,  $tf = NL * t * \cos(b1) = 1.016$

$f_{u,f} = 1055.00$

$E_f = 64828.00$

$u,f = 0.015$

$ase = \text{Max}(((A_{\text{conf,max}} - A_{\text{noConf}})/A_{\text{conf,max}}) * (A_{\text{conf,min}}/A_{\text{conf,max}}), 0) = 0.00$

The definitions of  $A_{\text{noConf}}$ ,  $A_{\text{conf,min}}$  and  $A_{\text{conf,max}}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988) "Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{\text{conf,max}} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{\text{conf,min}} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{\text{conf,max}}$  by a length equal to half the clear spacing between hoops.

$A_{\text{noConf}} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$psh_{\min} = \text{Min}(psh_x, psh_y) = 0.00165347$

Expression ((5.4d), TBDY) for  $psh_{\min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$psh_x \text{ ((5.4d), TBDY)} = L_{\text{stir}} * A_{\text{stir}} / (A_{\text{sec}} * s) = 0.00165347$

$L_{\text{stir}}$  (Length of stirrups along Y) = 960.00

$A_{\text{stir}}$  (stirrups area) = 78.53982

$A_{\text{sec}}$  (section area) = 120000.00

$psh_y \text{ ((5.4d), TBDY)} = L_{\text{stir}} * A_{\text{stir}} / (A_{\text{sec}} * s) = 0.00165347$

$L_{\text{stir}}$  (Length of stirrups along X) = 960.00

$A_{\text{stir}}$  (stirrups area) = 78.53982

$A_{\text{sec}}$  (section area) = 120000.00

$s = 380.00$

$f_{ywe} = 555.55$

$f_{ce} = 15.00$

From ((5.A5), TBDY), TBDY:  $cc = 0.00475778$

$c$  = confinement factor = 1.27578

$y1 = 0.0010562$

$sh1 = 0.00365026$

$ft1 = 304.185$

$fy1 = 253.4875$

$su1 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with  $\text{Shear\_factor} = 1.00$

$l_o/l_{o,\min} = l_b/l_d = 0.22053887$

$su1 = 0.4 * esu1_{\text{nominal}} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu1_{\text{nominal}} = 0.08$ ,

For calculation of  $esu1_{\text{nominal}}$  and  $y1, sh1, ft1, fy1$ , it is considered characteristic value  $fsy1 = fs1/1.2$ , from table 5.1, TBDY.

$y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 * (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.

with  $fs1 = fs = 253.4875$

with  $Es1 = Es = 200000.00$

$y2 = 0.0010562$

$sh2 = 0.00365026$

$ft2 = 304.185$

$fy2 = 253.4875$

$su2 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor

and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $l_o/l_{o,min} = l_b/l_{b,min} = 0.22053887$   
 $su_2 = 0.4 * esu_{2,nominal} ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esu_{2,nominal} = 0.08$ ,  
 For calculation of  $esu_{2,nominal}$  and  $y_2, sh_2, ft_2, fy_2$ , it is considered  
 characteristic value  $fsy_2 = fs_2/1.2$ , from table 5.1, TBDY.  
 $y_1, sh_1, ft_1, fy_1$ , are also multiplied by  $Min(1, 1.25 * (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fs_2 = fs = 253.4875$   
 with  $Es_2 = Es = 200000.00$   
 $y_v = 0.0010562$   
 $sh_v = 0.00365026$   
 $ft_v = 304.185$   
 $fy_v = 253.4875$   
 $suv = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $l_o/l_{o,min} = l_b/l_d = 0.22053887$   
 $suv = 0.4 * esuv_{nominal} ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esuv_{nominal} = 0.08$ ,  
 considering characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY  
 For calculation of  $esuv_{nominal}$  and  $y_v, sh_v, ft_v, fy_v$ , it is considered  
 characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY.  
 $y_1, sh_1, ft_1, fy_1$ , are also multiplied by  $Min(1, 1.25 * (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fsv = fs = 253.4875$   
 with  $Es_v = Es = 200000.00$   
 $1 = A_{sl,ten}/(b*d) * (fs_1/f_c) = 0.53536441$   
 $2 = A_{sl,com}/(b*d) * (fs_2/f_c) = 0.19630028$   
 $v = A_{sl,mid}/(b*d) * (fsv/f_c) = 0.48777647$   
 and confined core properties:  
 $b = 140.00$   
 $d = 327.00$   
 $d' = 13.00$   
 $f_{cc} (5A.2, TBDY) = 19.13667$   
 $cc (5A.5, TBDY) = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $1 = A_{sl,ten}/(b*d) * (fs_1/f_c) = 0.83497202$   
 $2 = A_{sl,com}/(b*d) * (fs_2/f_c) = 0.30615641$   
 $v = A_{sl,mid}/(b*d) * (fsv/f_c) = 0.76075229$   
 Case/Assumption: Unconfined full section - Steel rupture  
 ' satisfies Eq. (4.3)  
 --->  
 $v < v_{s,y2}$  - LHS eq.(4.5) is not satisfied  
 --->  
 $v < v_{s,c}$  - RHS eq.(4.5) is not satisfied  
 --->  
 Case/Assumption Rejected.  
 --->  
 New Case/Assumption: Unconfined full section - Spalling of concrete cover  
 ' satisfies Eq. (4.4)  
 --->  
 $v < s_{y1}$  - LHS eq.(4.7) is not satisfied  
 --->  
 $v < v_{c,y1}$  - RHS eq.(4.6) is satisfied  
 --->  
 $cu (4.10) = 0.46564051$   
 $M_{Rc} (4.17) = 2.0934E+008$   
 --->  
 New Case/Assumption: Ultimate curvature of confined core after spalling of concrete cover  
 In expressions below, the following modifications have been made  
 -  $b, d, d'$  replaced by geometric parameters of the core:  $bo, do, d'o$   
 -  $N, 1, 2, v$  normalised to  $bo*do$ , instead of  $b*d$   
 - parameters of confined concrete,  $f_{cc}, cc$ , used in lieu of  $f_c, ec_u$   
 --->  
 Subcase: Rupture of tension steel  
 --->

$v^* < v^*_{s,y2}$  - LHS eq.(4.5) is not satisfied

--->

$v^* < v^*_{s,c}$  - LHS eq.(4.5) is not satisfied

--->

Subcase rejected

--->

New Subcase: Failure of compression zone

--->

$v^* < v^*_{c,y2}$  - LHS eq.(4.6) is not satisfied

--->

$v^* < v^*_{c,y1}$  - RHS eq.(4.6) is satisfied

--->

$*c_u$  (4.10) = 0.55615794

$M_{Ro}$  (4.17) = 2.4313E+008

--->

$u = c_u$  (4.2) = 2.6161250E-005

$\mu = M_{Ro}$

Calculation of ratio  $l_b/l_d$

Lap Length:  $l_b/l_d = 0.22053887$

$l_b = 300.00$

$l_d = 1360.304$

Calculation of  $l_{b,min}$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

= 1

$d_b = 18.00$

Mean strength value of all re-bars:  $f_y = 555.55$

$f'_c = 15.00$ , but  $f'_c^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$t = 1.00$

$s = 0.80$

$e = 1.00$

$c_b = 24.02082$

$K_{tr} = 0.82673491$

$A_{tr} = \min(A_{tr_x}, A_{tr_y}) = 157.0796$

where  $A_{tr_x}, A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis

$s = 380.00$

$n = 20.00$

Calculation of  $\mu_2$ -

Calculation of ultimate curvature  $\mu$  according to 4.1, Biskinis/Fardis 2013:

$u = 1.3353763E-005$

$\mu = 1.2706E+008$

with full section properties:

$b = 400.00$

$d = 357.00$

$d' = 43.00$

$v = 0.00221164$

$N = 4737.328$

$f_c = 15.00$

$\phi$  (5A.5, TBDY) = 0.002

Final value of  $\phi$ :  $\phi^* = \text{shear\_factor} * \max(\phi_c, \phi_s) = 0.018$

The Shear\_factor is considered equal to 1 (pure moment strength)

From (5.4b), TBDY:  $\phi_c = 0.018$

$\phi_s$  ((5.4c), TBDY) =  $\alpha_s * \phi_{s,min} * f_{ywe}/f_{ce} + \min(\phi_x, \phi_y) = 0.15303423$

where  $\phi = \alpha_f * \phi_f * f_{fe}/f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$\phi_x = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $\alpha_f = 1 - (\text{Unconfined area})/(\text{total area})$

$\alpha_f = 0.43111111$

with Unconfined area =  $((b_{max}-2R)^2 + (h_{max}-2R)^2)/3 = 51733.333$



bmax = 400.00  
hmax = 400.00  
From EC8 A4.4.3(6),  $pf = 2tf/bw = 0.01016$   
bw = 200.00  
effective stress from (A.35),  $ff,e = 524.0792$

fy = 0.15303423  
Expression ((15B.6), TBDY) is modified as  $af = 1 - (\text{Unconfined area})/(\text{total area})$   
af = 0.43111111  
with Unconfined area =  $((bmax-2R)^2 + (hmax-2R)^2)/3 = 0.00$   
bmax = 400.00  
hmax = 400.00  
From EC8 A4.4.3(6),  $pf = 2tf/bw = 0.01016$   
bw = 200.00  
effective stress from (A.35),  $ff,e = 524.0792$

R = 40.00  
Effective FRP thickness,  $tf = NL*t*\text{Cos}(b1) = 1.016$   
fu,f = 1055.00  
Ef = 64828.00  
u,f = 0.015  
 $ase = \text{Max}(((Aconf,max - AnoConf)/Aconf,max) * (Aconf,min/Aconf,max), 0) = 0.00$   
The definitions of AnoConf, Aconf,min and Aconf,max are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).  
The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988) "Theoretical Stress-Strain Model for Confined Concrete."  
J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.  
Aconf,max = 75600.00 is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.  
Aconf,min = 0.00 is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area Aconf,max by a length equal to half the clear spacing between hoops.  
AnoConf = 33066.667 is the unconfined core area which is equal to  $bi^2/6$  as defined at (A.2).  
 $psh,min = \text{Min}(psh,x, psh,y) = 0.00165347$   
Expression ((5.4d), TBDY) for psh,min has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$psh,x \text{ ((5.4d), TBDY)} = Lstir * Astir / (Asec * s) = 0.00165347$   
Lstir (Length of stirrups along Y) = 960.00  
Astir (stirrups area) = 78.53982  
Asec (section area) = 120000.00

$psh,y \text{ ((5.4d), TBDY)} = Lstir * Astir / (Asec * s) = 0.00165347$   
Lstir (Length of stirrups along X) = 960.00  
Astir (stirrups area) = 78.53982  
Asec (section area) = 120000.00

s = 380.00  
fywe = 555.55  
fce = 15.00  
From ((5.A5), TBDY), TBDY:  $cc = 0.00475778$   
c = confinement factor = 1.27578  
y1 = 0.0010562  
sh1 = 0.00365026  
ft1 = 304.185  
fy1 = 253.4875  
su1 = 0.00365026  
using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00  
 $lo/lo,min = lb/ld = 0.22053887$   
 $su1 = 0.4 * esu1\_nominal \text{ ((5.5), TBDY)} = 0.032$   
From table 5A.1, TBDY:  $esu1\_nominal = 0.08$ ,  
For calculation of  $esu1\_nominal$  and y1, sh1, ft1, fy1, it is considered characteristic value  $fsy1 = fs1/1.2$ , from table 5.1, TBDY.  
y1, sh1, ft1, fy1, are also multiplied by  $\text{Min}(1, 1.25 * (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
with  $fs1 = fs = 253.4875$

```

    with Es1 = Es = 200000.00
    y2 = 0.0010562
    sh2 = 0.00365026
    ft2 = 304.185
    fy2 = 253.4875
    su2 = 0.00365026
    using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
    and also multiplied by the shear_factor according to 15.7.1.4, with
    Shear_factor = 1.00
    lo/lou,min = lb/lb,min = 0.22053887
    su2 = 0.4*esu2_nominal ((5.5), TBDY) = 0.032
    From table 5A.1, TBDY: esu2_nominal = 0.08,
    For calculation of esu2_nominal and y2, sh2,ft2,fy2, it is considered
    characteristic value fsy2 = fs2/1.2, from table 5.1, TBDY.
    y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/ld)^ 2/3), from 10.3.5, ASCE 41-17.
    with fs2 = fs = 253.4875
    with Es2 = Es = 200000.00
    yv = 0.0010562
    shv = 0.00365026
    ftv = 304.185
    fyv = 253.4875
    suv = 0.00365026
    using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
    and also multiplied by the shear_factor according to 15.7.1.4, with
    Shear_factor = 1.00
    lo/lou,min = lb/ld = 0.22053887
    suv = 0.4*esuv_nominal ((5.5), TBDY) = 0.032
    From table 5A.1, TBDY: esuv_nominal = 0.08,
    considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY
    For calculation of esuv_nominal and yv, shv,ftv,fyv, it is considered
    characteristic value fsyv = fsv/1.2, from table 5.1, TBDY.
    y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/ld)^ 2/3), from 10.3.5, ASCE 41-17.
    with fsv = fs = 253.4875
    with Esv = Es = 200000.00
    1 = Asl,ten/(b*d)*(fs1/fc) = 0.09815014
    2 = Asl,com/(b*d)*(fs2/fc) = 0.26768221
    v = Asl,mid/(b*d)*(fsv/fc) = 0.24388823
    and confined core properties:
    b = 340.00
    d = 327.00
    d' = 13.00
    fcc (5A.2, TBDY) = 19.13667
    cc (5A.5, TBDY) = 0.00475778
    c = confinement factor = 1.27578
    1 = Asl,ten/(b*d)*(fs1/fc) = 0.1260644
    2 = Asl,com/(b*d)*(fs2/fc) = 0.34381201
    v = Asl,mid/(b*d)*(fsv/fc) = 0.31325094
    Case/Assumption: Unconfined full section - Steel rupture
    ' satisfies Eq. (4.3)
    --->
    v < vs,y2 - LHS eq.(4.5) is satisfied
    --->
    su (4.9) = 0.23431248
    Mu = MRc (4.14) = 1.2706E+008
    u = su (4.1) = 1.3353763E-005

```

#### Calculation of ratio lb/ld

```

Lap Length: lb/ld = 0.22053887
lb = 300.00
ld = 1360.304
Calculation of lb,min according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.
= 1
db = 18.00
Mean strength value of all re-bars: fy = 555.55
fc' = 15.00, but fc^0.5 <= 8.3 MPa (22.5.3.1, ACI 318-14)

```

$t = 1.00$   
 $s = 0.80$   
 $e = 1.00$   
 $cb = 24.02082$   
 $Ktr = 0.82673491$   
 $Atr = \text{Min}(Atr_x, Atr_y) = 157.0796$   
 where  $Atr_x, Atr_y$  are the sum of the area of all stirrup legs along X and Y loxal axis  
 $s = 380.00$   
 $n = 20.00$

Calculation of Shear Strength  $V_r = \text{Min}(V_{r1}, V_{r2}) = 196005.816$

Calculation of Shear Strength at edge 1,  $V_{r1} = 227350.021$

$V_{r1} = V_{Col} ((10.3), \text{ASCE 41-17}) = knl * V_{Col0}$

$V_{Col0} = 227350.021$

$knl = 1$  (zero step-static loading)

NOTE: In expression (10-3) ' $V_s$ ' is replaced by ' $V_s + f * V_f$ '  
 where  $V_f$  is the contribution of FRPs (11.3), ACI 440).

$= 1$  (normal-weight concrete)

$fc' = 15.00$ , but  $fc^{0.5} \leq 8.3 \text{ MPa}$  (22.5.3.1, ACI 318-14)

$M/Vd = 2.00$

$\mu_u = 3.21769$

$V_u = 0.01054019$

$d = 0.8 * h = 320.00$

$N_u = 4737.328$

$A_g = 80000.00$

From (11.5.4.8), ACI 318-14:  $V_s = V_{s1} + V_{s2} = 0.00$

where:

$V_{s1} = 0.00$  is calculated for section web, with:

$d = 320.00$

$A_v = 157079.633$

$f_y = 444.44$

$s = 380.00$

$V_{s1}$  is multiplied by  $Col1 = 0.00$

$s/d = 1.1875$

$V_{s2} = 0.00$  is calculated for section flange, with:

$d = 160.00$

$A_v = 157079.633$

$f_y = 444.44$

$s = 380.00$

$V_{s2}$  is multiplied by  $Col2 = 0.00$

$s/d = 2.375$

$V_f ((11-3)-(11.4), \text{ACI 440}) = 188111.148$

$f = 0.95$ , for fully-wrapped sections

$wf/sf = 1$  (FRP strips adjacent to one another).

In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot a) \sin a$  which is more a generalised expression,  
 where  $a$  is the angle of the crack direction (see KANEPE).

This later relation, considered as a function  $V_f(, )$ , is implemented for every different fiber orientation  $a_i$ ,  
 as well as for 2 crack directions,  $a = 45^\circ$  and  $a = -45^\circ$  to take into consideration the cyclic seismic loading.

orientation 1:  $a_1 = b_1 + 90^\circ = 90.00$

$V_f = \text{Min}(|V_f(45, 1)|, |V_f(-45, a_1)|)$ , with:

total thickness per orientation,  $tf_1 = NL * t / \text{NoDir} = 1.016$

$dfv = d$  (figure 11.2, ACI 440) = 357.00

$ffe ((11-5), \text{ACI 440}) = 259.312$

$E_f = 64828.00$

$f_e = 0.004$ , from (11.6a), ACI 440

with  $f_u = 0.01$

From (11-11), ACI 440:  $V_s + V_f \leq 164661.611$

$bw = 200.00$

Calculation of Shear Strength at edge 2,  $V_{r2} = 196005.816$

$V_{r2} = V_{Col} ((10.3), ASCE 41-17) = k_{nl} * V_{Col0}$   
 $V_{Col0} = 196005.816$   
 $k_{nl} = 1$  (zero step-static loading)

NOTE: In expression (10-3) 'Vs' is replaced by 'Vs+ f\*Vf'  
where Vf is the contribution of FRPs (11.3), ACI 440).

= 1 (normal-weight concrete)  
 $f_c' = 15.00$ , but  $f_c'^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)  
 $M/Vd = 4.00$   
 $\mu_u = 23.99609$   
 $V_u = 0.01054019$   
 $d = 0.8 * h = 320.00$   
 $N_u = 4737.328$   
 $A_g = 80000.00$   
From (11.5.4.8), ACI 318-14:  $V_s = V_{s1} + V_{s2} = 0.00$   
where:  
 $V_{s1} = 0.00$  is calculated for section web, with:  
 $d = 320.00$   
 $A_v = 157079.633$   
 $f_y = 444.44$   
 $s = 380.00$   
 $V_{s1}$  is multiplied by  $Col1 = 0.00$   
 $s/d = 1.1875$   
 $V_{s2} = 0.00$  is calculated for section flange, with:  
 $d = 160.00$   
 $A_v = 157079.633$   
 $f_y = 444.44$   
 $s = 380.00$   
 $V_{s2}$  is multiplied by  $Col2 = 0.00$   
 $s/d = 2.375$   
 $V_f ((11-3)-(11.4), ACI 440) = 188111.148$   
 $f = 0.95$ , for fully-wrapped sections  
 $w_f/s_f = 1$  (FRP strips adjacent to one another).  
In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot a) \sin a$  which is more a generalised expression,  
where  $a$  is the angle of the crack direction (see KANEPE).  
This later relation, considered as a function  $V_f( , )$ , is implemented for every different fiber orientation  $a_i$ ,  
as well as for 2 crack directions,  $a = 45^\circ$  and  $a = -45^\circ$  to take into consideration the cyclic seismic loading.  
orientation 1:  $a = b1 + 90^\circ = 90.00$   
 $V_f = \text{Min}(|V_f(45, 1)|, |V_f(-45, a1)|)$ , with:  
total thickness per orientation,  $t_{f1} = N_L * t / N_{oDir} = 1.016$   
 $d_{fv} = d$  (figure 11.2, ACI 440) = 357.00  
 $f_{fe} ((11-5), ACI 440) = 259.312$   
 $E_f = 64828.00$   
 $f_e = 0.004$ , from (11.6a), ACI 440  
with  $f_u = 0.01$   
From (11-11), ACI 440:  $V_s + V_f \leq 164661.611$   
 $b_w = 200.00$

End Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1  
At local axis: 3

Start Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1  
At Shear local axis: 2  
(Bending local axis: 3)  
Section Type: rctcs

Constant Properties

Knowledge Factor,  $\gamma = 0.90$   
Mean strength values are used for both shear and moment calculations.  
Consequently:  
Existing material of Primary Member: Concrete Strength,  $f_c = f_{cm} = 15.00$

Existing material of Primary Member: Steel Strength,  $f_s = f_{sm} = 444.44$   
Concrete Elasticity,  $E_c = 18203.022$   
Steel Elasticity,  $E_s = 200000.00$   
#####  
Note: Especially for the calculation of moment strengths,  
the above steel re-bar strengths are multiplied by 1.25 according to R18.6.5, ACI 318-14  
Existing material: Steel Strength,  $f_s = 1.25 \cdot f_{sm} = 555.55$   
#####  
Max Height,  $H_{max} = 400.00$   
Min Height,  $H_{min} = 200.00$   
Max Width,  $W_{max} = 400.00$   
Min Width,  $W_{min} = 200.00$   
Eccentricity,  $Ecc = 100.00$   
Cover Thickness,  $c = 25.00$   
Mean Confinement Factor overall section = 1.27578  
Element Length,  $L = 3000.00$   
Primary Member  
Ribbed Bars  
Ductile Steel  
Without Detailing for Earthquake Resistance (including stirrups not closed at 135°)  
Longitudinal Bars With Ends Lapped Starting at the End Sections  
Lap Length  $l_o = 300.00$   
FRP Wrapping Data  
Type: Carbon  
Cured laminate properties (design values)  
Thickness,  $t = 1.016$   
Tensile Strength,  $f_{fu} = 1055.00$   
Tensile Modulus,  $E_f = 64828.00$   
Elongation,  $\epsilon_{fu} = 0.01$   
Number of directions,  $N_{oDir} = 1$   
Fiber orientations,  $b_i: 0.00^\circ$   
Number of layers,  $N_L = 1$   
Radius of rounding corners,  $R = 40.00$

#### Stepwise Properties

At local axis: 2  
EDGE -A-  
Shear Force,  $V_a = 1.5456333E-009$   
EDGE -B-  
Shear Force,  $V_b = -1.5456333E-009$   
BOTH EDGES  
Axial Force,  $F = -4737.328$   
Longitudinal Reinforcement Area Distribution (in 2 divisions)  
-Tension:  $A_{sl,t} = 0.00$   
-Compression:  $A_{sl,c} = 5152.212$   
Longitudinal Reinforcement Area Distribution (in 3 divisions)  
-Tension:  $A_{sl,ten} = 1231.504$   
-Compression:  $A_{sl,com} = 1231.504$   
-Middle:  $A_{sl,mid} = 2689.203$

Calculation of Shear Capacity ratio,  $V_e/V_r = 0.55718248$   
Member Controlled by Flexure ( $V_e/V_r < 1$ )  
Calculation of Shear Demand from fig. R18.6.5, ACI 318-14  $V_e = (M_{pr1} + M_{pr2})/l_n = 126675.449$   
with  
 $M_{pr1} = \max(\mu_{u1+}, \mu_{u1-}) = 1.9001E+008$   
 $\mu_{u1+} = 1.9001E+008$ , is the ultimate moment strength at the edge 1 of the member in the actual moment direction  
which is defined for the static loading combination  
 $\mu_{u1-} = 1.9001E+008$ , is the ultimate moment strength at the edge 1 of the member in the opposite moment  
direction which is defined for the static loading combination  
 $M_{pr2} = \max(\mu_{u2+}, \mu_{u2-}) = 1.9001E+008$   
 $\mu_{u2+} = 1.9001E+008$ , is the ultimate moment strength at the edge 2 of the member in the actual moment direction  
which is defined for the static loading combination

Mu2- = 1.9001E+008, is the ultimate moment strength at the edge 2 of the member in the opposite moment direction which is defined for the static loading combination

#### Calculation of Mu1+

Calculation of ultimate curvature  $\phi_u$  according to 4.1, Biskinis/Fardis 2013:

$$\phi_u = 1.7086748E-005$$

$$M_u = 1.9001E+008$$

with full section properties:

$$b = 200.00$$

$$d = 357.00$$

$$d' = 43.00$$

$$v = 0.00442328$$

$$N = 4737.328$$

$$f_c = 15.00$$

$$\phi_{co} \text{ (5A.5, TBDY)} = 0.002$$

$$\text{Final value of } \phi_{cu}: \phi_{cu}^* = \text{shear\_factor} * \text{Max}(\phi_{cu}, \phi_{co}) = 0.018$$

The Shear\_factor is considered equal to 1 (pure moment strength)

$$\text{From (5.4b), TBDY: } \phi_{cu} = 0.018$$

$$\phi_{we} \text{ ((5.4c), TBDY)} = a_{se} * \phi_{sh,min} * f_{ywe} / f_{ce} + \text{Min}(\phi_{fx}, \phi_{fy}) = 0.15303423$$

where  $\phi_{fx} = a_f * \phi_{pf} * f_{fe} / f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$$\phi_{fx} = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{max} - 2R)^2 + (h_{max} - 2R)^2) / 3 = 51733.333$$

$$b_{max} = 400.00$$

$$h_{max} = 400.00$$

$$\text{From EC8 A4.4.3(6), } \phi_{pf} = 2t_f / b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$\phi_{fy} = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{max} - 2R)^2 + (h_{max} - 2R)^2) / 3 = 0.00$$

$$b_{max} = 400.00$$

$$h_{max} = 400.00$$

$$\text{From EC8 A4.4.3(6), } \phi_{pf} = 2t_f / b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$R = 40.00$$

$$\text{Effective FRP thickness, } t_f = N L^* t \cos(b_1) = 1.016$$

$$f_{u,f} = 1055.00$$

$$E_f = 64828.00$$

$$\phi_{u,f} = 0.015$$

$$a_{se} = \text{Max}(((A_{conf,max} - A_{noConf}) / A_{conf,max}) * (A_{conf,min} / A_{conf,max}), 0) = 0.00$$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2 / 6$  as defined at (A.2).

$$\phi_{sh,min} = \text{Min}(\phi_{sh,x}, \phi_{sh,y}) = 0.00165347$$

Expression ((5.4d), TBDY) for  $\phi_{sh,min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$$psh,x ((5.4d), TBDY) = Lstir * Astir / (Asec * s) = 0.00165347$$

$$Lstir \text{ (Length of stirrups along Y)} = 960.00$$

$$Astir \text{ (stirrups area)} = 78.53982$$

$$Asec \text{ (section area)} = 120000.00$$

$$psh,y ((5.4d), TBDY) = Lstir * Astir / (Asec * s) = 0.00165347$$

$$Lstir \text{ (Length of stirrups along X)} = 960.00$$

$$Astir \text{ (stirrups area)} = 78.53982$$

$$Asec \text{ (section area)} = 120000.00$$

$$s = 380.00$$

$$fywe = 555.55$$

$$fce = 15.00$$

$$\text{From } ((5.A5), TBDY), TBDY: cc = 0.00475778$$

$$c = \text{confinement factor} = 1.27578$$

$$y1 = 0.0010562$$

$$sh1 = 0.00365026$$

$$ft1 = 304.185$$

$$fy1 = 253.4875$$

$$su1 = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00

$$lo/lou,min = lb/ld = 0.22053887$$

$$su1 = 0.4 * esu1\_nominal ((5.5), TBDY) = 0.032$$

$$\text{From table 5A.1, TBDY: } esu1\_nominal = 0.08,$$

For calculation of esu1\_nominal and y1, sh1,ft1,fy1, it is considered  
characteristic value fsy1 = fs1/1.2, from table 5.1, TBDY.

$$y1, sh1,ft1,fy1, \text{ are also multiplied by } \text{Min}(1, 1.25 * (lb/ld)^{2/3}), \text{ from 10.3.5, ASCE 41-17.}$$

$$\text{with } fs1 = fs = 253.4875$$

$$\text{with } Es1 = Es = 200000.00$$

$$y2 = 0.0010562$$

$$sh2 = 0.00365026$$

$$ft2 = 304.185$$

$$fy2 = 253.4875$$

$$su2 = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00

$$lo/lou,min = lb/lb,min = 0.22053887$$

$$su2 = 0.4 * esu2\_nominal ((5.5), TBDY) = 0.032$$

$$\text{From table 5A.1, TBDY: } esu2\_nominal = 0.08,$$

For calculation of esu2\_nominal and y2, sh2,ft2,fy2, it is considered  
characteristic value fsy2 = fs2/1.2, from table 5.1, TBDY.

$$y1, sh1,ft1,fy1, \text{ are also multiplied by } \text{Min}(1, 1.25 * (lb/ld)^{2/3}), \text{ from 10.3.5, ASCE 41-17.}$$

$$\text{with } fs2 = fs = 253.4875$$

$$\text{with } Es2 = Es = 200000.00$$

$$yv = 0.0010562$$

$$shv = 0.00365026$$

$$ftv = 304.185$$

$$fyv = 253.4875$$

$$suv = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00

$$lo/lou,min = lb/ld = 0.22053887$$

$$suv = 0.4 * esuv\_nominal ((5.5), TBDY) = 0.032$$

$$\text{From table 5A.1, TBDY: } esuv\_nominal = 0.08,$$

considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY

For calculation of esuv\_nominal and yv, shv,ftv,fyv, it is considered  
characteristic value fsyv = fsv/1.2, from table 5.1, TBDY.

$$y1, sh1,ft1,fy1, \text{ are also multiplied by } \text{Min}(1, 1.25 * (lb/ld)^{2/3}), \text{ from 10.3.5, ASCE 41-17.}$$

$$\text{with } fsv = fs = 253.4875$$

$$\text{with } Esv = Es = 200000.00$$

$$1 = Asl,ten / (b * d) * (fs1 / fc) = 0.29147618$$

$$2 = Asl,com / (b * d) * (fs2 / fc) = 0.29147618$$

$$v = Asl,mid / (b * d) * (fsv / fc) = 0.6364888$$

and confined core properties:

$$b = 140.00$$

$$d = 327.00$$

$$d' = 13.00$$

$$fcc(5A.2, TBDY) = 19.13667$$

$$cc(5A.5, TBDY) = 0.00475778$$

$$c = \text{confinement factor} = 1.27578$$

$$1 = A_{sl,ten}/(b*d)*(f_{s1}/f_c) = 0.45459588$$

$$2 = A_{sl,com}/(b*d)*(f_{s2}/f_c) = 0.45459588$$

$$v = A_{sl,mid}/(b*d)*(f_{sv}/f_c) = 0.99268896$$

Case/Assumption: Unconfined full section - Steel rupture

' satisfies Eq. (4.3)

--->

$v < v_{s,y2}$  - LHS eq.(4.5) is not satisfied

--->

$v < v_{s,c}$  - RHS eq.(4.5) is satisfied

--->

$$su(4.8) = 0.40159417$$

$$Mu = MR_c(4.15) = 1.9001E+008$$

$$u = su(4.1) = 1.7086748E-005$$

Calculation of ratio  $l_b/d$

Lap Length:  $l_b/d = 0.22053887$

$$l_b = 300.00$$

$$l_d = 1360.304$$

Calculation of  $l_b, \min$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$$= 1$$

$$d_b = 18.00$$

Mean strength value of all re-bars:  $f_y = 555.55$

$$f_c' = 15.00, \text{ but } f_c'^{0.5} \leq 8.3 \text{ MPa (22.5.3.1, ACI 318-14)}$$

$$t = 1.00$$

$$s = 0.80$$

$$e = 1.00$$

$$c_b = 24.02082$$

$$K_{tr} = 0.82673491$$

$$A_{tr} = \min(A_{tr,x}, A_{tr,y}) = 157.0796$$

where  $A_{tr,x}$ ,  $A_{tr,y}$  are the sum of the area of all stirrup legs along X and Y loxal axis

$$s = 380.00$$

$$n = 20.00$$

Calculation of  $Mu_1$ -

Calculation of ultimate curvature  $u$  according to 4.1, Biskinis/Fardis 2013:

$$u = 1.7086748E-005$$

$$Mu = 1.9001E+008$$

with full section properties:

$$b = 200.00$$

$$d = 357.00$$

$$d' = 43.00$$

$$v = 0.00442328$$

$$N = 4737.328$$

$$f_c = 15.00$$

$$co(5A.5, TBDY) = 0.002$$

$$\text{Final value of } cu: cu^* = \text{shear\_factor} * \max(cu, cc) = 0.018$$

The Shear\_factor is considered equal to 1 (pure moment strength)

$$\text{From (5.4b), TBDY: } cu = 0.018$$

$$we((5.4c), TBDY) = ase * sh_{min} * f_{ywe}/f_{ce} + \min(f_x, f_y) = 0.15303423$$

where  $f = af * pf * f_{fe}/f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$$f_x = 0.15303423$$



Expression ((15B.6), TBDY) is modified as  $af = 1 - (\text{Unconfined area})/(\text{total area})$

$af = 0.43111111$

with Unconfined area =  $((b_{max}-2R)^2 + (h_{max}-2R)^2)/3 = 51733.333$

$b_{max} = 400.00$

$h_{max} = 400.00$

From EC8 A.4.4.3(6),  $pf = 2tf/bw = 0.01016$

$bw = 200.00$

effective stress from (A.35),  $ff,e = 524.0792$

$fy = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $af = 1 - (\text{Unconfined area})/(\text{total area})$

$af = 0.43111111$

with Unconfined area =  $((b_{max}-2R)^2 + (h_{max}-2R)^2)/3 = 0.00$

$b_{max} = 400.00$

$h_{max} = 400.00$

From EC8 A.4.4.3(6),  $pf = 2tf/bw = 0.01016$

$bw = 200.00$

effective stress from (A.35),  $ff,e = 524.0792$

$R = 40.00$

Effective FRP thickness,  $tf = NL \cdot t \cdot \cos(b1) = 1.016$

$fu,f = 1055.00$

$Ef = 64828.00$

$u,f = 0.015$

$ase = \text{Max}(((A_{conf,max} - A_{noConf})/A_{conf,max}) \cdot (A_{conf,min}/A_{conf,max}), 0) = 0.00$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$psh,min = \text{Min}(psh,x, psh,y) = 0.00165347$

Expression ((5.4d), TBDY) for  $psh,min$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$psh,x$  ((5.4d), TBDY) =  $L_{stir} \cdot A_{stir} / (A_{sec} \cdot s) = 0.00165347$

$L_{stir}$  (Length of stirrups along Y) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$psh,y$  ((5.4d), TBDY) =  $L_{stir} \cdot A_{stir} / (A_{sec} \cdot s) = 0.00165347$

$L_{stir}$  (Length of stirrups along X) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$s = 380.00$

$fywe = 555.55$

$fce = 15.00$

From ((5.A5), TBDY), TBDY:  $cc = 0.00475778$

$c$  = confinement factor = 1.27578

$y1 = 0.0010562$

$sh1 = 0.00365026$

$ft1 = 304.185$

$fy1 = 253.4875$

$su1 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$lo/lo_{u,min} = lb/ld = 0.22053887$

$su1 = 0.4 \cdot esu1_{nominal}$  ((5.5), TBDY) = 0.032

From table 5A.1, TBDY:  $esu1_{nominal} = 0.08$ ,

For calculation of  $esu1_{nominal}$  and  $y1, sh1, ft1, fy1$ , it is considered

characteristic value  $f_{sy1} = f_{s1}/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
with  $f_{s1} = f_s = 253.4875$   
with  $E_{s1} = E_s = 200000.00$   
 $y2 = 0.0010562$   
 $sh2 = 0.00365026$   
 $ft2 = 304.185$   
 $fy2 = 253.4875$   
 $su2 = 0.00365026$   
using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00  
 $l_o/l_{o,min} = l_b/l_{b,min} = 0.22053887$   
 $su2 = 0.4 \cdot esu2\_nominal \cdot ((5.5), TBDY) = 0.032$   
From table 5A.1, TBDY:  $esu2\_nominal = 0.08$ ,  
For calculation of  $esu2\_nominal$  and  $y2, sh2, ft2, fy2$ , it is considered  
characteristic value  $f_{sy2} = f_{s2}/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
with  $f_{s2} = f_s = 253.4875$   
with  $E_{s2} = E_s = 200000.00$   
 $yv = 0.0010562$   
 $shv = 0.00365026$   
 $ftv = 304.185$   
 $fyv = 253.4875$   
 $suv = 0.00365026$   
using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00  
 $l_o/l_{o,min} = l_b/l_d = 0.22053887$   
 $suv = 0.4 \cdot esuv\_nominal \cdot ((5.5), TBDY) = 0.032$   
From table 5A.1, TBDY:  $esuv\_nominal = 0.08$ ,  
considering characteristic value  $f_{syv} = f_{sv}/1.2$ , from table 5.1, TBDY  
For calculation of  $esuv\_nominal$  and  $yv, shv, ftv, fyv$ , it is considered  
characteristic value  $f_{syv} = f_{sv}/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
with  $f_{sv} = f_s = 253.4875$   
with  $E_{sv} = E_s = 200000.00$   
 $1 = A_{sl,ten}/(b \cdot d) \cdot (f_{s1}/f_c) = 0.29147618$   
 $2 = A_{sl,com}/(b \cdot d) \cdot (f_{s2}/f_c) = 0.29147618$   
 $v = A_{sl,mid}/(b \cdot d) \cdot (f_{sv}/f_c) = 0.6364888$

and confined core properties:

$b = 140.00$   
 $d = 327.00$   
 $d' = 13.00$   
 $f_{cc} (5A.2, TBDY) = 19.13667$   
 $cc (5A.5, TBDY) = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $1 = A_{sl,ten}/(b \cdot d) \cdot (f_{s1}/f_c) = 0.45459588$   
 $2 = A_{sl,com}/(b \cdot d) \cdot (f_{s2}/f_c) = 0.45459588$   
 $v = A_{sl,mid}/(b \cdot d) \cdot (f_{sv}/f_c) = 0.99268896$

Case/Assumption: Unconfined full section - Steel rupture  
'satisfies Eq. (4.3)

--->  
 $v < v_{s,y2}$  - LHS eq.(4.5) is not satisfied

--->  
 $v < v_{s,c}$  - RHS eq.(4.5) is satisfied

--->  
 $su (4.8) = 0.40159417$   
 $Mu = MRc (4.15) = 1.9001E+008$   
 $u = su (4.1) = 1.7086748E-005$

-----  
Calculation of ratio  $l_b/l_d$

-----  
Lap Length:  $l_b/l_d = 0.22053887$   
 $l_b = 300.00$   
 $l_d = 1360.304$

Calculation of  $I_{b,min}$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$$= 1$$

$$d_b = 18.00$$

Mean strength value of all re-bars:  $f_y = 555.55$

$$f'_c = 15.00, \text{ but } f_c^{0.5} \leq 8.3 \text{ MPa (22.5.3.1, ACI 318-14)}$$

$$t = 1.00$$

$$s = 0.80$$

$$e = 1.00$$

$$c_b = 24.02082$$

$$K_{tr} = 0.82673491$$

$$A_{tr} = \text{Min}(A_{tr_x}, A_{tr_y}) = 157.0796$$

where  $A_{tr_x}$ ,  $A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis

$$s = 380.00$$

$$n = 20.00$$

Calculation of  $\mu_{2+}$

Calculation of ultimate curvature  $\mu$  according to 4.1, Biskinis/Fardis 2013:

$$\mu = 1.7086748E-005$$

$$\mu = 1.9001E+008$$

with full section properties:

$$b = 200.00$$

$$d = 357.00$$

$$d' = 43.00$$

$$v = 0.00442328$$

$$N = 4737.328$$

$$f'_c = 15.00$$

$$\alpha (5A.5, \text{ TBDY}) = 0.002$$

$$\text{Final value of } \mu: \mu^* = \text{shear\_factor} * \text{Max}(\mu, \mu_c) = 0.018$$

The Shear\_factor is considered equal to 1 (pure moment strength)

$$\text{From (5.4b), TBDY: } \mu = 0.018$$

$$\mu_e ((5.4c), \text{ TBDY}) = \alpha s_e * \text{sh}_{min} * f_{ywe} / f_{ce} + \text{Min}(\mu_x, \mu_y) = 0.15303423$$

where  $\mu = \alpha s_e * p_f * f_{fe} / f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$$\mu_x = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $\alpha_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$$\alpha_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{max} - 2R)^2 + (h_{max} - 2R)^2) / 3 = 51733.333$$

$$b_{max} = 400.00$$

$$h_{max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } p_f = 2t_f / b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$f_y = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $\alpha_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$$\alpha_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{max} - 2R)^2 + (h_{max} - 2R)^2) / 3 = 0.00$$

$$b_{max} = 400.00$$

$$h_{max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } p_f = 2t_f / b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$R = 40.00$$

$$\text{Effective FRP thickness, } t_f = N L * t * \text{Cos}(b_1) = 1.016$$

$$f_{u,f} = 1055.00$$

$$E_f = 64828.00$$

$$\mu_{u,f} = 0.015$$

$$\alpha_s = \text{Max}(((A_{conf,max} - A_{noConf}) / A_{conf,max}) * (A_{conf,min} / A_{conf,max}), 0) = 0.00$$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)  
"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and  
is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and  
is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length  
equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$psh,min = \text{Min}(psh,x, psh,y) = 0.00165347$

Expression ((5.4d), TBDY) for  $psh,min$  has been multiplied by 0.3 according to 15.7.1.3 for members without  
earthquake detailing (90° closed stirrups)

$psh,x \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$

$L_{stir}$  (Length of stirrups along Y) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$psh,y \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$

$L_{stir}$  (Length of stirrups along X) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$s = 380.00$

$f_{ywe} = 555.55$

$f_{ce} = 15.00$

From ((5.A5), TBDY), TBDY:  $cc = 0.00475778$

$c = \text{confinement factor} = 1.27578$

$y1 = 0.0010562$

$sh1 = 0.00365026$

$ft1 = 304.185$

$fy1 = 253.4875$

$su1 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00

$lo/lou,min = lb/ld = 0.22053887$

$su1 = 0.4 * esu1_{nominal} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu1_{nominal} = 0.08$ ,

For calculation of  $esu1_{nominal}$  and  $y1, sh1, ft1, fy1$ , it is considered  
characteristic value  $fsy1 = fs1/1.2$ , from table 5.1, TBDY.

$y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 * (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.

with  $fs1 = fs = 253.4875$

with  $Es1 = Es = 200000.00$

$y2 = 0.0010562$

$sh2 = 0.00365026$

$ft2 = 304.185$

$fy2 = 253.4875$

$su2 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00

$lo/lou,min = lb/lb,min = 0.22053887$

$su2 = 0.4 * esu2_{nominal} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu2_{nominal} = 0.08$ ,

For calculation of  $esu2_{nominal}$  and  $y2, sh2, ft2, fy2$ , it is considered  
characteristic value  $fsy2 = fs2/1.2$ , from table 5.1, TBDY.

$y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 * (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.

with  $fs2 = fs = 253.4875$

with  $Es2 = Es = 200000.00$

$yv = 0.0010562$

$shv = 0.00365026$

$ftv = 304.185$

$fyv = 253.4875$

$suv = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with

Shear\_factor = 1.00  
 $l_o/l_{ou,min} = l_b/l_d = 0.22053887$   
 $suv = 0.4 * esuv_{nominal} ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esuv_{nominal} = 0.08$ ,  
 considering characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY  
 For calculation of  $esuv_{nominal}$  and  $y_v$ ,  $shv,ftv,fyv$ , it is considered  
 characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY.  
 $y_1, sh_1, ft_1, fy_1$ , are also multiplied by  $Min(1, 1.25 * (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fsv = fs = 253.4875$   
 with  $Esv = Es = 200000.00$   
 $1 = A_{sl,ten}/(b*d) * (fs_1/fc) = 0.29147618$   
 $2 = A_{sl,com}/(b*d) * (fs_2/fc) = 0.29147618$   
 $v = A_{sl,mid}/(b*d) * (fsv/fc) = 0.6364888$

and confined core properties:

$b = 140.00$   
 $d = 327.00$   
 $d' = 13.00$   
 $f_{cc} (5A.2, TBDY) = 19.13667$   
 $cc (5A.5, TBDY) = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $1 = A_{sl,ten}/(b*d) * (fs_1/fc) = 0.45459588$   
 $2 = A_{sl,com}/(b*d) * (fs_2/fc) = 0.45459588$   
 $v = A_{sl,mid}/(b*d) * (fsv/fc) = 0.99268896$

Case/Assumption: Unconfined full section - Steel rupture  
 ' satisfies Eq. (4.3)

---->  
 $v < v_{s,y2}$  - LHS eq.(4.5) is not satisfied  
 ---->  
 $v < v_{s,c}$  - RHS eq.(4.5) is satisfied  
 ---->  
 $su (4.8) = 0.40159417$   
 $Mu = MRc (4.15) = 1.9001E+008$   
 $u = su (4.1) = 1.7086748E-005$

Calculation of ratio  $l_b/l_d$

Lap Length:  $l_b/l_d = 0.22053887$   
 $l_b = 300.00$   
 $l_d = 1360.304$   
 Calculation of  $l_b,min$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.  
 $= 1$   
 $db = 18.00$   
 Mean strength value of all re-bars:  $f_y = 555.55$   
 $fc' = 15.00$ , but  $fc'^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)  
 $t = 1.00$   
 $s = 0.80$   
 $e = 1.00$   
 $cb = 24.02082$   
 $K_{tr} = 0.82673491$   
 $A_{tr} = Min(A_{tr_x}, A_{tr_y}) = 157.0796$   
 where  $A_{tr_x}, A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis  
 $s = 380.00$   
 $n = 20.00$

Calculation of  $Mu_2$ -

Calculation of ultimate curvature  $u$  according to 4.1, Biskinis/Fardis 2013:  
 $u = 1.7086748E-005$   
 $Mu = 1.9001E+008$

with full section properties:  
 $b = 200.00$

$$d = 357.00$$

$$d' = 43.00$$

$$v = 0.00442328$$

$$N = 4737.328$$

$$f_c = 15.00$$

$$c_o(5A.5, TBDY) = 0.002$$

$$\text{Final value of } c_u: c_u^* = \text{shear\_factor} * \text{Max}(c_u, c_c) = 0.018$$

The Shear\_factor is considered equal to 1 (pure moment strength)

$$\text{From (5.4b), TBDY: } c_u = 0.018$$

$$w_e(5.4c, TBDY) = a_s e^* s_{h,min} * f_{ywe} / f_{ce} + \text{Min}(f_x, f_y) = 0.15303423$$

where  $f = a_f * p_f * f_{fe} / f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$$f_x = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{max} - 2R)^2 + (h_{max} - 2R)^2) / 3 = 51733.333$$

$$b_{max} = 400.00$$

$$h_{max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } p_f = 2t_f / b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$f_y = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{max} - 2R)^2 + (h_{max} - 2R)^2) / 3 = 0.00$$

$$b_{max} = 400.00$$

$$h_{max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } p_f = 2t_f / b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$R = 40.00$$

$$\text{Effective FRP thickness, } t_f = N L * t * \cos(b_1) = 1.016$$

$$f_{u,f} = 1055.00$$

$$E_f = 64828.00$$

$$u_{f,f} = 0.015$$

$$a_s e = \text{Max}(((A_{conf,max} - A_{noConf}) / A_{conf,max}) * (A_{conf,min} / A_{conf,max}), 0) = 0.00$$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2 / 6$  as defined at (A.2).

$$p_{sh,min} = \text{Min}(p_{sh,x}, p_{sh,y}) = 0.00165347$$

Expression ((5.4d), TBDY) for  $p_{sh,min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$$p_{sh,x}((5.4d), TBDY) = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$$

$$L_{stir} (\text{Length of stirrups along } Y) = 960.00$$

$$A_{stir} (\text{stirrups area}) = 78.53982$$

$$A_{sec} (\text{section area}) = 120000.00$$

$$p_{sh,y}((5.4d), TBDY) = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$$

$$L_{stir} (\text{Length of stirrups along } X) = 960.00$$

$$A_{stir} (\text{stirrups area}) = 78.53982$$

$$A_{sec} (\text{section area}) = 120000.00$$

$$s = 380.00$$

$$f_{ywe} = 555.55$$

$$f_{ce} = 15.00$$

$$\text{From ((5A5), TBDY), TBDY: } c_c = 0.00475778$$

```

c = confinement factor = 1.27578
y1 = 0.0010562
sh1 = 0.00365026
ft1 = 304.185
fy1 = 253.4875
su1 = 0.00365026
using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
and also multiplied by the shear_factor according to 15.7.1.4, with
Shear_factor = 1.00
lo/lou,min = lb/ld = 0.22053887
su1 = 0.4*esu1_nominal ((5.5), TBDY) = 0.032
From table 5A.1, TBDY: esu1_nominal = 0.08,
For calculation of esu1_nominal and y1, sh1,ft1,fy1, it is considered
characteristic value fsy1 = fs1/1.2, from table 5.1, TBDY.
y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/ld)^ 2/3), from 10.3.5, ASCE 41-17.
with fs1 = fs = 253.4875
with Es1 = Es = 200000.00
y2 = 0.0010562
sh2 = 0.00365026
ft2 = 304.185
fy2 = 253.4875
su2 = 0.00365026
using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
and also multiplied by the shear_factor according to 15.7.1.4, with
Shear_factor = 1.00
lo/lou,min = lb/lb,min = 0.22053887
su2 = 0.4*esu2_nominal ((5.5), TBDY) = 0.032
From table 5A.1, TBDY: esu2_nominal = 0.08,
For calculation of esu2_nominal and y2, sh2,ft2,fy2, it is considered
characteristic value fsy2 = fs2/1.2, from table 5.1, TBDY.
y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/ld)^ 2/3), from 10.3.5, ASCE 41-17.
with fs2 = fs = 253.4875
with Es2 = Es = 200000.00
yv = 0.0010562
shv = 0.00365026
ftv = 304.185
fyv = 253.4875
suv = 0.00365026
using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
and also multiplied by the shear_factor according to 15.7.1.4, with
Shear_factor = 1.00
lo/lou,min = lb/ld = 0.22053887
suv = 0.4*esuv_nominal ((5.5), TBDY) = 0.032
From table 5A.1, TBDY: esuv_nominal = 0.08,
considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY
For calculation of esuv_nominal and yv, shv,ftv,fyv, it is considered
characteristic value fsyv = fsv/1.2, from table 5.1, TBDY.
y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/ld)^ 2/3), from 10.3.5, ASCE 41-17.
with fsv = fs = 253.4875
with Esv = Es = 200000.00
1 = Asl,ten/(b*d)*(fs1/fc) = 0.29147618
2 = Asl,com/(b*d)*(fs2/fc) = 0.29147618
v = Asl,mid/(b*d)*(fsv/fc) = 0.6364888
and confined core properties:
b = 140.00
d = 327.00
d' = 13.00
fcc (5A.2, TBDY) = 19.13667
cc (5A.5, TBDY) = 0.00475778
c = confinement factor = 1.27578
1 = Asl,ten/(b*d)*(fs1/fc) = 0.45459588
2 = Asl,com/(b*d)*(fs2/fc) = 0.45459588
v = Asl,mid/(b*d)*(fsv/fc) = 0.99268896
Case/Assumption: Unconfined full section - Steel rupture
'satisfies Eq. (4.3)
--->
v < vs,y2 - LHS eq.(4.5) is not satisfied

```

```

--->
v < vs,c - RHS eq.(4.5) is satisfied
--->
su (4.8) = 0.40159417
Mu = MRc (4.15) = 1.9001E+008
u = su (4.1) = 1.7086748E-005
-----

Calculation of ratio lb/ld
-----

Lap Length: lb/ld = 0.22053887
lb = 300.00
ld = 1360.304
Calculation of lb,min according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.
= 1
db = 18.00
Mean strength value of all re-bars: fy = 555.55
fc' = 15.00, but fc'^0.5 <= 8.3 MPa (22.5.3.1, ACI 318-14)
t = 1.00
s = 0.80
e = 1.00
cb = 24.02082
Ktr = 0.82673491
Atr = Min(Atrx,Atry) = 157.0796
where Atrx, Atry are the sum of the area of all stirrup legs along X and Y loxal axis
s = 380.00
n = 20.00
-----

Calculation of Shear Strength Vr = Min(Vr1,Vr2) = 227350.021
-----

Calculation of Shear Strength at edge 1, Vr1 = 227350.021
Vr1 = VCol ((10.3), ASCE 41-17) = knl*VCol0
VCol0 = 227350.021
knl = 1 (zero step-static loading)
-----

NOTE: In expression (10-3) 'Vs' is replaced by 'Vs+ f*Vf'
where Vf is the contribution of FRPs (11.3), ACI 440).
-----

= 1 (normal-weight concrete)
fc' = 15.00, but fc'^0.5 <= 8.3 MPa (22.5.3.1, ACI 318-14)
M/Vd = 2.00
Mu = 0.00988804
Vu = 1.5456333E-009
d = 0.8*h = 320.00
Nu = 4737.328
Ag = 80000.00
From (11.5.4.8), ACI 318-14: Vs = Vs1 + Vs2 = 0.00
where:
Vs1 = 0.00 is calculated for section web, with:
d = 160.00
Av = 157079.633
fy = 444.44
s = 380.00
Vs1 is multiplied by Col1 = 0.00
s/d = 2.375
Vs2 = 0.00 is calculated for section flange, with:
d = 320.00
Av = 157079.633
fy = 444.44
s = 380.00
Vs2 is multiplied by Col2 = 0.00
s/d = 1.1875
Vf ((11-3)-(11.4), ACI 440) = 188111.148
f = 0.95, for fully-wrapped sections

```



$wf/sf = 1$  (FRP strips adjacent to one another).

In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot a)\sin a$  which is more a generalised expression, where  $a$  is the angle of the crack direction (see KANEPE).

This later relation, considered as a function  $Vf(\theta, a)$ , is implemented for every different fiber orientation  $a_i$ , as well as for 2 crack directions,  $\theta = 45^\circ$  and  $\theta = -45^\circ$  to take into consideration the cyclic seismic loading.

orientation 1:  $\theta = b1 + 90^\circ = 90.00$

$Vf = \text{Min}(|Vf(45, \theta)|, |Vf(-45, a1)|)$ , with:

total thickness per orientation,  $tf1 = NL \cdot t / \text{NoDir} = 1.016$

$dfv = d$  (figure 11.2, ACI 440) = 357.00

$ffe$  ((11-5), ACI 440) = 259.312

$Ef = 64828.00$

$fe = 0.004$ , from (11.6a), ACI 440

with  $fu = 0.01$

From (11-11), ACI 440:  $Vs + Vf \leq 164661.611$

$bw = 200.00$

Calculation of Shear Strength at edge 2,  $Vr2 = 227350.021$

$Vr2 = VCol$  ((10.3), ASCE 41-17) =  $knl \cdot VCol0$

$VCol0 = 227350.021$

$knl = 1$  (zero step-static loading)

NOTE: In expression (10-3) ' $Vs$ ' is replaced by ' $Vs + f \cdot Vf$ ' where  $Vf$  is the contribution of FRPs (11.3), ACI 440).

$= 1$  (normal-weight concrete)

$fc' = 15.00$ , but  $fc'^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$M/Vd = 2.00$

$Mu = 0.00525978$

$Vu = 1.5456333E-009$

$d = 0.8 \cdot h = 320.00$

$Nu = 4737.328$

$Ag = 80000.00$

From (11.5.4.8), ACI 318-14:  $Vs = Vs1 + Vs2 = 0.00$

where:

$Vs1 = 0.00$  is calculated for section web, with:

$d = 160.00$

$Av = 157079.633$

$fy = 444.44$

$s = 380.00$

$Vs1$  is multiplied by  $Col1 = 0.00$

$s/d = 2.375$

$Vs2 = 0.00$  is calculated for section flange, with:

$d = 320.00$

$Av = 157079.633$

$fy = 444.44$

$s = 380.00$

$Vs2$  is multiplied by  $Col2 = 0.00$

$s/d = 1.1875$

$Vf$  ((11-3)-(11.4), ACI 440) = 188111.148

$f = 0.95$ , for fully-wrapped sections

$wf/sf = 1$  (FRP strips adjacent to one another).

In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot a)\sin a$  which is more a generalised expression, where  $a$  is the angle of the crack direction (see KANEPE).

This later relation, considered as a function  $Vf(\theta, a)$ , is implemented for every different fiber orientation  $a_i$ , as well as for 2 crack directions,  $\theta = 45^\circ$  and  $\theta = -45^\circ$  to take into consideration the cyclic seismic loading.

orientation 1:  $\theta = b1 + 90^\circ = 90.00$

$Vf = \text{Min}(|Vf(45, \theta)|, |Vf(-45, a1)|)$ , with:

total thickness per orientation,  $tf1 = NL \cdot t / \text{NoDir} = 1.016$

$dfv = d$  (figure 11.2, ACI 440) = 357.00

$ffe$  ((11-5), ACI 440) = 259.312

$Ef = 64828.00$

$fe = 0.004$ , from (11.6a), ACI 440

with  $fu = 0.01$

From (11-11), ACI 440:  $Vs + Vf \leq 164661.611$

$bw = 200.00$

End Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1  
At local axis: 2

Start Of Calculation of Chord Rotation Capacity for element: column TC1 of floor 1  
At local axis: 2  
Integration Section: (a)  
Section Type: rctcs

#### Constant Properties

Knowledge Factor,  $\gamma = 0.90$   
Chord Rotation is generally considered as Deformation-Controlled Action according to Table C7-1, ASCE 41-17.  
Mean strengths are used for Deformation-Controlled Actions according to 7.5.1.3, ASCE 41-17  
Consequently:  
Existing material of Primary Member: Concrete Strength,  $f_c = f_{cm} = 15.00$   
Existing material of Primary Member: Steel Strength,  $f_s = f_{sm} = 444.44$   
Concrete Elasticity,  $E_c = 18203.022$   
Steel Elasticity,  $E_s = 200000.00$   
Max Height,  $H_{max} = 400.00$   
Min Height,  $H_{min} = 200.00$   
Max Width,  $W_{max} = 400.00$   
Min Width,  $W_{min} = 200.00$   
Eccentricity,  $E_{cc} = 100.00$   
Cover Thickness,  $c = 25.00$   
Element Length,  $L = 3000.00$   
Primary Member  
Ribbed Bars  
Ductile Steel  
Without Detailing for Earthquake Resistance (including stirrups not closed at 135°)  
Longitudinal Bars With Ends Lapped Starting at the End Sections  
Lap Length  $l_b = 300.00$   
FRP Wrapping Data  
Type: Carbon  
Cured laminate properties (design values)  
Thickness,  $t = 1.016$   
Tensile Strength,  $f_{fu} = 1055.00$   
Tensile Modulus,  $E_f = 64828.00$   
Elongation,  $e_{fu} = 0.01$   
Number of directions,  $N_{oDir} = 1$   
Fiber orientations,  $b_i = 0.00^\circ$   
Number of layers,  $N_L = 1$   
Radius of rounding corners,  $R = 40.00$

#### Stepwise Properties

Bending Moment,  $M = -1284.318$   
Shear Force,  $V_2 = -3961.043$   
Shear Force,  $V_3 = 0.77690092$   
Axial Force,  $F = -4742.638$   
Longitudinal Reinforcement Area Distribution (in 2 divisions)  
-Tension:  $A_{st} = 2375.044$   
-Compression:  $A_{sc} = 2777.168$   
Longitudinal Reinforcement Area Distribution (in 3 divisions)  
-Tension:  $A_{st,ten} = 2261.947$   
-Compression:  $A_{st,com} = 829.3805$   
-Middle:  $A_{st,mid} = 2060.885$   
Mean Diameter of Tension Reinforcement,  $Db_L = 17.77778$

Existing component: From table 7-7, ASCE 41\_17: Final chord rotation Capacity  $\phi_{u,R} = \phi_u = 0.0501325$

$$u = y + p = 0.05570277$$

- Calculation of  $y$  -

$$y = (M_y * L_s / 3) / E_{eff} = 0.01370277 \text{ ((4.29), Biskinis Phd)}$$

$$M_y = 1.9917E+008$$

$$L_s = M/V \text{ (with } L_s > 0.1 * L \text{ and } L_s < 2 * L) = 1653.13$$

$$\text{From table 10.5, ASCE 41\_17: } E_{eff} = \text{factor} * E_c * I_g = 8.0093E+012$$

$$\text{factor} = 0.30$$

$$A_g = 120000.00$$

$$f_c' = 15.00$$

$$N = 4742.638$$

$$E_c * I_g = 2.6698E+013$$

Calculation of Yielding Moment  $M_y$

Calculation of  $y$  and  $M_y$  according to Annex 7 -

Assuming neutral axis within flange ( $y < t/d$ , compression zone rectangular) with:

flange width,  $b = 400.00$

web width,  $b_w = 200.00$

flange thickness,  $t = 200.00$

$$y = \text{Min}(y_{ten}, y_{com})$$

$$y_{ten} = 5.8877969E-006$$

$$\text{with ((10.1), ASCE 41-17) } f_y = \text{Min}(f_y, 1.25 * f_y * (I_b / I_d)^{2/3}) = 235.317$$

$$d = 357.00$$

$$y = 0.44023952$$

$$A = 0.03622105$$

$$B = 0.0247658$$

$$\text{with } p_t = 0.0075814$$

$$p_c = 0.00580799$$

$$p_v = 0.01443197$$

$$N = 4742.638$$

$$b = 400.00$$

$$" = 0.12044818$$

$$y_{comp} = 1.0200757E-005$$

$$\text{with } f_c' (12.3, \text{ACI 440}) = 16.19674$$

$$f_c = 15.00$$

$$f_l = 0.93147527$$

$$b = b_{max} = 400.00$$

$$h = h_{max} = 400.00$$

$$A_g = 120000.00$$

$$g = p_t + p_c + p_v = 0.03607992$$

$$r_c = 40.00$$

$$A_e / A_c = 0.40981737$$

$$\text{Effective FRP thickness, } t_f = N L * t * \cos(b_1) = 1.016$$

$$\text{effective strain from (12.5) and (12.12), } e_{fe} = 0.004$$

$$f_u = 0.01$$

$$E_f = 64828.00$$

$$E_c = 18203.022$$

$$y = 0.43980075$$

$$A = 0.03597623$$

$$B = 0.02462466$$

$$\text{with } E_s = 200000.00$$

$$\text{CONFIRMATION: } y = 0.43980075 < t/d$$

Calculation of ratio  $I_b / I_d$

Lap Length:  $I_d / I_{d,min} = 0.27567359$

$I_b = 300.00$

$I_d = 1088.244$

Calculation of  $I$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$$= 1$$

$$db = 18.00$$

$$\text{Mean strength value of all re-bars: } f_y = 444.44$$

$$f'_c = 15.00, \text{ but } f_c^{0.5} \leq 8.3 \text{ MPa (22.5.3.1, ACI 318-14)}$$

$$t = 1.00$$

$$s = 0.80$$

$$e = 1.00$$

$$cb = 24.02082$$

$$K_{tr} = 0.82673491$$

$$A_{tr} = \text{Min}(A_{tr_x}, A_{tr_y}) = 157.0796$$

where  $A_{tr_x}$ ,  $A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y local axis

$$s = 380.00$$

$$n = 20.00$$

- Calculation of  $p$  -

From table 10-8:  $p = 0.042$

with:

- Columns controlled by inadequate development or splicing along the clear height because  $l_b/l_d < 1$

$$\text{shear control ratio } V_y E / V_{col} E = 0.82694402$$

$$d = 357.00$$

$$s = 0.00$$

$$t = A_v / (b_w * s) + 2 * t_f / b_w * (f_{fe} / f_s) = A_v * L_{stir} / (A_g * s) + 2 * t_f / b_w * (f_{fe} / f_s) = 0.0075814$$

$A_v = 78.53982$ , is the area of every stirrup

$L_{stir} = 960.00$ , is the total Length of all stirrups parallel to loading (shear) direction

The term  $2 * t_f / b_w * (f_{fe} / f_s)$  is implemented to account for FRP contribution

where  $f = 2 * t_f / b_w$  is FRP ratio (EC8 - 3, A.4.4.3(6)) and  $f_{fe} / f_s$  normalises  $f$  to steel strength

All these variables have already been given in Shear control ratio calculation.

$$N_{UD} = 4742.638$$

$$A_g = 120000.00$$

$$f'_c E = 15.00$$

$$f_{yt} E = f_{yl} E = 444.44$$

$$p_l = \text{Area\_Tot\_Long\_Rein} / (b * d) = 0.03607992$$

$$b = 400.00$$

$$d = 357.00$$

$$f'_c E = 15.00$$

End Of Calculation of Chord Rotation Capacity for element: column TC1 of floor 1

At local axis: 2

Integration Section: (a)

## Calculation No. 11

column C1, Floor 1

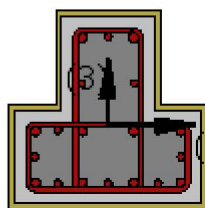
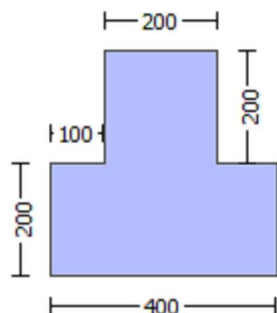
Limit State: Collapse Prevention (data interpolation between analysis steps 2 and 3)

Analysis: Uniform +X

Check: Shear capacity VRd

Edge: Start

Local Axis: (3)



Start Of Calculation of Shear Capacity for element: column TC1 of floor 1

At local axis: 3

Integration Section: (a)

Section Type: rctcs

Constant Properties

Knowledge Factor,  $\gamma = 0.90$

Member Shear Force is generally considered as Force-Controlled Action according to Table C7-1, ASCE 41-17.

Lower-bound strengths are used for Force-Controlled Actions according to 7.5.1.3, ASCE 41-17

Consequently:

Existing material of Primary Member: Concrete Strength,  $f_c = f_{c\_lower\_bound} = 10.00$

Existing material of Primary Member: Steel Strength,  $f_s = f_{s\_lower\_bound} = 400.00$

Concrete Elasticity,  $E_c = 18203.022$

Steel Elasticity,  $E_s = 200000.00$

#####

Note: Especially for the calculation of  $\gamma$  for displacement ductility demand, the expected (mean value) strengths are used (7.5.1.3, ASCE 41-17) because bending is considered as Deformation-Controlled Action (Table C7-1, ASCE 41-17).

Existing material: Concrete Strength,  $f_c = f_{cm} = 15.00$

Existing material: Steel Strength,  $f_s = f_{sm} = 444.44$

#####

Max Height,  $H_{max} = 400.00$

Min Height,  $H_{min} = 200.00$

Max Width,  $W_{max} = 400.00$

Min Width,  $W_{min} = 200.00$

Eccentricity,  $Ecc = 100.00$

Cover Thickness,  $c = 25.00$

Element Length,  $L = 3000.00$

Primary Member

Ribbed Bars

Ductile Steel

Without Detailing for Earthquake Resistance (including stirrups not closed at 135°)

Longitudinal Bars With Ends Lapped Starting at the End Sections

Lap Length  $l_o = l_b = 300.00$

FRP Wrapping Data

Type: Carbon

Cured laminate properties (design values)

Thickness,  $t = 1.016$

Tensile Strength,  $f_{fu} = 1055.00$   
Tensile Modulus,  $E_f = 64828.00$   
Elongation,  $\epsilon_{fu} = 0.01$   
Number of directions,  $NoDir = 1$   
Fiber orientations,  $b_i = 0.00^\circ$   
Number of layers,  $NL = 1$   
Radius of rounding corners,  $R = 40.00$

#### Stepwise Properties

EDGE -A-  
Bending Moment,  $M_a = -1284.318$   
Shear Force,  $V_a = 0.77690092$   
EDGE -B-  
Bending Moment,  $M_b = -853.8761$   
Shear Force,  $V_b = -0.77690092$   
BOTH EDGES  
Axial Force,  $F = -4742.638$   
Longitudinal Reinforcement Area Distribution (in 2 divisions)  
-Tension:  $As_t = 2375.044$   
-Compression:  $As_c = 2777.168$   
Longitudinal Reinforcement Area Distribution (in 3 divisions)  
-Tension:  $As_{t,ten} = 2261.947$   
-Compression:  $As_{c,com} = 829.3805$   
-Middle:  $As_{mid} = 2060.885$   
Mean Diameter of Tension Reinforcement,  $Db_{L,ten} = 17.77778$

Existing component: From table 7-7, ASCE 41\_17: Final Shear Capacity  $V_R = *V_n = 144111.676$   
 $V_n ((10.3), ASCE 41-17) = knl * V_{CoIO} = 160124.085$   
 $V_{CoI} = 160124.085$   
 $knl = 1.00$   
 $displacement\_ductility\_demand = 0.00098248$

NOTE: In expression (10-3) ' $V_s$ ' is replaced by ' $V_{s+} + f * V_f$ '  
where  $V_f$  is the contribution of FRPs (11.3), ACI 440).

$= 1$  (normal-weight concrete)  
 $f'_c = 10.00$ , but  $f_c^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)  
 $M/Vd = 4.00$   
 $M_u = 1284.318$   
 $V_u = 0.77690092$   
 $d = 0.8 * h = 320.00$   
 $N_u = 4742.638$   
 $A_g = 80000.00$   
From (11.5.4.8), ACI 318-14:  $V_s = V_{s1} + V_{s2} = 0.00$   
where:  
 $V_{s1} = 0.00$  is calculated for section web, with:  
 $d = 320.00$   
 $A_v = 157079.633$   
 $f_y = 400.00$   
 $s = 380.00$   
 $V_{s1}$  is multiplied by  $Col1 = 0.00$   
 $s/d = 1.1875$   
 $V_{s2} = 0.00$  is calculated for section flange, with:  
 $d = 160.00$   
 $A_v = 157079.633$   
 $f_y = 400.00$   
 $s = 380.00$   
 $V_{s2}$  is multiplied by  $Col2 = 0.00$   
 $s/d = 2.375$   
 $V_f ((11-3)-(11.4), ACI 440) = 188111.148$   
 $f = 0.95$ , for fully-wrapped sections  
 $wf/sf = 1$  (FRP strips adjacent to one another).

In (11.3)  $\sin \theta + \cos \theta$  is replaced with  $(\cot \theta + \csc \theta) \sin \theta$  which is more a generalised expression, where  $\theta$  is the angle of the crack direction (see KANEPE).  
This later relation, considered as a function  $V_f(\theta)$ , is implemented for every different fiber orientation  $\theta_i$ , as well as for 2 crack directions,  $\theta = 45^\circ$  and  $\theta = -45^\circ$  to take into consideration the cyclic seismic loading.  
orientation 1:  $\theta_1 = \theta_1 + 90^\circ = 90.00$   
 $V_f = \text{Min}(|V_f(45, \theta_1)|, |V_f(-45, \theta_1)|)$ , with:  
total thickness per orientation,  $t_{f1} = N_L \cdot t / N_{\text{Dir}} = 1.016$   
 $d_{fv} = d$  (figure 11.2, ACI 440) = 357.00  
 $f_{fe}((11-5), \text{ACI 440}) = 259.312$   
 $E_f = 64828.00$   
 $f_e = 0.004$ , from (11.6a), ACI 440  
with  $f_u = 0.01$   
From (11-11), ACI 440:  $V_s + V_f \leq 134445.642$   
 $b_w = 200.00$

displacement ductility demand is calculated as  $\delta / y$

- Calculation of  $\delta / y$  for END A -  
for rotation axis 2 and integ. section (a)

From analysis, chord rotation  $\theta = 1.3462679\text{E-}005$   
 $y = (M_y \cdot L_s / 3) / E_{\text{eff}} = 0.01370277$  ((4.29), Biskinis Phd))  
 $M_y = 1.9917\text{E+}008$   
 $L_s = M/V$  (with  $L_s > 0.1 \cdot L$  and  $L_s < 2 \cdot L$ ) = 1653.13  
From table 10.5, ASCE 41\_17:  $E_{\text{eff}} = \text{factor} \cdot E_c \cdot I_g = 8.0093\text{E+}012$   
factor = 0.30  
 $A_g = 120000.00$   
 $f_c' = 15.00$   
 $N = 4742.638$   
 $E_c \cdot I_g = 2.6698\text{E+}013$

Calculation of Yielding Moment  $M_y$

Calculation of  $\delta$  and  $M_y$  according to Annex 7 -

Assuming neutral axis within flange ( $\delta < t/d$ , compression zone rectangular) with:

flange width,  $b = 400.00$   
web width,  $b_w = 200.00$   
flange thickness,  $t = 200.00$

$y = \text{Min}(\delta_{\text{ten}}, \delta_{\text{com}})$   
 $\delta_{\text{ten}} = 5.8877969\text{E-}006$   
with ((10.1), ASCE 41-17)  $f_y = \text{Min}(f_y, 1.25 \cdot f_y \cdot (b/d)^{2/3}) = 235.317$   
 $d = 357.00$   
 $y = 0.44023952$   
 $A = 0.03622105$   
 $B = 0.0247658$   
with  $p_t = 0.01583996$   
 $p_c = 0.00580799$   
 $p_v = 0.01443197$   
 $N = 4742.638$   
 $b = 400.00$   
 $\rho = 0.12044818$   
 $y_{\text{comp}} = 1.0200757\text{E-}005$   
with  $f_c' (12.3, (\text{ACI 440})) = 16.19674$   
 $f_c = 15.00$   
 $f_l = 0.93147527$   
 $b = b_{\text{max}} = 400.00$   
 $h = h_{\text{max}} = 400.00$   
 $A_g = 120000.00$   
 $g = p_t + p_c + p_v = 0.03607992$   
 $r_c = 40.00$   
 $A_e/A_c = 0.40981737$

Effective FRP thickness,  $t_f = NL \cdot t \cdot \cos(b_1) = 1.016$   
effective strain from (12.5) and (12.12),  $\epsilon_{fe} = 0.004$   
 $f_u = 0.01$   
 $E_f = 64828.00$   
 $E_c = 18203.022$   
 $y = 0.43980075$   
 $A = 0.03597623$   
 $B = 0.02462466$   
with  $E_s = 200000.00$   
CONFIRMATION:  $y = 0.43980075 < t/d$

-----

-----

Calculation of ratio  $I_b/I_d$

-----

Lap Length:  $I_d/I_{d,min} = 0.27567359$   
 $I_b = 300.00$   
 $I_d = 1088.244$   
Calculation of  $I$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.  
 $= 1$   
 $db = 18.00$   
Mean strength value of all re-bars:  $f_y = 444.44$   
 $f_c' = 15.00$ , but  $f_c'^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)  
 $t = 1.00$   
 $s = 0.80$   
 $e = 1.00$   
 $cb = 24.02082$   
 $K_{tr} = 0.82673491$   
 $A_{tr} = \min(A_{tr_x}, A_{tr_y}) = 157.0796$   
where  $A_{tr_x}$ ,  $A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y local axis  
 $s = 380.00$   
 $n = 20.00$

-----

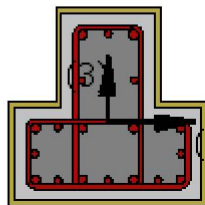
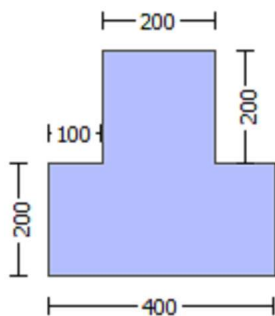
End Of Calculation of Shear Capacity for element: column TC1 of floor 1  
At local axis: 3  
Integration Section: (a)

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## Calculation No. 12

column C1, Floor 1  
Limit State: Collapse Prevention (data interpolation between analysis steps 2 and 3)  
Analysis: Uniform +X  
Check: Chord rotation capacity (  $\phi$  )  
Edge: Start  
Local Axis: (3)





Start Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1

At Shear local axis: 3

(Bending local axis: 2)

Section Type: rctcs

Constant Properties

Knowledge Factor,  $\gamma = 0.90$

Mean strength values are used for both shear and moment calculations.

Consequently:

Existing material of Primary Member: Concrete Strength,  $f_c = f_{cm} = 15.00$

Existing material of Primary Member: Steel Strength,  $f_s = f_{sm} = 444.44$

Concrete Elasticity,  $E_c = 18203.022$

Steel Elasticity,  $E_s = 200000.00$

#####

Note: Especially for the calculation of moment strengths,

the above steel re-bar strengths are multiplied by 1.25 according to R18.6.5, ACI 318-14

Existing material: Steel Strength,  $f_s = 1.25 \cdot f_{sm} = 555.55$

#####

Max Height,  $H_{max} = 400.00$

Min Height,  $H_{min} = 200.00$

Max Width,  $W_{max} = 400.00$

Min Width,  $W_{min} = 200.00$

Eccentricity,  $Ecc = 100.00$

Cover Thickness,  $c = 25.00$

Mean Confinement Factor overall section = 1.27578

Element Length,  $L = 3000.00$

Primary Member

Ribbed Bars

Ductile Steel

Without Detailing for Earthquake Resistance (including stirrups not closed at 135°)

Longitudinal Bars With Ends Lapped Starting at the End Sections

Lap Length  $l_o = 300.00$

FRP Wrapping Data

Type: Carbon

Cured laminate properties (design values)

Thickness,  $t = 1.016$

Tensile Strength,  $f_{fu} = 1055.00$

Tensile Modulus,  $E_f = 64828.00$

Elongation,  $ef_u = 0.01$

Number of directions,  $NoDir = 1$

Fiber orientations,  $bi: 0.00^\circ$

Number of layers,  $NL = 1$

Radius of rounding corners,  $R = 40.00$

Stepwise Properties

At local axis: 3

EDGE -A-

Shear Force,  $V_a = 0.01054019$

EDGE -B-

Shear Force,  $V_b = -0.01054019$   
 BOTH EDGES  
 Axial Force,  $F = -4737.328$   
 Longitudinal Reinforcement Area Distribution (in 2 divisions)  
   -Tension:  $As_t = 0.00$   
   -Compression:  $As_c = 5152.212$   
 Longitudinal Reinforcement Area Distribution (in 3 divisions)  
   -Tension:  $As_{ten} = 2261.947$   
   -Compression:  $As_{com} = 829.3805$   
   -Middle:  $As_{mid} = 2060.885$

Calculation of Shear Capacity ratio,  $V_e/V_r = 0.82694402$   
 Member Controlled by Flexure ( $V_e/V_r < 1$ )  
 Calculation of Shear Demand from fig. R18.6.5, ACI 318-14  $V_e = (M_{pr1} + M_{pr2})/l_n = 162085.836$   
 with  
 $M_{pr1} = \text{Max}(\mu_{u1+}, \mu_{u1-}) = 2.4313E+008$   
 $\mu_{u1+} = 2.4313E+008$ , is the ultimate moment strength at the edge 1 of the member in the actual moment direction which is defined for the static loading combination  
 $\mu_{u1-} = 1.2706E+008$ , is the ultimate moment strength at the edge 1 of the member in the opposite moment direction which is defined for the static loading combination  
 $M_{pr2} = \text{Max}(\mu_{u2+}, \mu_{u2-}) = 2.4313E+008$   
 $\mu_{u2+} = 2.4313E+008$ , is the ultimate moment strength at the edge 2 of the member in the actual moment direction which is defined for the static loading combination  
 $\mu_{u2-} = 1.2706E+008$ , is the ultimate moment strength at the edge 2 of the member in the opposite moment direction which is defined for the static loading combination

Calculation of  $\mu_{u1+}$

Calculation of ultimate curvature  $\phi_u$  according to 4.1, Biskinis/Fardis 2013:  
 $\phi_u = 2.6161250E-005$   
 $M_u = 2.4313E+008$

with full section properties:

$b = 200.00$   
 $d = 357.00$   
 $d' = 43.00$   
 $v = 0.00442328$   
 $N = 4737.328$   
 $f_c = 15.00$   
 $\phi_c (5A.5, \text{TBDY}) = 0.002$

Final value of  $\phi_u$ :  $\phi_u^* = \text{shear\_factor} * \text{Max}(\phi_u, \phi_c) = 0.018$

The Shear\_factor is considered equal to 1 (pure moment strength)

From (5.4b), TBDY:  $\phi_u = 0.018$

we ((5.4c), TBDY)  $= a_s e^* \phi_{u, \min} * f_{ywe} / f_{ce} + \text{Min}(\phi_x, \phi_y) = 0.15303423$

where  $\phi = a_f * \phi_f * f_{fe} / f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$\phi_x = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area})/(\text{total area})$

$a_f = 0.43111111$

with Unconfined area  $= ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 51733.333$

$b_{\max} = 400.00$

$h_{\max} = 400.00$

From EC8 A.4.4.3(6),  $\phi_f = 2t_f/b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

$\phi_y = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area})/(\text{total area})$

$a_f = 0.43111111$

with Unconfined area  $= ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 0.00$

$b_{\max} = 400.00$

hmax = 400.00  
From EC8 A4.4.3(6),  $pf = 2tf/bw = 0.01016$   
bw = 200.00  
effective stress from (A.35),  $ff_e = 524.0792$

R = 40.00  
Effective FRP thickness,  $tf = NL*t*Cos(b1) = 1.016$   
 $f_{u,f} = 1055.00$   
 $E_f = 64828.00$   
 $u_{,f} = 0.015$

$ase = \text{Max}(((A_{conf,max} - A_{noConf})/A_{conf,max}) * (A_{conf,min}/A_{conf,max}), 0) = 0.00$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988) "Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$psh_{,min} = \text{Min}(psh_x, psh_y) = 0.00165347$

Expression ((5.4d), TBDY) for  $psh_{,min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$psh_x \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$   
 $L_{stir}$  (Length of stirrups along Y) = 960.00  
 $A_{stir}$  (stirrups area) = 78.53982  
 $A_{sec}$  (section area) = 120000.00

$psh_y \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$   
 $L_{stir}$  (Length of stirrups along X) = 960.00  
 $A_{stir}$  (stirrups area) = 78.53982  
 $A_{sec}$  (section area) = 120000.00

s = 380.00  
 $f_{ywe} = 555.55$   
 $f_{ce} = 15.00$

From ((5.A5), TBDY), TBDY:  $cc = 0.00475778$   
c = confinement factor = 1.27578

$y1 = 0.0010562$   
 $sh1 = 0.00365026$   
 $ft1 = 304.185$   
 $fy1 = 253.4875$   
 $su1 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$lo/lo_{,min} = lb/l_d = 0.22053887$

$su1 = 0.4 * esu1_{nominal} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu1_{nominal} = 0.08$ ,

For calculation of  $esu1_{nominal}$  and  $y1, sh1, ft1, fy1$ , it is considered characteristic value  $fsy1 = fs1/1.2$ , from table 5.1, TBDY.

$y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 * (lb/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.

with  $fs1 = fs = 253.4875$

with  $Es1 = Es = 200000.00$

$y2 = 0.0010562$   
 $sh2 = 0.00365026$   
 $ft2 = 304.185$   
 $fy2 = 253.4875$   
 $su2 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$lo/lo_{,min} = lb/l_{b,min} = 0.22053887$

$su2 = 0.4 * esu2_{nominal} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $es_{u2\_nominal} = 0.08$ ,  
For calculation of  $es_{u2\_nominal}$  and  $y_2$ ,  $sh_2$ ,  $ft_2$ ,  $fy_2$ , it is considered  
characteristic value  $fs_{y2} = fs_2/1.2$ , from table 5.1, TBDY.  
 $y_1$ ,  $sh_1$ ,  $ft_1$ ,  $fy_1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
with  $fs_2 = fs = 253.4875$   
with  $Es_2 = Es = 200000.00$   
 $y_v = 0.0010562$   
 $sh_v = 0.00365026$   
 $ft_v = 304.185$   
 $fy_v = 253.4875$   
 $s_{uv} = 0.00365026$   
using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00  
 $l_o/l_{ou,min} = l_b/l_d = 0.22053887$   
 $s_{uv} = 0.4 \cdot es_{uv\_nominal} ((5.5), TBDY) = 0.032$   
From table 5A.1, TBDY:  $es_{uv\_nominal} = 0.08$ ,  
considering characteristic value  $fs_{yv} = f_{sv}/1.2$ , from table 5.1, TBDY  
For calculation of  $es_{uv\_nominal}$  and  $y_v$ ,  $sh_v$ ,  $ft_v$ ,  $fy_v$ , it is considered  
characteristic value  $fs_{yv} = f_{sv}/1.2$ , from table 5.1, TBDY.  
 $y_1$ ,  $sh_1$ ,  $ft_1$ ,  $fy_1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
with  $f_{sv} = fs = 253.4875$   
with  $Es_v = Es = 200000.00$   
 $1 = A_{sl,ten}/(b \cdot d) \cdot (f_{s1}/f_c) = 0.53536441$   
 $2 = A_{sl,com}/(b \cdot d) \cdot (f_{s2}/f_c) = 0.19630028$   
 $v = A_{sl,mid}/(b \cdot d) \cdot (f_{sv}/f_c) = 0.48777647$   
and confined core properties:  
 $b = 140.00$   
 $d = 327.00$   
 $d' = 13.00$   
 $f_{cc} (5A.2, TBDY) = 19.13667$   
 $cc (5A.5, TBDY) = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $1 = A_{sl,ten}/(b \cdot d) \cdot (f_{s1}/f_c) = 0.83497202$   
 $2 = A_{sl,com}/(b \cdot d) \cdot (f_{s2}/f_c) = 0.30615641$   
 $v = A_{sl,mid}/(b \cdot d) \cdot (f_{sv}/f_c) = 0.76075229$   
Case/Assumption: Unconfined full section - Steel rupture  
' satisfies Eq. (4.3)  
--->  
 $v < v_{s,y2}$  - LHS eq.(4.5) is not satisfied  
--->  
 $v < v_{s,c}$  - RHS eq.(4.5) is not satisfied  
--->  
Case/Assumption Rejected.  
--->  
New Case/Assumption: Unconfined full section - Spalling of concrete cover  
' satisfies Eq. (4.4)  
--->  
 $v < s_{y1}$  - LHS eq.(4.7) is not satisfied  
--->  
 $v < v_{c,y1}$  - RHS eq.(4.6) is satisfied  
--->  
 $cu (4.10) = 0.46564051$   
 $M_{Rc} (4.17) = 2.0934E+008$   
--->  
New Case/Assumption: Ultimate curvature of confined core after spalling of concrete cover  
In expressions below, the following modifications have been made  
-  $b$ ,  $d$ ,  $d'$  replaced by geometric parameters of the core:  $b_o$ ,  $d_o$ ,  $d'_o$   
-  $N$ ,  $1$ ,  $2$ ,  $v$  normalised to  $b_o \cdot d_o$ , instead of  $b \cdot d$   
- parameters of confined concrete,  $f_{cc}$ ,  $cc$ , used in lieu of  $f_c$ ,  $ecu$   
--->  
Subcase: Rupture of tension steel  
--->  
 $v^* < v^*_{s,y2}$  - LHS eq.(4.5) is not satisfied  
--->  
 $v^* < v^*_{s,c}$  - LHS eq.(4.5) is not satisfied  
--->

Subcase rejected

--->

New Subcase: Failure of compression zone

--->

$v^* < v^*_{c,y2}$  - LHS eq.(4.6) is not satisfied

--->

$v^* < v^*_{c,y1}$  - RHS eq.(4.6) is satisfied

--->

$\mu_{cu}(4.10) = 0.55615794$

$M_{Ro}(4.17) = 2.4313E+008$

--->

$\mu_u = \mu_{cu}(4.2) = 2.6161250E-005$

$\mu_u = M_{Ro}$

Calculation of ratio  $l_b/l_d$

Lap Length:  $l_b/l_d = 0.22053887$

$l_b = 300.00$

$l_d = 1360.304$

Calculation of  $l_{b,min}$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

= 1

$d_b = 18.00$

Mean strength value of all re-bars:  $f_y = 555.55$

$f'_c = 15.00$ , but  $f'_c^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$t = 1.00$

$s = 0.80$

$e = 1.00$

$c_b = 24.02082$

$K_{tr} = 0.82673491$

$A_{tr} = \min(A_{tr_x}, A_{tr_y}) = 157.0796$

where  $A_{tr_x}$ ,  $A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis

$s = 380.00$

$n = 20.00$

Calculation of  $\mu_{u1}$ -

Calculation of ultimate curvature  $\mu_u$  according to 4.1, Biskinis/Fardis 2013:

$\mu_u = 1.3353763E-005$

$\mu_u = 1.2706E+008$

with full section properties:

$b = 400.00$

$d = 357.00$

$d' = 43.00$

$v = 0.00221164$

$N = 4737.328$

$f'_c = 15.00$

$\mu_{co}(5A.5, TBDY) = 0.002$

Final value of  $\mu_{cu}$ :  $\mu_{cu}^* = \text{shear\_factor} * \max(\mu_{cu}, \mu_{co}) = 0.018$

The Shear\_factor is considered equal to 1 (pure moment strength)

From (5.4b), TBDY:  $\mu_{cu} = 0.018$

we ((5.4c), TBDY) =  $\mu_{cu}^* * \mu_{co} / \mu_{cu} = 0.15303423$

where  $\mu_{co} = \mu_{cu}^* * \mu_{co} / \mu_{cu}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$\mu_{cu} = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $\mu_{cu} = 1 - (\text{Unconfined area})/(\text{total area})$

$\mu_{cu} = 0.43111111$

with Unconfined area =  $((b_{max}-2R)^2 + (h_{max}-2R)^2)/3 = 51733.333$

$b_{max} = 400.00$

$h_{max} = 400.00$

From EC8 A.4.4.3(6),  $\mu_{cu} = 2t_f/b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{f,e} = 524.0792$

$f_y = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area})/(\text{total area})$

$a_f = 0.43111111$

with Unconfined area =  $((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 0.00$

$b_{\max} = 400.00$

$h_{\max} = 400.00$

From EC8 A4.4.3(6),  $p_f = 2t_f/b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{f,e} = 524.0792$

$R = 40.00$

Effective FRP thickness,  $t_f = NL \cdot t \cdot \cos(b_1) = 1.016$

$f_{u,f} = 1055.00$

$E_f = 64828.00$

$u_f = 0.015$

$a_{se} = \text{Max}(((A_{\text{conf,max}} - A_{\text{noConf}})/A_{\text{conf,max}}) \cdot (A_{\text{conf,min}}/A_{\text{conf,max}}), 0) = 0.00$

The definitions of  $A_{\text{noConf}}$ ,  $A_{\text{conf,min}}$  and  $A_{\text{conf,max}}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{\text{conf,max}} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{\text{conf,min}} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{\text{conf,max}}$  by a length equal to half the clear spacing between hoops.

$A_{\text{noConf}} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$p_{sh,min} = \text{Min}(p_{sh,x}, p_{sh,y}) = 0.00165347$

Expression ((5.4d), TBDY) for  $p_{sh,min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$p_{sh,x} \text{ ((5.4d), TBDY)} = L_{\text{stir}} \cdot A_{\text{stir}} / (A_{\text{sec}} \cdot s) = 0.00165347$

$L_{\text{stir}}$  (Length of stirrups along Y) = 960.00

$A_{\text{stir}}$  (stirrups area) = 78.53982

$A_{\text{sec}}$  (section area) = 120000.00

$p_{sh,y} \text{ ((5.4d), TBDY)} = L_{\text{stir}} \cdot A_{\text{stir}} / (A_{\text{sec}} \cdot s) = 0.00165347$

$L_{\text{stir}}$  (Length of stirrups along X) = 960.00

$A_{\text{stir}}$  (stirrups area) = 78.53982

$A_{\text{sec}}$  (section area) = 120000.00

$s = 380.00$

$f_{ywe} = 555.55$

$f_{ce} = 15.00$

From ((5.A5), TBDY), TBDY:  $c_c = 0.00475778$

$c$  = confinement factor = 1.27578

$y_1 = 0.0010562$

$sh_1 = 0.00365026$

$ft_1 = 304.185$

$fy_1 = 253.4875$

$su_1 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$l_o/l_{ou,min} = l_b/l_d = 0.22053887$

$su_1 = 0.4 \cdot esu_{1,nominal} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu_{1,nominal} = 0.08$ ,

For calculation of  $esu_{1,nominal}$  and  $y_1, sh_1, ft_1, fy_1$ , it is considered characteristic value  $fsy_1 = fs_1/1.2$ , from table 5.1, TBDY.

$y_1, sh_1, ft_1, fy_1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.

with  $fs_1 = fs = 253.4875$

with  $Es_1 = Es = 200000.00$

$y_2 = 0.0010562$

$sh_2 = 0.00365026$

$ft_2 = 304.185$

```

fy2 = 253.4875
su2 = 0.00365026
    using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
    and also multiplied by the shear_factor according to 15.7.1.4, with
    Shear_factor = 1.00
    lo/lou,min = lb/lb,min = 0.22053887
    su2 = 0.4*esu2_nominal ((5.5), TBDY) = 0.032
    From table 5A.1, TBDY: esu2_nominal = 0.08,
    For calculation of esu2_nominal and y2, sh2,ft2,fy2, it is considered
    characteristic value fsy2 = fs2/1.2, from table 5.1, TBDY.
    y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/ld)^ 2/3), from 10.3.5, ASCE 41-17.
    with fs2 = fs = 253.4875
    with Es2 = Es = 200000.00
    yv = 0.0010562
    shv = 0.00365026
ftv = 304.185
fyv = 253.4875
suv = 0.00365026
    using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
    and also multiplied by the shear_factor according to 15.7.1.4, with
    Shear_factor = 1.00
    lo/lou,min = lb/ld = 0.22053887
    suv = 0.4*esuv_nominal ((5.5), TBDY) = 0.032
    From table 5A.1, TBDY: esuv_nominal = 0.08,
    considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY
    For calculation of esuv_nominal and yv, shv,ftv,fyv, it is considered
    characteristic value fsyv = fsv/1.2, from table 5.1, TBDY.
    y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/ld)^ 2/3), from 10.3.5, ASCE 41-17.
    with fsv = fs = 253.4875
    with Esv = Es = 200000.00
    1 = Asl,ten/(b*d)*(fs1/fc) = 0.09815014
    2 = Asl,com/(b*d)*(fs2/fc) = 0.26768221
    v = Asl,mid/(b*d)*(fsv/fc) = 0.24388823
and confined core properties:
b = 340.00
d = 327.00
d' = 13.00
fcc (5A.2, TBDY) = 19.13667
cc (5A.5, TBDY) = 0.00475778
    c = confinement factor = 1.27578
    1 = Asl,ten/(b*d)*(fs1/fc) = 0.1260644
    2 = Asl,com/(b*d)*(fs2/fc) = 0.34381201
    v = Asl,mid/(b*d)*(fsv/fc) = 0.31325094

```

Case/Assumption: Unconfined full section - Steel rupture  
 ' satisfies Eq. (4.3)

```

--->
v < vs,y2 - LHS eq.(4.5) is satisfied
--->
su (4.9) = 0.23431248
Mu = MRc (4.14) = 1.2706E+008
u = su (4.1) = 1.3353763E-005

```

---

Calculation of ratio lb/ld

---

```

Lap Length: lb/ld = 0.22053887
lb = 300.00
ld = 1360.304
Calculation of lb,min according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.
= 1
db = 18.00
Mean strength value of all re-bars: fy = 555.55
fc' = 15.00, but fc'^0.5 <= 8.3 MPa (22.5.3.1, ACI 318-14)
t = 1.00
s = 0.80
e = 1.00
cb = 24.02082

```

$K_{tr} = 0.82673491$   
 $A_{tr} = \text{Min}(A_{tr\_x}, A_{tr\_y}) = 157.0796$   
 where  $A_{tr\_x}$ ,  $A_{tr\_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis  
 $s = 380.00$   
 $n = 20.00$

Calculation of  $\mu_{2+}$

Calculation of ultimate curvature  $\mu$  according to 4.1, Biskinis/Fardis 2013:

$\mu = 2.6161250E-005$

$\mu_{2+} = 2.4313E+008$

with full section properties:

$b = 200.00$

$d = 357.00$

$d' = 43.00$

$v = 0.00442328$

$N = 4737.328$

$f_c = 15.00$

$\alpha_{co} (5A.5, \text{TBDY}) = 0.002$

Final value of  $\mu_{cu}$ :  $\mu_{cu}^* = \text{shear\_factor} * \text{Max}(\mu_{cu}, \mu_{cc}) = 0.018$

The Shear\_factor is considered equal to 1 (pure moment strength)

From (5.4b), TBDY:  $\mu_{cu} = 0.018$

we ((5.4c), TBDY)  $= \alpha_{se} * \text{sh}_{\min} * f_{ywe} / f_{ce} + \text{Min}(f_x, f_y) = 0.15303423$

where  $f = \alpha_f * \rho_f * f_{fe} / f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$f_x = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $\alpha_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$\alpha_f = 0.43111111$

with Unconfined area  $= ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2) / 3 = 51733.333$

$b_{\max} = 400.00$

$h_{\max} = 400.00$

From EC8 A.4.4.3(6),  $\rho_f = 2t_f / b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

$f_y = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $\alpha_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$\alpha_f = 0.43111111$

with Unconfined area  $= ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2) / 3 = 0.00$

$b_{\max} = 400.00$

$h_{\max} = 400.00$

From EC8 A.4.4.3(6),  $\rho_f = 2t_f / b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

$R = 40.00$

Effective FRP thickness,  $t_f = N L * t * \cos(b_1) = 1.016$

$f_{u,f} = 1055.00$

$E_f = 64828.00$

$u_{,f} = 0.015$

$\alpha_{se} = \text{Max}(((A_{\text{conf,max}} - A_{\text{noConf}}) / A_{\text{conf,max}}) * (A_{\text{conf,min}} / A_{\text{conf,max}}), 0) = 0.00$

The definitions of  $A_{\text{noConf}}$ ,  $A_{\text{conf,min}}$  and  $A_{\text{conf,max}}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{\text{conf,max}} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{\text{conf,min}} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{\text{conf,max}}$  by a length equal to half the clear spacing between hoops.

$A_{\text{noConf}} = 33066.667$  is the unconfined core area which is equal to  $b_i^2 / 6$  as defined at (A.2).



psh,min = Min(psh,x , psh,y) = 0.00165347  
 Expression ((5.4d), TBDY) for psh,min has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

---


$$psh,x \text{ ((5.4d), TBDY)} = Lstir * Astir / (Asec * s) = 0.00165347$$

Lstir (Length of stirrups along Y) = 960.00

Astir (stirrups area) = 78.53982

Asec (section area) = 120000.00

---


$$psh,y \text{ ((5.4d), TBDY)} = Lstir * Astir / (Asec * s) = 0.00165347$$

Lstir (Length of stirrups along X) = 960.00

Astir (stirrups area) = 78.53982

Asec (section area) = 120000.00

---


$$s = 380.00$$

fywe = 555.55

fce = 15.00

From ((5.A5), TBDY), TBDY: cc = 0.00475778

c = confinement factor = 1.27578

$$y1 = 0.0010562$$

$$sh1 = 0.00365026$$

$$ft1 = 304.185$$

$$fy1 = 253.4875$$

$$su1 = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with

Shear\_factor = 1.00

$$lo/lou,min = lb/l_d = 0.22053887$$

$$su1 = 0.4 * esu1\_nominal \text{ ((5.5), TBDY)} = 0.032$$

From table 5A.1, TBDY: esu1\_nominal = 0.08,

For calculation of esu1\_nominal and y1, sh1,ft1,fy1, it is considered  
 characteristic value fsy1 = fs1/1.2, from table 5.1, TBDY.

y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25\*(lb/l\_d)^2/3), from 10.3.5, ASCE 41-17.

with fs1 = fs = 253.4875

with Es1 = Es = 200000.00

$$y2 = 0.0010562$$

$$sh2 = 0.00365026$$

$$ft2 = 304.185$$

$$fy2 = 253.4875$$

$$su2 = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with

Shear\_factor = 1.00

$$lo/lou,min = lb/l_b,min = 0.22053887$$

$$su2 = 0.4 * esu2\_nominal \text{ ((5.5), TBDY)} = 0.032$$

From table 5A.1, TBDY: esu2\_nominal = 0.08,

For calculation of esu2\_nominal and y2, sh2,ft2,fy2, it is considered  
 characteristic value fsy2 = fs2/1.2, from table 5.1, TBDY.

y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25\*(lb/l\_d)^2/3), from 10.3.5, ASCE 41-17.

with fs2 = fs = 253.4875

with Es2 = Es = 200000.00

$$yv = 0.0010562$$

$$shv = 0.00365026$$

$$ftv = 304.185$$

$$fyv = 253.4875$$

$$suv = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with

Shear\_factor = 1.00

$$lo/lou,min = lb/l_d = 0.22053887$$

$$suv = 0.4 * esuv\_nominal \text{ ((5.5), TBDY)} = 0.032$$

From table 5A.1, TBDY: esuv\_nominal = 0.08,

considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY

For calculation of esuv\_nominal and yv, shv,ftv,fyv, it is considered  
 characteristic value fsyv = fsv/1.2, from table 5.1, TBDY.

y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25\*(lb/l\_d)^2/3), from 10.3.5, ASCE 41-17.

with fsv = fs = 253.4875

```

with Esv = Es = 200000.00
1 = Asl,ten/(b*d)*(fs1/fc) = 0.53536441
2 = Asl,com/(b*d)*(fs2/fc) = 0.19630028
v = Asl,mid/(b*d)*(fsv/fc) = 0.48777647
and confined core properties:
b = 140.00
d = 327.00
d' = 13.00
fcc (5A.2, TBDY) = 19.13667
cc (5A.5, TBDY) = 0.00475778
c = confinement factor = 1.27578
1 = Asl,ten/(b*d)*(fs1/fc) = 0.83497202
2 = Asl,com/(b*d)*(fs2/fc) = 0.30615641
v = Asl,mid/(b*d)*(fsv/fc) = 0.76075229
Case/Assumption: Unconfined full section - Steel rupture
' satisfies Eq. (4.3)
---->
v < vs,y2 - LHS eq.(4.5) is not satisfied
---->
v < vs,c - RHS eq.(4.5) is not satisfied
---->
Case/Assumption Rejected.
---->
New Case/Assumption: Unconfined full section - Spalling of concrete cover
' satisfies Eq. (4.4)
---->
v < s,y1 - LHS eq.(4.7) is not satisfied
---->
v < vc,y1 - RHS eq.(4.6) is satisfied
---->
cu (4.10) = 0.46564051
MRc (4.17) = 2.0934E+008
---->
New Case/Assumption: Ultimate curvature of confined core after spalling of concrete cover
In expressions below, the following modifications have been made
- b, d, d' replaced by geometric parameters of the core: bo, do, d'o
- N, 1, 2, v normalised to bo*do, instead of b*d
- - parameters of confined concrete, fcc, cc, used in lieu of fc, ecu
---->
Subcase: Rupture of tension steel
---->
v* < v*s,y2 - LHS eq.(4.5) is not satisfied
---->
v* < v*s,c - LHS eq.(4.5) is not satisfied
---->
Subcase rejected
---->
New Subcase: Failure of compression zone
---->
v* < v*c,y2 - LHS eq.(4.6) is not satisfied
---->
v* < v*c,y1 - RHS eq.(4.6) is satisfied
---->
*cu (4.10) = 0.55615794
MRo (4.17) = 2.4313E+008
---->
u = cu (4.2) = 2.6161250E-005
Mu = MRo
-----

Calculation of ratio lb/lc
-----

Lap Length: lb/lc = 0.22053887
lb = 300.00
lc = 1360.304
Calculation of lb,min according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.
= 1

```

$db = 18.00$   
Mean strength value of all re-bars:  $f_y = 555.55$   
 $fc' = 15.00$ , but  $fc'^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)  
 $t = 1.00$   
 $s = 0.80$   
 $e = 1.00$   
 $cb = 24.02082$   
 $K_{tr} = 0.82673491$   
 $A_{tr} = \text{Min}(A_{tr_x}, A_{tr_y}) = 157.0796$   
where  $A_{tr_x}$ ,  $A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis  
 $s = 380.00$   
 $n = 20.00$

#### Calculation of $\mu_2$ -

Calculation of ultimate curvature  $\mu$  according to 4.1, Biskinis/Fardis 2013:

$$\mu = 1.3353763E-005$$

$$\mu_u = 1.2706E+008$$

with full section properties:

$$b = 400.00$$

$$d = 357.00$$

$$d' = 43.00$$

$$v = 0.00221164$$

$$N = 4737.328$$

$$fc = 15.00$$

$$co(5A.5, \text{TB DY}) = 0.002$$

$$\text{Final value of } \mu_u: \mu_u^* = \text{shear\_factor} * \text{Max}(\mu_u, \mu_c) = 0.018$$

The Shear\_factor is considered equal to 1 (pure moment strength)

$$\text{From (5.4b), TB DY: } \mu_u = 0.018$$

$$\mu_u \text{ ((5.4c), TB DY)} = a_{se} * \mu_{sh, \min} * f_{ywe} / f_{ce} + \text{Min}(\mu_{fx}, \mu_{fy}) = 0.15303423$$

where  $\mu_f = a_f * \mu_{pf} * f_{fe} / f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$$\mu_{fx} = 0.15303423$$

Expression ((15B.6), TB DY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2) / 3 = 51733.333$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } \mu_{pf} = 2t_f / b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$\mu_{fy} = 0.15303423$$

Expression ((15B.6), TB DY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2) / 3 = 0.00$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } \mu_{pf} = 2t_f / b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$R = 40.00$$

$$\text{Effective FRP thickness, } t_f = N L * t * \cos(b_1) = 1.016$$

$$f_{u,f} = 1055.00$$

$$E_f = 64828.00$$

$$\mu_{u,f} = 0.015$$

$$a_{se} = \text{Max}(((A_{\text{conf,max}} - A_{\text{noConf}}) / A_{\text{conf,max}}) * (A_{\text{conf,min}} / A_{\text{conf,max}}), 0) = 0.00$$

The definitions of  $A_{\text{noConf}}$ ,  $A_{\text{conf,min}}$  and  $A_{\text{conf,max}}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

Aconf,max = 75600.00 is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

Aconf,min = 0.00 is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area Aconf,max by a length equal to half the clear spacing between hoops.

AnoConf = 33066.667 is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

psh,min = Min(psh,x , psh,y) = 0.00165347

Expression ((5.4d), TBDY) for psh,min has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

psh,x ((5.4d), TBDY) = Lstir\*Astir/(Asec\*s) = 0.00165347

Lstir (Length of stirrups along Y) = 960.00

Astir (stirrups area) = 78.53982

Asec (section area) = 120000.00

psh,y ((5.4d), TBDY) = Lstir\*Astir/(Asec\*s) = 0.00165347

Lstir (Length of stirrups along X) = 960.00

Astir (stirrups area) = 78.53982

Asec (section area) = 120000.00

s = 380.00

fywe = 555.55

fce = 15.00

From ((5.A5), TBDY), TBDY: cc = 0.00475778

c = confinement factor = 1.27578

y1 = 0.0010562

sh1 = 0.00365026

ft1 = 304.185

fy1 = 253.4875

su1 = 0.00365026

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

lo/lou,min = lb/lb = 0.22053887

su1 = 0.4\*esu1\_nominal ((5.5), TBDY) = 0.032

From table 5A.1, TBDY: esu1\_nominal = 0.08,

For calculation of esu1\_nominal and y1, sh1,ft1,fy1, it is considered characteristic value fsy1 = fs1/1.2, from table 5.1, TBDY.

y1, sh1,ft1,fy1, are also multiplied by  $\text{Min}(1, 1.25*(lb/lb)^{2/3})$ , from 10.3.5, ASCE 41-17.

with fs1 = fs = 253.4875

with Es1 = Es = 200000.00

y2 = 0.0010562

sh2 = 0.00365026

ft2 = 304.185

fy2 = 253.4875

su2 = 0.00365026

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

lo/lou,min = lb/lb,min = 0.22053887

su2 = 0.4\*esu2\_nominal ((5.5), TBDY) = 0.032

From table 5A.1, TBDY: esu2\_nominal = 0.08,

For calculation of esu2\_nominal and y2, sh2,ft2,fy2, it is considered characteristic value fsy2 = fs2/1.2, from table 5.1, TBDY.

y1, sh1,ft1,fy1, are also multiplied by  $\text{Min}(1, 1.25*(lb/lb)^{2/3})$ , from 10.3.5, ASCE 41-17.

with fs2 = fs = 253.4875

with Es2 = Es = 200000.00

yv = 0.0010562

shv = 0.00365026

ftv = 304.185

fyv = 253.4875

suv = 0.00365026

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

lo/lou,min = lb/lb = 0.22053887

$\text{suv} = 0.4 \cdot \text{esuv\_nominal} \text{ ((5.5), TBDY)} = 0.032$   
 From table 5A.1, TBDY:  $\text{esuv\_nominal} = 0.08$ ,  
 considering characteristic value  $\text{fsyv} = \text{fsv}/1.2$ , from table 5.1, TBDY  
 For calculation of  $\text{esuv\_nominal}$  and  $\text{yv}$ ,  $\text{shv}$ ,  $\text{ftv}$ ,  $\text{fyv}$ , it is considered  
 characteristic value  $\text{fsyv} = \text{fsv}/1.2$ , from table 5.1, TBDY.  
 $\text{y1}$ ,  $\text{sh1}$ ,  $\text{ft1}$ ,  $\text{fy1}$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (\text{lb}/\text{ld})^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $\text{fsv} = \text{fs} = 253.4875$   
 with  $\text{Esv} = \text{Es} = 200000.00$   
 $1 = \text{Asl,ten}/(\text{b} \cdot \text{d}) \cdot (\text{fs1}/\text{fc}) = 0.09815014$   
 $2 = \text{Asl,com}/(\text{b} \cdot \text{d}) \cdot (\text{fs2}/\text{fc}) = 0.26768221$   
 $\text{v} = \text{Asl,mid}/(\text{b} \cdot \text{d}) \cdot (\text{fsv}/\text{fc}) = 0.24388823$

and confined core properties:

$\text{b} = 340.00$   
 $\text{d} = 327.00$   
 $\text{d}' = 13.00$   
 $\text{fcc} \text{ (5A.2, TBDY)} = 19.13667$   
 $\text{cc} \text{ (5A.5, TBDY)} = 0.00475778$   
 $\text{c} = \text{confinement factor} = 1.27578$   
 $1 = \text{Asl,ten}/(\text{b} \cdot \text{d}) \cdot (\text{fs1}/\text{fc}) = 0.1260644$   
 $2 = \text{Asl,com}/(\text{b} \cdot \text{d}) \cdot (\text{fs2}/\text{fc}) = 0.34381201$   
 $\text{v} = \text{Asl,mid}/(\text{b} \cdot \text{d}) \cdot (\text{fsv}/\text{fc}) = 0.31325094$

Case/Assumption: Unconfined full section - Steel rupture  
 ' satisfies Eq. (4.3)

--->  
 $\text{v} < \text{vs,y2}$  - LHS eq.(4.5) is satisfied  
 ---->  
 $\text{su} \text{ (4.9)} = 0.23431248$   
 $\text{Mu} = \text{MRc} \text{ (4.14)} = 1.2706\text{E}+008$   
 $\text{u} = \text{su} \text{ (4.1)} = 1.3353763\text{E}-005$

Calculation of ratio  $\text{lb}/\text{ld}$

Lap Length:  $\text{lb}/\text{ld} = 0.22053887$   
 $\text{lb} = 300.00$   
 $\text{ld} = 1360.304$   
 Calculation of  $\text{lb,min}$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.  
 $= 1$   
 $\text{db} = 18.00$   
 Mean strength value of all re-bars:  $\text{fy} = 555.55$   
 $\text{fc}' = 15.00$ , but  $\text{fc}'^{0.5} \leq 8.3 \text{ MPa}$  (22.5.3.1, ACI 318-14)  
 $\text{t} = 1.00$   
 $\text{s} = 0.80$   
 $\text{e} = 1.00$   
 $\text{cb} = 24.02082$   
 $\text{Ktr} = 0.82673491$   
 $\text{Atr} = \text{Min}(\text{Atr}_x, \text{Atr}_y) = 157.0796$   
 where  $\text{Atr}_x$ ,  $\text{Atr}_y$  are the sum of the area of all stirrup legs along X and Y loxal axis  
 $\text{s} = 380.00$   
 $\text{n} = 20.00$

Calculation of Shear Strength  $\text{Vr} = \text{Min}(\text{Vr1}, \text{Vr2}) = 196005.816$

Calculation of Shear Strength at edge 1,  $\text{Vr1} = 227350.021$   
 $\text{Vr1} = \text{VCol} \text{ ((10.3), ASCE 41-17)} = \text{knl} \cdot \text{VCol0}$   
 $\text{VCol0} = 227350.021$   
 $\text{knl} = 1$  (zero step-static loading)

NOTE: In expression (10-3) ' $\text{Vs}$ ' is replaced by ' $\text{Vs} + \text{f} \cdot \text{Vf}$ '  
 where  $\text{Vf}$  is the contribution of FRPs (11.3), ACI 440).

$= 1$  (normal-weight concrete)  
 $\text{fc}' = 15.00$ , but  $\text{fc}'^{0.5} \leq 8.3 \text{ MPa}$  (22.5.3.1, ACI 318-14)  
 $\text{M}/\text{Vd} = 2.00$

$\mu_u = 3.21769$   
 $\mu_v = 0.01054019$   
 $d = 0.8 \cdot h = 320.00$   
 $N_u = 4737.328$   
 $A_g = 80000.00$   
 From (11.5.4.8), ACI 318-14:  $V_s = V_{s1} + V_{s2} = 0.00$   
 where:  
 $V_{s1} = 0.00$  is calculated for section web, with:  
 $d = 320.00$   
 $A_v = 157079.633$   
 $f_y = 444.44$   
 $s = 380.00$   
 $V_{s1}$  is multiplied by  $\text{Col1} = 0.00$   
 $s/d = 1.1875$   
 $V_{s2} = 0.00$  is calculated for section flange, with:  
 $d = 160.00$   
 $A_v = 157079.633$   
 $f_y = 444.44$   
 $s = 380.00$   
 $V_{s2}$  is multiplied by  $\text{Col2} = 0.00$   
 $s/d = 2.375$   
 $V_f ((11-3)-(11.4), \text{ACI 440}) = 188111.148$   
 $f = 0.95$ , for fully-wrapped sections  
 $w_f/s_f = 1$  (FRP strips adjacent to one another).  
 In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot \alpha) \sin \alpha$  which is more a generalised expression,  
 where  $\alpha$  is the angle of the crack direction (see KANEPE).  
 This later relation, considered as a function  $V_f(\alpha)$ , is implemented for every different fiber orientation  $\alpha_i$ ,  
 as well as for 2 crack directions,  $\alpha = 45^\circ$  and  $\alpha = -45^\circ$  to take into consideration the cyclic seismic loading.  
 orientation 1:  $\alpha_1 = \alpha_1 + 90^\circ = 90.00$   
 $V_f = \text{Min}(|V_f(45, \alpha_1)|, |V_f(-45, \alpha_1)|)$ , with:  
 total thickness per orientation,  $t_{f1} = N_L \cdot t / N_{\text{Dir}} = 1.016$   
 $d_{fv} = d$  (figure 11.2, ACI 440) = 357.00  
 $f_{fe} ((11-5), \text{ACI 440}) = 259.312$   
 $E_f = 64828.00$   
 $f_e = 0.004$ , from (11.6a), ACI 440  
 with  $f_u = 0.01$   
 From (11-11), ACI 440:  $V_s + V_f \leq 164661.611$   
 $b_w = 200.00$

Calculation of Shear Strength at edge 2,  $V_{r2} = 196005.816$   
 $V_{r2} = V_{\text{Col}} ((10.3), \text{ASCE 41-17}) = k_n l \cdot V_{\text{Col0}}$   
 $V_{\text{Col0}} = 196005.816$   
 $k_n l = 1$  (zero step-static loading)

NOTE: In expression (10-3) ' $V_s$ ' is replaced by ' $V_s + f \cdot V_f$ '  
 where  $V_f$  is the contribution of FRPs (11.3), ACI 440).

$\beta = 1$  (normal-weight concrete)  
 $f_c' = 15.00$ , but  $f_c'^{0.5} \leq 8.3 \text{ MPa}$  (22.5.3.1, ACI 318-14)  
 $M/Vd = 4.00$   
 $\mu_u = 23.99609$   
 $\mu_v = 0.01054019$   
 $d = 0.8 \cdot h = 320.00$   
 $N_u = 4737.328$   
 $A_g = 80000.00$   
 From (11.5.4.8), ACI 318-14:  $V_s = V_{s1} + V_{s2} = 0.00$   
 where:  
 $V_{s1} = 0.00$  is calculated for section web, with:  
 $d = 320.00$   
 $A_v = 157079.633$   
 $f_y = 444.44$   
 $s = 380.00$   
 $V_{s1}$  is multiplied by  $\text{Col1} = 0.00$   
 $s/d = 1.1875$   
 $V_{s2} = 0.00$  is calculated for section flange, with:  
 $d = 160.00$

Av = 157079.633

fy = 444.44

s = 380.00

Vs2 is multiplied by Col2 = 0.00

s/d = 2.375

Vf ((11-3)-(11.4), ACI 440) = 188111.148

f = 0.95, for fully-wrapped sections

wf/sf = 1 (FRP strips adjacent to one another).

In (11.3)  $\sin \theta + \cos \theta$  is replaced with  $(\cot \theta + \cot \alpha) \sin \alpha$  which is more a generalised expression, where  $\theta$  is the angle of the crack direction (see KANEPE).

This later relation, considered as a function  $V_f(\theta, \alpha)$ , is implemented for every different fiber orientation  $\alpha_i$ , as well as for 2 crack directions,  $\theta = 45^\circ$  and  $\theta = -45^\circ$  to take into consideration the cyclic seismic loading.

orientation 1:  $\theta_1 = \theta_1 + 90^\circ = 90.00$

$V_f = \text{Min}(|V_f(45, \theta_1)|, |V_f(-45, \theta_1)|)$ , with:

total thickness per orientation,  $t_{f1} = N_L \cdot t / N_{oDir} = 1.016$

$d_{fv} = d$  (figure 11.2, ACI 440) = 357.00

$f_{fe}((11-5), \text{ACI 440}) = 259.312$

$E_f = 64828.00$

$f_e = 0.004$ , from (11.6a), ACI 440

with  $f_u = 0.01$

From (11-11), ACI 440:  $V_s + V_f \leq 164661.611$

bw = 200.00

-----  
End Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1

At local axis: 3

-----  
Start Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1

At Shear local axis: 2

(Bending local axis: 3)

Section Type: rctcs

Constant Properties

-----  
Knowledge Factor,  $\phi = 0.90$

Mean strength values are used for both shear and moment calculations.

Consequently:

Existing material of Primary Member: Concrete Strength,  $f_c = f_{cm} = 15.00$

Existing material of Primary Member: Steel Strength,  $f_s = f_{sm} = 444.44$

Concrete Elasticity,  $E_c = 18203.022$

Steel Elasticity,  $E_s = 200000.00$

#####

Note: Especially for the calculation of moment strengths,

the above steel re-bar strengths are multiplied by 1.25 according to R18.6.5, ACI 318-14

Existing material: Steel Strength,  $f_s = 1.25 \cdot f_{sm} = 555.55$

#####

Max Height,  $H_{max} = 400.00$

Min Height,  $H_{min} = 200.00$

Max Width,  $W_{max} = 400.00$

Min Width,  $W_{min} = 200.00$

Eccentricity,  $Ecc = 100.00$

Cover Thickness,  $c = 25.00$

Mean Confinement Factor overall section = 1.27578

Element Length,  $L = 3000.00$

Primary Member

Ribbed Bars

Ductile Steel

Without Detailing for Earthquake Resistance (including stirrups not closed at  $135^\circ$ )

Longitudinal Bars With Ends Lapped Starting at the End Sections

Lap Length  $l_o = 300.00$

FRP Wrapping Data

Type: Carbon

Cured laminate properties (design values)

Thickness,  $t = 1.016$

Tensile Strength,  $f_{fu} = 1055.00$   
Tensile Modulus,  $E_f = 64828.00$   
Elongation,  $\epsilon_{fu} = 0.01$   
Number of directions,  $NoDir = 1$   
Fiber orientations,  $b_i = 0.00^\circ$   
Number of layers,  $NL = 1$   
Radius of rounding corners,  $R = 40.00$

#### Stepwise Properties

At local axis: 2  
EDGE -A-  
Shear Force,  $V_a = 1.5456333E-009$   
EDGE -B-  
Shear Force,  $V_b = -1.5456333E-009$   
BOTH EDGES  
Axial Force,  $F = -4737.328$   
Longitudinal Reinforcement Area Distribution (in 2 divisions)  
-Tension:  $As_t = 0.00$   
-Compression:  $As_c = 5152.212$   
Longitudinal Reinforcement Area Distribution (in 3 divisions)  
-Tension:  $As_{t,ten} = 1231.504$   
-Compression:  $As_{l,com} = 1231.504$   
-Middle:  $As_{l,mid} = 2689.203$

Calculation of Shear Capacity ratio,  $V_e/V_r = 0.55718248$   
Member Controlled by Flexure ( $V_e/V_r < 1$ )  
Calculation of Shear Demand from fig. R18.6.5, ACI 318-14  $V_e = (M_{pr1} + M_{pr2})/l_n = 126675.449$   
with  
 $M_{pr1} = \max(\mu_{u1+}, \mu_{u1-}) = 1.9001E+008$   
 $\mu_{u1+} = 1.9001E+008$ , is the ultimate moment strength at the edge 1 of the member in the actual moment direction which is defined for the static loading combination  
 $\mu_{u1-} = 1.9001E+008$ , is the ultimate moment strength at the edge 1 of the member in the opposite moment direction which is defined for the static loading combination  
 $M_{pr2} = \max(\mu_{u2+}, \mu_{u2-}) = 1.9001E+008$   
 $\mu_{u2+} = 1.9001E+008$ , is the ultimate moment strength at the edge 2 of the member in the actual moment direction which is defined for the static loading combination  
 $\mu_{u2-} = 1.9001E+008$ , is the ultimate moment strength at the edge 2 of the member in the opposite moment direction which is defined for the static loading combination

#### Calculation of $\mu_{u1+}$

Calculation of ultimate curvature  $\mu_u$  according to 4.1, Biskinis/Fardis 2013:  
 $\mu_u = 1.7086748E-005$   
 $\mu_u = 1.9001E+008$

with full section properties:

$b = 200.00$   
 $d = 357.00$   
 $d' = 43.00$   
 $v = 0.00442328$   
 $N = 4737.328$   
 $f_c = 15.00$   
 $\phi_o$  (5A.5, TBDY) = 0.002  
Final value of  $\phi_u$ :  $\phi_u^* = \text{shear\_factor} * \max(\phi_u, \phi_o) = 0.018$   
The Shear\_factor is considered equal to 1 (pure moment strength)  
From (5.4b), TBDY:  $\phi_u = 0.018$   
where  $\phi_u$  ((5.4c), TBDY) =  $\phi_u^* \cdot \phi_{u,FRP} / \phi_{u,FRP} + \phi_o$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)



$$f_x = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area})/(\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 51733.333$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A4.4.3(6), } p_f = 2t_f/b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{f,e} = 524.0792$$

$$f_y = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area})/(\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 0.00$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A4.4.3(6), } p_f = 2t_f/b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{f,e} = 524.0792$$

$$R = 40.00$$

$$\text{Effective FRP thickness, } t_f = N_L * t * \cos(\beta_1) = 1.016$$

$$f_{u,f} = 1055.00$$

$$E_f = 64828.00$$

$$u_{f,f} = 0.015$$

$$a_{se} = \text{Max}(((A_{\text{conf,max}} - A_{\text{noConf}})/A_{\text{conf,max}}) * (A_{\text{conf,min}}/A_{\text{conf,max}}), 0) = 0.00$$

The definitions of  $A_{\text{noConf}}$ ,  $A_{\text{conf,min}}$  and  $A_{\text{conf,max}}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{\text{conf,max}} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{\text{conf,min}} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{\text{conf,max}}$  by a length equal to half the clear spacing between hoops.

$A_{\text{noConf}} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$$p_{sh,min} = \text{Min}(p_{sh,x}, p_{sh,y}) = 0.00165347$$

Expression ((5.4d), TBDY) for  $p_{sh,min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$$p_{sh,x} \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$$

$$L_{stir} \text{ (Length of stirrups along Y)} = 960.00$$

$$A_{stir} \text{ (stirrups area)} = 78.53982$$

$$A_{sec} \text{ (section area)} = 120000.00$$

$$p_{sh,y} \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$$

$$L_{stir} \text{ (Length of stirrups along X)} = 960.00$$

$$A_{stir} \text{ (stirrups area)} = 78.53982$$

$$A_{sec} \text{ (section area)} = 120000.00$$

$$s = 380.00$$

$$f_{ywe} = 555.55$$

$$f_{ce} = 15.00$$

$$\text{From ((5.A5), TBDY), TBDY: } c_c = 0.00475778$$

$$c = \text{confinement factor} = 1.27578$$

$$y_1 = 0.0010562$$

$$sh_1 = 0.00365026$$

$$ft_1 = 304.185$$

$$fy_1 = 253.4875$$

$$su_1 = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$$l_o/l_{o,min} = l_b/l_d = 0.22053887$$

$$su_1 = 0.4 * esu_{1,nominal} \text{ ((5.5), TBDY)} = 0.032$$

$$\text{From table 5A.1, TBDY: } esu_{1,nominal} = 0.08,$$

For calculation of  $esu1\_nominal$  and  $y1, sh1, ft1, fy1$ , it is considered characteristic value  $fsy1 = fs1/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fs1 = fs = 253.4875$   
 with  $Es1 = Es = 200000.00$   
 $y2 = 0.0010562$   
 $sh2 = 0.00365026$   
 $ft2 = 304.185$   
 $fy2 = 253.4875$   
 $su2 = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $lo/lo_{ou,min} = lb/lb_{,min} = 0.22053887$   
 $su2 = 0.4 \cdot esu2\_nominal \cdot ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esu2\_nominal = 0.08$ ,  
 For calculation of  $esu2\_nominal$  and  $y2, sh2, ft2, fy2$ , it is considered characteristic value  $fsy2 = fs2/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fs2 = fs = 253.4875$   
 with  $Es2 = Es = 200000.00$   
 $yv = 0.0010562$   
 $shv = 0.00365026$   
 $ftv = 304.185$   
 $fyv = 253.4875$   
 $suv = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $lo/lo_{ou,min} = lb/ld = 0.22053887$   
 $suv = 0.4 \cdot esuv\_nominal \cdot ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esuv\_nominal = 0.08$ ,  
 considering characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY  
 For calculation of  $esuv\_nominal$  and  $yv, shv, ftv, fyv$ , it is considered characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fsv = fs = 253.4875$   
 with  $Esv = Es = 200000.00$   
 $1 = Asl_{ten}/(b \cdot d) \cdot (fs1/fc) = 0.29147618$   
 $2 = Asl_{com}/(b \cdot d) \cdot (fs2/fc) = 0.29147618$   
 $v = Asl_{mid}/(b \cdot d) \cdot (fsv/fc) = 0.6364888$

and confined core properties:

$b = 140.00$   
 $d = 327.00$   
 $d' = 13.00$   
 $f_{cc} (5A.2, TBDY) = 19.13667$   
 $cc (5A.5, TBDY) = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $1 = Asl_{ten}/(b \cdot d) \cdot (fs1/fc) = 0.45459588$   
 $2 = Asl_{com}/(b \cdot d) \cdot (fs2/fc) = 0.45459588$   
 $v = Asl_{mid}/(b \cdot d) \cdot (fsv/fc) = 0.99268896$

Case/Assumption: Unconfined full section - Steel rupture

' satisfies Eq. (4.3)

--->

$v < v_{s,y2}$  - LHS eq.(4.5) is not satisfied

--->

$v < v_{s,c}$  - RHS eq.(4.5) is satisfied

--->

$su (4.8) = 0.40159417$

$Mu = MRc (4.15) = 1.9001E+008$

$u = su (4.1) = 1.7086748E-005$

Calculation of ratio  $lb/ld$

Lap Length:  $lb/ld = 0.22053887$

$lb = 300.00$

$$I_d = 1360.304$$

Calculation of  $I_{b,min}$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.  
 $= 1$

$$d_b = 18.00$$

Mean strength value of all re-bars:  $f_y = 555.55$

$$f_c' = 15.00, \text{ but } f_c'^{0.5} \leq 8.3 \text{ MPa (22.5.3.1, ACI 318-14)}$$

$$t = 1.00$$

$$s = 0.80$$

$$e = 1.00$$

$$c_b = 24.02082$$

$$K_{tr} = 0.82673491$$

$$A_{tr} = \text{Min}(A_{tr_x}, A_{tr_y}) = 157.0796$$

where  $A_{tr_x}$ ,  $A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis

$$s = 380.00$$

$$n = 20.00$$

Calculation of  $\mu_{u1}$ -

Calculation of ultimate curvature  $\mu_u$  according to 4.1, Biskinis/Fardis 2013:

$$\mu_u = 1.7086748E-005$$

$$\mu_u = 1.9001E+008$$

with full section properties:

$$b = 200.00$$

$$d = 357.00$$

$$d' = 43.00$$

$$v = 0.00442328$$

$$N = 4737.328$$

$$f_c = 15.00$$

$$\phi (5A.5, \text{ TBDY}) = 0.002$$

$$\text{Final value of } \mu_u: \mu_u^* = \text{shear\_factor} * \text{Max}(\mu_u, \mu_c) = 0.018$$

The Shear\_factor is considered equal to 1 (pure moment strength)

$$\text{From (5.4b), TBDY: } \mu_u = 0.018$$

$$\mu_u ((5.4c), \text{ TBDY}) = a_s e^* \text{sh}_{min} * f_{ywe} / f_{ce} + \text{Min}(\mu_{fx}, \mu_{fy}) = 0.15303423$$

where  $\mu_f = a_f * \rho_f * f_{fe} / f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$$\mu_{fx} = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{max} - 2R)^2 + (h_{max} - 2R)^2) / 3 = 51733.333$$

$$b_{max} = 400.00$$

$$h_{max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } \rho_f = 2t_f / b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$\mu_{fy} = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{max} - 2R)^2 + (h_{max} - 2R)^2) / 3 = 0.00$$

$$b_{max} = 400.00$$

$$h_{max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } \rho_f = 2t_f / b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$R = 40.00$$

$$\text{Effective FRP thickness, } t_f = N_L * t * \text{Cos}(b_1) = 1.016$$

$$f_{u,f} = 1055.00$$

$$E_f = 64828.00$$

$$\mu_{u,f} = 0.015$$

$$a_s = \text{Max}(((A_{conf,max} - A_{noConf}) / A_{conf,max}) * (A_{conf,min} / A_{conf,max}), 0) = 0.00$$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization

of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$p_{sh,min} = \text{Min}(p_{sh,x}, p_{sh,y}) = 0.00165347$

Expression ((5.4d), TBDY) for  $p_{sh,min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$p_{sh,x} \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$

$L_{stir}$  (Length of stirrups along Y) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$p_{sh,y} \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$

$L_{stir}$  (Length of stirrups along X) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$s = 380.00$

$f_{ywe} = 555.55$

$f_{ce} = 15.00$

From ((5.A5), TBDY), TBDY:  $cc = 0.00475778$

$c$  = confinement factor = 1.27578

$y_1 = 0.0010562$

$sh_1 = 0.00365026$

$ft_1 = 304.185$

$fy_1 = 253.4875$

$su_1 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor

and also multiplied by the shear\_factor according to 15.7.1.4, with

Shear\_factor = 1.00

$lo/lou,min = lb/ld = 0.22053887$

$su_1 = 0.4 * esu1_{nominal} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu1_{nominal} = 0.08$ ,

For calculation of  $esu1_{nominal}$  and  $y_1, sh_1, ft_1, fy_1$ , it is considered

characteristic value  $fsy_1 = fs_1/1.2$ , from table 5.1, TBDY.

$y_1, sh_1, ft_1, fy_1$ , are also multiplied by  $\text{Min}(1, 1.25 * (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.

with  $fs_1 = fs = 253.4875$

with  $Es_1 = Es = 200000.00$

$y_2 = 0.0010562$

$sh_2 = 0.00365026$

$ft_2 = 304.185$

$fy_2 = 253.4875$

$su_2 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor

and also multiplied by the shear\_factor according to 15.7.1.4, with

Shear\_factor = 1.00

$lo/lou,min = lb/lb,min = 0.22053887$

$su_2 = 0.4 * esu2_{nominal} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu2_{nominal} = 0.08$ ,

For calculation of  $esu2_{nominal}$  and  $y_2, sh_2, ft_2, fy_2$ , it is considered

characteristic value  $fsy_2 = fs_2/1.2$ , from table 5.1, TBDY.

$y_2, sh_2, ft_2, fy_2$ , are also multiplied by  $\text{Min}(1, 1.25 * (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.

with  $fs_2 = fs = 253.4875$

with  $Es_2 = Es = 200000.00$

$y_v = 0.0010562$

$sh_v = 0.00365026$

$ft_v = 304.185$

$fy_v = 253.4875$

$suv = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor

and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $l_o/l_{o,min} = l_b/l_d = 0.22053887$   
 $suv = 0.4 * esuv_{nominal} ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esuv_{nominal} = 0.08$ ,  
 considering characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY  
 For calculation of  $esuv_{nominal}$  and  $yv, shv, ftv, fyv$ , it is considered  
 characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $Min(1, 1.25 * (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fsv = fs = 253.4875$   
 with  $Esv = Es = 200000.00$   
 $1 = Asl_{ten}/(b*d) * (fs1/fc) = 0.29147618$   
 $2 = Asl_{com}/(b*d) * (fs2/fc) = 0.29147618$   
 $v = Asl_{mid}/(b*d) * (fsv/fc) = 0.6364888$

and confined core properties:

$b = 140.00$   
 $d = 327.00$   
 $d' = 13.00$   
 $fcc (5A.2, TBDY) = 19.13667$   
 $cc (5A.5, TBDY) = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $1 = Asl_{ten}/(b*d) * (fs1/fc) = 0.45459588$   
 $2 = Asl_{com}/(b*d) * (fs2/fc) = 0.45459588$   
 $v = Asl_{mid}/(b*d) * (fsv/fc) = 0.99268896$

Case/Assumption: Unconfined full section - Steel rupture

' satisfies Eq. (4.3)

--->  
 $v < v_{s,y2}$  - LHS eq.(4.5) is not satisfied

--->  
 $v < v_{s,c}$  - RHS eq.(4.5) is satisfied

--->  
 $su (4.8) = 0.40159417$   
 $Mu = MRc (4.15) = 1.9001E+008$   
 $u = su (4.1) = 1.7086748E-005$

Calculation of ratio  $l_b/l_d$

Lap Length:  $l_b/l_d = 0.22053887$

$l_b = 300.00$   
 $l_d = 1360.304$

Calculation of  $l_b,min$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$= 1$   
 $db = 18.00$   
 Mean strength value of all re-bars:  $fy = 555.55$   
 $fc' = 15.00$ , but  $fc^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)  
 $t = 1.00$   
 $s = 0.80$   
 $e = 1.00$   
 $cb = 24.02082$   
 $Ktr = 0.82673491$   
 $Atr = Min(Atr_x, Atr_y) = 157.0796$   
 where  $Atr_x, Atr_y$  are the sum of the area of all stirrup legs along X and Y loxal axis  
 $s = 380.00$   
 $n = 20.00$

Calculation of  $Mu_{2+}$

Calculation of ultimate curvature  $u$  according to 4.1, Biskinis/Fardis 2013:

$u = 1.7086748E-005$   
 $Mu = 1.9001E+008$

with full section properties:

$$b = 200.00$$

$$d = 357.00$$

$$d' = 43.00$$

$$v = 0.00442328$$

$$N = 4737.328$$

$$f_c = 15.00$$

$$\alpha = 0.002$$

$$\text{Final value of } \alpha = \alpha_{\text{shear\_factor}} * \text{Max}(\alpha_c, \alpha_c) = 0.018$$

The Shear\_factor is considered equal to 1 (pure moment strength)

$$\text{From (5.4b), TBDY: } \alpha = 0.018$$

$$\alpha_{\text{shear\_factor}} ((5.4c), \text{TBDY}) = \alpha_{\text{shear\_factor}} * \min(f_{ywe}/f_c + \min(f_x, f_y)) = 0.15303423$$

where  $f = \alpha_{\text{FRP}} * f_{fe}/f_c$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$$f_x = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $\alpha_{\text{FRP}} = 1 - (\text{Unconfined area})/(\text{total area})$

$$\alpha_{\text{FRP}} = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\text{max}} - 2R)^2 + (h_{\text{max}} - 2R)^2)/3 = 51733.333$$

$$b_{\text{max}} = 400.00$$

$$h_{\text{max}} = 400.00$$

$$\text{From EC8 A4.4.3(6), } \alpha_{\text{FRP}} = 2t_f/b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$f_y = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $\alpha_{\text{FRP}} = 1 - (\text{Unconfined area})/(\text{total area})$

$$\alpha_{\text{FRP}} = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\text{max}} - 2R)^2 + (h_{\text{max}} - 2R)^2)/3 = 0.00$$

$$b_{\text{max}} = 400.00$$

$$h_{\text{max}} = 400.00$$

$$\text{From EC8 A4.4.3(6), } \alpha_{\text{FRP}} = 2t_f/b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$R = 40.00$$

$$\text{Effective FRP thickness, } t_f = N L * t * \cos(\beta_1) = 1.016$$

$$f_{u,f} = 1055.00$$

$$E_f = 64828.00$$

$$u_{f,f} = 0.015$$

$$\alpha_{\text{se}} = \text{Max}(((A_{\text{conf,max}} - A_{\text{noConf}})/A_{\text{conf,max}}) * (A_{\text{conf,min}}/A_{\text{conf,max}}), 0) = 0.00$$

The definitions of  $A_{\text{noConf}}$ ,  $A_{\text{conf,min}}$  and  $A_{\text{conf,max}}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{\text{conf,max}} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{\text{conf,min}} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{\text{conf,max}}$  by a length equal to half the clear spacing between hoops.

$A_{\text{noConf}} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$$\alpha_{\text{shear\_factor}} = \min(\alpha_{\text{shear\_factor,x}}, \alpha_{\text{shear\_factor,y}}) = 0.00165347$$

Expression ((5.4d), TBDY) for  $\alpha_{\text{shear\_factor,min}}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$$\alpha_{\text{shear\_factor,x}} ((5.4d), \text{TBDY}) = L_{\text{stir}} * A_{\text{stir}} / (A_{\text{sec}} * s) = 0.00165347$$

$$L_{\text{stir}} (\text{Length of stirrups along Y}) = 960.00$$

$$A_{\text{stir}} (\text{stirrups area}) = 78.53982$$

$$A_{\text{sec}} (\text{section area}) = 120000.00$$

$$\alpha_{\text{shear\_factor,y}} ((5.4d), \text{TBDY}) = L_{\text{stir}} * A_{\text{stir}} / (A_{\text{sec}} * s) = 0.00165347$$

$$L_{\text{stir}} (\text{Length of stirrups along X}) = 960.00$$

$$A_{\text{stir}} (\text{stirrups area}) = 78.53982$$

$$A_{\text{sec}} (\text{section area}) = 120000.00$$

$$s = 380.00$$

$$f_{ywe} = 555.55$$

$$f_c = 15.00$$

From ((5.A.5), TBDY), TBDY:  $cc = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $y1 = 0.0010562$   
 $sh1 = 0.00365026$   
 $ft1 = 304.185$   
 $fy1 = 253.4875$   
 $su1 = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $lo/lou,min = lb/ld = 0.22053887$   
 $su1 = 0.4 * esu1\_nominal ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esu1\_nominal = 0.08$ ,  
 For calculation of  $esu1\_nominal$  and  $y1, sh1, ft1, fy1$ , it is considered  
 characteristic value  $fsy1 = fs1/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 * (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fs1 = fs = 253.4875$   
 with  $Es1 = Es = 200000.00$   
 $y2 = 0.0010562$   
 $sh2 = 0.00365026$   
 $ft2 = 304.185$   
 $fy2 = 253.4875$   
 $su2 = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $lo/lou,min = lb/lb,min = 0.22053887$   
 $su2 = 0.4 * esu2\_nominal ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esu2\_nominal = 0.08$ ,  
 For calculation of  $esu2\_nominal$  and  $y2, sh2, ft2, fy2$ , it is considered  
 characteristic value  $fsy2 = fs2/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 * (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fs2 = fs = 253.4875$   
 with  $Es2 = Es = 200000.00$   
 $yv = 0.0010562$   
 $shv = 0.00365026$   
 $ftv = 304.185$   
 $fyv = 253.4875$   
 $suv = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $lo/lou,min = lb/ld = 0.22053887$   
 $suv = 0.4 * esuv\_nominal ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esuv\_nominal = 0.08$ ,  
 considering characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY  
 For calculation of  $esuv\_nominal$  and  $yv, shv, ftv, fyv$ , it is considered  
 characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 * (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fsv = fs = 253.4875$   
 with  $Esv = Es = 200000.00$   
 $1 = Asl,ten/(b*d)*(fs1/fc) = 0.29147618$   
 $2 = Asl,com/(b*d)*(fs2/fc) = 0.29147618$   
 $v = Asl,mid/(b*d)*(fsv/fc) = 0.6364888$   
 and confined core properties:  
 $b = 140.00$   
 $d = 327.00$   
 $d' = 13.00$   
 $fcc (5A.2, TBDY) = 19.13667$   
 $cc (5A.5, TBDY) = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $1 = Asl,ten/(b*d)*(fs1/fc) = 0.45459588$   
 $2 = Asl,com/(b*d)*(fs2/fc) = 0.45459588$   
 $v = Asl,mid/(b*d)*(fsv/fc) = 0.99268896$   
 Case/Assumption: Unconfined full section - Steel rupture  
 ' satisfies Eq. (4.3)

--->

$v < v_{s,y2}$  - LHS eq.(4.5) is not satisfied

---->

$v < v_{s,c}$  - RHS eq.(4.5) is satisfied

---->

$\mu_u(4.8) = 0.40159417$

$\mu_u = M_{Rc}(4.15) = 1.9001E+008$

$u = \mu_u(4.1) = 1.7086748E-005$

Calculation of ratio  $l_b/l_d$

Lap Length:  $l_b/l_d = 0.22053887$

$l_b = 300.00$

$l_d = 1360.304$

Calculation of  $l_b$ ,min according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$= 1$

$d_b = 18.00$

Mean strength value of all re-bars:  $f_y = 555.55$

$f_c' = 15.00$ , but  $f_c'^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$t = 1.00$

$s = 0.80$

$e = 1.00$

$c_b = 24.02082$

$K_{tr} = 0.82673491$

$A_{tr} = \text{Min}(A_{tr,x}, A_{tr,y}) = 157.0796$

where  $A_{tr,x}$ ,  $A_{tr,y}$  are the sum of the area of all stirrup legs along X and Y loxal axis

$s = 380.00$

$n = 20.00$

Calculation of  $\mu_u$

Calculation of ultimate curvature  $\mu_u$  according to 4.1, Biskinis/Fardis 2013:

$u = 1.7086748E-005$

$\mu_u = 1.9001E+008$

with full section properties:

$b = 200.00$

$d = 357.00$

$d' = 43.00$

$v = 0.00442328$

$N = 4737.328$

$f_c = 15.00$

$\alpha_{co}(5A.5, \text{TB DY}) = 0.002$

Final value of  $\mu_u$ :  $\mu_u^* = \text{shear\_factor} * \text{Max}(\mu_u, \alpha_{co}) = 0.018$

The Shear\_factor is considered equal to 1 (pure moment strength)

From (5.4b), TB DY:  $\mu_u = 0.018$

we ((5.4c), TB DY) =  $\alpha_{se} * \text{sh}_{\min} * f_{ywe}/f_{ce} + \text{Min}(f_x, f_y) = 0.15303423$

where  $f = \alpha_f * p_f * f_{fe}/f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$f_x = 0.15303423$

Expression ((15B.6), TB DY) is modified as  $\alpha_f = 1 - (\text{Unconfined area})/(\text{total area})$

$\alpha_f = 0.43111111$

with Unconfined area =  $((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 51733.333$

$b_{\max} = 400.00$

$h_{\max} = 400.00$

From EC8 A.4.4.3(6),  $p_f = 2t_f/b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

$f_y = 0.15303423$

Expression ((15B.6), TB DY) is modified as  $\alpha_f = 1 - (\text{Unconfined area})/(\text{total area})$

$\alpha_f = 0.43111111$

with Unconfined area =  $((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 0.00$



bmax = 400.00  
hmax = 400.00  
From EC8 A4.4.3(6),  $pf = 2tf/bw = 0.01016$   
bw = 200.00  
effective stress from (A.35),  $ff,e = 524.0792$

R = 40.00  
Effective FRP thickness,  $tf = NL*t*Cos(b1) = 1.016$   
 $f_{u,f} = 1055.00$   
 $E_f = 64828.00$   
 $u_{,f} = 0.015$

$ase = \text{Max}(((A_{conf,max} - A_{noConf}) / A_{conf,max}) * (A_{conf,min} / A_{conf,max}), 0) = 0.00$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988) "Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$psh,min = \text{Min}(psh,x, psh,y) = 0.00165347$

Expression ((5.4d), TBDY) for  $psh,min$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$psh,x \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$   
 $L_{stir}$  (Length of stirrups along Y) = 960.00  
 $A_{stir}$  (stirrups area) = 78.53982  
 $A_{sec}$  (section area) = 120000.00

$psh,y \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$   
 $L_{stir}$  (Length of stirrups along X) = 960.00  
 $A_{stir}$  (stirrups area) = 78.53982  
 $A_{sec}$  (section area) = 120000.00

s = 380.00  
 $f_{ywe} = 555.55$   
 $f_{ce} = 15.00$

From ((5.A5), TBDY), TBDY:  $cc = 0.00475778$

c = confinement factor = 1.27578

$y1 = 0.0010562$   
 $sh1 = 0.00365026$

$ft1 = 304.185$

$fy1 = 253.4875$

$su1 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$lo/lo_{u,min} = lb/ld = 0.22053887$

$su1 = 0.4 * esu1_{nominal} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu1_{nominal} = 0.08$ ,

For calculation of  $esu1_{nominal}$  and  $y1, sh1, ft1, fy1$ , it is considered characteristic value  $fsy1 = fs1/1.2$ , from table 5.1, TBDY.

$y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 * (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.

with  $fs1 = fs = 253.4875$

with  $Es1 = Es = 200000.00$

$y2 = 0.0010562$   
 $sh2 = 0.00365026$

$ft2 = 304.185$

$fy2 = 253.4875$

$su2 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$lo/lo_{u,min} = lb/lb_{,min} = 0.22053887$

```

su2 = 0.4*esu2_nominal ((5.5), TBDY) = 0.032
From table 5A.1, TBDY: esu2_nominal = 0.08,
For calculation of esu2_nominal and y2, sh2,ft2,fy2, it is considered
characteristic value fsy2 = fs2/1.2, from table 5.1, TBDY.
y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/d)^ 2/3), from 10.3.5, ASCE 41-17.
with fs2 = fs = 253.4875
with Es2 = Es = 200000.00
yv = 0.0010562
shv = 0.00365026
ftv = 304.185
fyv = 253.4875
suv = 0.00365026
using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
and also multiplied by the shear_factor according to 15.7.1.4, with
Shear_factor = 1.00
lo/lou,min = lb/d = 0.22053887
suv = 0.4*esuv_nominal ((5.5), TBDY) = 0.032
From table 5A.1, TBDY: esuv_nominal = 0.08,
considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY
For calculation of esuv_nominal and yv, shv,ftv,fyv, it is considered
characteristic value fsyv = fsv/1.2, from table 5.1, TBDY.
y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/d)^ 2/3), from 10.3.5, ASCE 41-17.
with fsv = fs = 253.4875
with Esv = Es = 200000.00
1 = Asl,ten/(b*d)*(fs1/fc) = 0.29147618
2 = Asl,com/(b*d)*(fs2/fc) = 0.29147618
v = Asl,mid/(b*d)*(fsv/fc) = 0.6364888
and confined core properties:
b = 140.00
d = 327.00
d' = 13.00
fcc (5A.2, TBDY) = 19.13667
cc (5A.5, TBDY) = 0.00475778
c = confinement factor = 1.27578
1 = Asl,ten/(b*d)*(fs1/fc) = 0.45459588
2 = Asl,com/(b*d)*(fs2/fc) = 0.45459588
v = Asl,mid/(b*d)*(fsv/fc) = 0.99268896
Case/Assumption: Unconfined full section - Steel rupture
'satisfies Eq. (4.3)
--->
v < vs,y2 - LHS eq.(4.5) is not satisfied
--->
v < vs,c - RHS eq.(4.5) is satisfied
--->
su (4.8) = 0.40159417
Mu = MRc (4.15) = 1.9001E+008
u = su (4.1) = 1.7086748E-005

```

#### Calculation of ratio lb/d

```

Lap Length: lb/d = 0.22053887
lb = 300.00
ld = 1360.304
Calculation of lb,min according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.
= 1
db = 18.00
Mean strength value of all re-bars: fy = 555.55
fc' = 15.00, but fc^0.5 <= 8.3 MPa (22.5.3.1, ACI 318-14)
t = 1.00
s = 0.80
e = 1.00
cb = 24.02082
Ktr = 0.82673491
Atr = Min(Atr_x,Atr_y) = 157.0796
where Atr_x, Atr_y are the sum of the area of all stirrup legs along X and Y loxal axis
s = 380.00

```

$$n = 20.00$$

$$\text{Calculation of Shear Strength } V_r = \text{Min}(V_{r1}, V_{r2}) = 227350.021$$

$$\text{Calculation of Shear Strength at edge 1, } V_{r1} = 227350.021$$

$$V_{r1} = V_{\text{Col}} \text{ ((10.3), ASCE 41-17)} = k_{nl} \cdot V_{\text{Col0}}$$

$$V_{\text{Col0}} = 227350.021$$

$$k_{nl} = 1 \text{ (zero step-static loading)}$$

NOTE: In expression (10-3) 'Vs' is replaced by 'Vs+ f\*Vf' where Vf is the contribution of FRPs (11.3), ACI 440).

$$= 1 \text{ (normal-weight concrete)}$$

$$f_c' = 15.00, \text{ but } f_c'^{0.5} \leq 8.3 \text{ MPa (22.5.3.1, ACI 318-14)}$$

$$M/Vd = 2.00$$

$$\mu_u = 0.00988804$$

$$V_u = 1.5456333\text{E-}009$$

$$d = 0.8 \cdot h = 320.00$$

$$N_u = 4737.328$$

$$A_g = 80000.00$$

$$\text{From (11.5.4.8), ACI 318-14: } V_s = V_{s1} + V_{s2} = 0.00$$

where:

Vs1 = 0.00 is calculated for section web, with:

$$d = 160.00$$

$$A_v = 157079.633$$

$$f_y = 444.44$$

$$s = 380.00$$

Vs1 is multiplied by Col1 = 0.00

$$s/d = 2.375$$

Vs2 = 0.00 is calculated for section flange, with:

$$d = 320.00$$

$$A_v = 157079.633$$

$$f_y = 444.44$$

$$s = 380.00$$

Vs2 is multiplied by Col2 = 0.00

$$s/d = 1.1875$$

$$V_f \text{ ((11-3)-(11.4), ACI 440)} = 188111.148$$

$$f = 0.95, \text{ for fully-wrapped sections}$$

wf/sf = 1 (FRP strips adjacent to one another).

In (11.3)  $\sin \theta + \cos \theta$  is replaced with  $(\cot \theta + \cot \alpha) \sin \alpha$  which is more a generalised expression, where  $\theta$  is the angle of the crack direction (see KANEPE).

This later relation, considered as a function  $V_f(\theta, \alpha)$ , is implemented for every different fiber orientation  $\alpha_i$ , as well as for 2 crack directions,  $\theta = 45^\circ$  and  $\theta = -45^\circ$  to take into consideration the cyclic seismic loading.

$$\text{orientation 1: } \theta_1 = \theta_1 + 90^\circ = 90.00$$

$$V_f = \text{Min}(|V_f(45, \theta_1)|, |V_f(-45, \theta_1)|), \text{ with:}$$

$$\text{total thickness per orientation, } t_{f1} = N_L \cdot t / N_{\text{Dir}} = 1.016$$

$$d_{fv} = d \text{ (figure 11.2, ACI 440)} = 357.00$$

$$f_{fe} \text{ ((11-5), ACI 440)} = 259.312$$

$$E_f = 64828.00$$

$$f_e = 0.004, \text{ from (11.6a), ACI 440}$$

$$\text{with } f_u = 0.01$$

$$\text{From (11-11), ACI 440: } V_s + V_f \leq 164661.611$$

$$b_w = 200.00$$

$$\text{Calculation of Shear Strength at edge 2, } V_{r2} = 227350.021$$

$$V_{r2} = V_{\text{Col}} \text{ ((10.3), ASCE 41-17)} = k_{nl} \cdot V_{\text{Col0}}$$

$$V_{\text{Col0}} = 227350.021$$

$$k_{nl} = 1 \text{ (zero step-static loading)}$$

NOTE: In expression (10-3) 'Vs' is replaced by 'Vs+ f\*Vf' where Vf is the contribution of FRPs (11.3), ACI 440).

$$= 1 \text{ (normal-weight concrete)}$$

$f_c' = 15.00$ , but  $f_c'^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$M/Vd = 2.00$

$\mu_u = 0.00525978$

$V_u = 1.5456333E-009$

$d = 0.8 \cdot h = 320.00$

$N_u = 4737.328$

$A_g = 80000.00$

From (11.5.4.8), ACI 318-14:  $V_s = V_{s1} + V_{s2} = 0.00$

where:

$V_{s1} = 0.00$  is calculated for section web, with:

$d = 160.00$

$A_v = 157079.633$

$f_y = 444.44$

$s = 380.00$

$V_{s1}$  is multiplied by  $\text{Col1} = 0.00$

$s/d = 2.375$

$V_{s2} = 0.00$  is calculated for section flange, with:

$d = 320.00$

$A_v = 157079.633$

$f_y = 444.44$

$s = 380.00$

$V_{s2}$  is multiplied by  $\text{Col2} = 0.00$

$s/d = 1.1875$

$V_f$  ((11-3)-(11.4), ACI 440) = 188111.148

$f = 0.95$ , for fully-wrapped sections

$w_f/s_f = 1$  (FRP strips adjacent to one another).

In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot a) \sin a$  which is more a generalised expression, where  $a$  is the angle of the crack direction (see KANEPE).

This later relation, considered as a function  $V_f(\theta, a)$ , is implemented for every different fiber orientation  $a_i$ , as well as for 2 crack directions,  $\theta = 45^\circ$  and  $\theta = -45^\circ$  to take into consideration the cyclic seismic loading.

orientation 1:  $\theta_1 = \theta_1 + 90^\circ = 90.00$

$V_f = \text{Min}(|V_f(45, \theta_1)|, |V_f(-45, a_1)|)$ , with:

total thickness per orientation,  $t_{f1} = N_L \cdot t / N_{\text{Dir}} = 1.016$

$d_{fv} = d$  (figure 11.2, ACI 440) = 357.00

$f_{fe}$  ((11-5), ACI 440) = 259.312

$E_f = 64828.00$

$f_e = 0.004$ , from (11.6a), ACI 440

with  $f_u = 0.01$

From (11-11), ACI 440:  $V_s + V_f \leq 164661.611$

$b_w = 200.00$

End Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1

At local axis: 2

Start Of Calculation of Chord Rotation Capacity for element: column TC1 of floor 1

At local axis: 3

Integration Section: (a)

Section Type: rctcs

Constant Properties

Knowledge Factor,  $\phi = 0.90$

Chord Rotation is generally considered as Deformation-Controlled Action according to Table C7-1, ASCE 41-17.

Mean strengths are used for Deformation-Controlled Actions according to 7.5.1.3, ASCE 41-17

Consequently:

Existing material of Primary Member: Concrete Strength,  $f_c = f_{cm} = 15.00$

Existing material of Primary Member: Steel Strength,  $f_s = f_{sm} = 444.44$

Concrete Elasticity,  $E_c = 18203.022$

Steel Elasticity,  $E_s = 200000.00$

Max Height,  $H_{\max} = 400.00$

Min Height,  $H_{\min} = 200.00$

Max Width,  $W_{\max} = 400.00$

Min Width,  $W_{\min} = 200.00$

Eccentricity, Ecc = 100.00  
 Cover Thickness, c = 25.00  
 Element Length, L = 3000.00  
 Primary Member  
 Ribbed Bars  
 Ductile Steel  
 Without Detailing for Earthquake Resistance (including stirrups not closed at 135°)  
 Longitudinal Bars With Ends Lapped Starting at the End Sections  
 Lap Length lb = 300.00  
 FRP Wrapping Data  
 Type: Carbon  
 Cured laminate properties (design values)  
 Thickness, t = 1.016  
 Tensile Strength, ffu = 1055.00  
 Tensile Modulus, Ef = 64828.00  
 Elongation, efu = 0.01  
 Number of directions, NoDir = 1  
 Fiber orientations, bi: 0.00°  
 Number of layers, NL = 1  
 Radius of rounding corners, R = 40.00

#### Stepwise Properties

Bending Moment, M = -1.1892E+007  
 Shear Force, V2 = -3961.043  
 Shear Force, V3 = 0.77690092  
 Axial Force, F = -4742.638  
 Longitudinal Reinforcement Area Distribution (in 2 divisions)  
   -Tension: Aslt = 2375.044  
   -Compression: Aslc = 2777.168  
 Longitudinal Reinforcement Area Distribution (in 3 divisions)  
   -Tension: Asl,ten = 1231.504  
   -Compression: Asl,com = 1231.504  
   -Middle: Asl,mid = 2689.203  
 Mean Diameter of Tension Reinforcement, DbL = 17.60

Existing component: From table 7-7, ASCE 41\_17: Final chord rotation Capacity  $u_R = \frac{u}{p} = 0.05657054$   
 $u = y + p = 0.06285615$

- Calculation of  $y$  -

$y = (M_y * L_s / 3) / E_{eff} = 0.02085615$  ((4.29), Biskinis Phd))  
 $M_y = 1.3657E+008$   
 $L_s = M/V$  (with  $L_s > 0.1 * L$  and  $L_s < 2 * L$ ) = 3002.161  
 From table 10.5, ASCE 41\_17:  $E_{eff} = factor * E_c * I_g = 6.5531E+012$   
 factor = 0.30  
 $A_g = 120000.00$   
 $f_c' = 15.00$   
 $N = 4742.638$   
 $E_c * I_g = 2.1844E+013$

Calculation of Yielding Moment  $M_y$

Calculation of  $y$  and  $M_y$  according to Annex 7 -

$y = \min(y_{ten}, y_{com})$   
 $y_{ten} = 5.8874430E-006$   
 with ((10.1), ASCE 41-17)  $f_y = \min(f_y, 1.25 * f_y * (l_b / d)^{2/3}) = 235.317$   
 $d = 357.00$   
 $y = 0.44020587$

```

A = 0.0724421
B = 0.04070795
with pt = 0.0075814
    pc = 0.01724796
    pv = 0.03766391
    N = 4742.638
    b = 200.00
    " = 0.12044818
y_comp = 1.0162879E-005
with fc* (12.3, (ACI 440)) = 16.12972
    fc = 15.00
    fl = 0.93147527
    b = bmax = 400.00
    h = hmax = 400.00
    Ag = 120000.00
    g = pt + pc + pv = 0.07215983
    rc = 40.00
    Ae/Ac = 0.38686758
    Effective FRP thickness, tf = NL*t*cos(b1) = 1.016
    effective strain from (12.5) and (12.12), efe = 0.004
    fu = 0.01
    Ef = 64828.00
    Ec = 18203.022
    y = 0.43961339
    A = 0.0719516
    B = 0.04042568
    with Es = 200000.00

```

-----

Calculation of ratio lb/l<sub>d</sub>

-----

Lap Length: l<sub>d</sub>/l<sub>d,min</sub> = 0.27567359

l<sub>b</sub> = 300.00

l<sub>d</sub> = 1088.244

Calculation of l according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

= 1

db = 18.00

Mean strength value of all re-bars: f<sub>y</sub> = 444.44

f<sub>c</sub>' = 15.00, but f<sub>c</sub>'<sup>0.5</sup> ≤ 8.3 MPa (22.5.3.1, ACI 318-14)

t = 1.00

s = 0.80

e = 1.00

cb = 24.02082

K<sub>tr</sub> = 0.82673491

A<sub>tr</sub> = Min(A<sub>tr,x</sub>, A<sub>tr,y</sub>) = 157.0796

where A<sub>tr,x</sub>, A<sub>tr,y</sub> are the sum of the area of all stirrup legs along X and Y loxal axis

s = 380.00

n = 20.00

-----

- Calculation of p -

-----

From table 10-8: p = 0.042

with:

- Columns controlled by inadequate development or splicing along the clear height because l<sub>b</sub>/l<sub>d</sub> < 1

shear control ratio V<sub>yE</sub>/V<sub>ColOE</sub> = 0.55718248

d = 357.00

s = 0.00

t = A<sub>v</sub>/(b<sub>w</sub>\*s) + 2\*tf/b<sub>w</sub>\*(f<sub>fe</sub>/f<sub>s</sub>) = A<sub>v</sub>\*L<sub>stir</sub>/(A<sub>g</sub>\*s) + 2\*tf/b<sub>w</sub>\*(f<sub>fe</sub>/f<sub>s</sub>) = 0.0075814

A<sub>v</sub> = 78.53982, is the area of every stirrup

L<sub>stir</sub> = 960.00, is the total Length of all stirrups parallel to loading (shear) direction

The term 2\*tf/b<sub>w</sub>\*(f<sub>fe</sub>/f<sub>s</sub>) is implemented to account for FRP contribution

where f = 2\*tf/b<sub>w</sub> is FRP ratio (EC8 - 3, A.4.4.3(6)) and f<sub>fe</sub>/f<sub>s</sub> normalises f to steel strength

All these variables have already been given in Shear control ratio calculation.

NUD = 4742.638

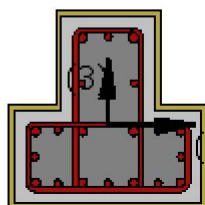
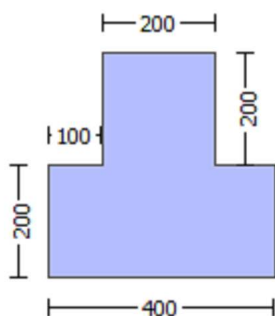
Ag = 120000.00

$f_{cE} = 15.00$   
 $f_{ytE} = f_{yIE} = 444.44$   
 $\rho_l = \text{Area\_Tot\_Long\_Rein}/(b*d) = 0.07215983$   
 $b = 200.00$   
 $d = 357.00$   
 $f_{cE} = 15.00$

-----  
 End Of Calculation of Chord Rotation Capacity for element: column TC1 of floor 1  
 At local axis: 3  
 Integration Section: (a)  
 -----

## Calculation No. 13

column C1, Floor 1  
 Limit State: Collapse Prevention (data interpolation between analysis steps 2 and 3)  
 Analysis: Uniform +X  
 Check: Shear capacity VRd  
 Edge: End  
 Local Axis: (2)



Start Of Calculation of Shear Capacity for element: column TC1 of floor 1  
 At local axis: 2  
 Integration Section: (b)  
 Section Type: rctcs

Constant Properties

-----  
 Knowledge Factor,  $\gamma = 0.90$   
 Member Shear Force is generally considered as Force-Controlled Action according to Table C7-1, ASCE 41-17.  
 Lower-bound strengths are used for Force-Controlled Actions according to 7.5.1.3, ASCE 41-17  
 Consequently:  
 Existing material of Primary Member: Concrete Strength,  $f_c = f_{c\_lower\_bound} = 10.00$   
 Existing material of Primary Member: Steel Strength,  $f_s = f_{s\_lower\_bound} = 400.00$   
 Concrete Elasticity,  $E_c = 18203.022$

Steel Elasticity,  $E_s = 200000.00$   
#####  
Note: Especially for the calculation of  $\gamma$  for displacement ductility demand,  
the expected (mean value) strengths are used (7.5.1.3, ASCE 41-17) because bending is considered as  
Deformation-Controlled Action (Table C7-1, ASCE 41-17).  
Existing material: Concrete Strength,  $f_c = f_{cm} = 15.00$   
Existing material: Steel Strength,  $f_s = f_{sm} = 444.44$   
#####  
Max Height,  $H_{max} = 400.00$   
Min Height,  $H_{min} = 200.00$   
Max Width,  $W_{max} = 400.00$   
Min Width,  $W_{min} = 200.00$   
Eccentricity,  $Ecc = 100.00$   
Cover Thickness,  $c = 25.00$   
Element Length,  $L = 3000.00$   
Primary Member  
Ribbed Bars  
Ductile Steel  
Without Detailing for Earthquake Resistance (including stirrups not closed at 135°)  
Longitudinal Bars With Ends Lapped Starting at the End Sections  
Lap Length  $l_o = l_b = 300.00$   
FRP Wrapping Data  
Type: Carbon  
Cured laminate properties (design values)  
Thickness,  $t = 1.016$   
Tensile Strength,  $f_{fu} = 1055.00$   
Tensile Modulus,  $E_f = 64828.00$   
Elongation,  $\epsilon_{fu} = 0.01$   
Number of directions,  $NoDir = 1$   
Fiber orientations,  $b_i: 0.00^\circ$   
Number of layers,  $NL = 1$   
Radius of rounding corners,  $R = 40.00$

#### Stepwise Properties

EDGE -A-  
Bending Moment,  $M_a = -1.1892E+007$   
Shear Force,  $V_a = -3961.043$   
EDGE -B-  
Bending Moment,  $M_b = 1473.353$   
Shear Force,  $V_b = 3961.043$   
BOTH EDGES  
Axial Force,  $F = -4742.638$   
Longitudinal Reinforcement Area Distribution (in 2 divisions)  
-Tension:  $As_t = 0.00$   
-Compression:  $As_c = 5152.212$   
Longitudinal Reinforcement Area Distribution (in 3 divisions)  
-Tension:  $As_{t,ten} = 1231.504$   
-Compression:  $As_{c,com} = 1231.504$   
-Middle:  $As_{mid} = 2689.203$   
Mean Diameter of Tension Reinforcement,  $Db_{L,ten} = 17.60$

Existing component: From table 7-7, ASCE 41-17: Final Shear Capacity  $V_R = \phi V_n = 167222.274$   
 $V_n$  ((10.3), ASCE 41-17) =  $k_n \phi V_{CoI} = 185802.527$   
 $V_{CoI} = 185802.527$   
 $k_n = 1.00$   
displacement\_ductility\_demand = 0.13062129

NOTE: In expression (10-3) ' $V_s$ ' is replaced by ' $V_s + \phi V_f$ '  
where  $V_f$  is the contribution of FRPs (11.3), ACI 440).

= 1 (normal-weight concrete)  
 $f'_c = 10.00$ , but  $f'_c^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)



$M/Vd = 2.00$   
 $\mu_u = 1473.353$   
 $V_u = 3961.043$   
 $d = 0.8 \cdot h = 320.00$   
 $N_u = 4742.638$   
 $A_g = 80000.00$   
 From (11.5.4.8), ACI 318-14:  $V_s = V_{s1} + V_{s2} = 0.00$   
 where:  
 $V_{s1} = 0.00$  is calculated for section web, with:  
 $d = 160.00$   
 $A_v = 157079.633$   
 $f_y = 400.00$   
 $s = 380.00$   
 $V_{s1}$  is multiplied by  $\text{Col1} = 0.00$   
 $s/d = 2.375$   
 $V_{s2} = 0.00$  is calculated for section flange, with:  
 $d = 320.00$   
 $A_v = 157079.633$   
 $f_y = 400.00$   
 $s = 380.00$   
 $V_{s2}$  is multiplied by  $\text{Col2} = 0.00$   
 $s/d = 1.1875$   
 $V_f ((11-3)-(11.4), \text{ACI } 440) = 188111.148$   
 $f = 0.95$ , for fully-wrapped sections  
 $w_f/s_f = 1$  (FRP strips adjacent to one another).  
 In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot a) \sin a$  which is more a generalised expression,  
 where  $a$  is the angle of the crack direction (see KANEPE).  
 This later relation, considered as a function  $V_f(\theta, a)$ , is implemented for every different fiber orientation  $a_i$ ,  
 as well as for 2 crack directions,  $\theta = 45^\circ$  and  $\theta = -45^\circ$  to take into consideration the cyclic seismic loading.  
 orientation 1:  $\theta = b_1 + 90^\circ = 90.00$   
 $V_f = \text{Min}(|V_f(45, \theta)|, |V_f(-45, a_1)|)$ , with:  
 total thickness per orientation,  $t_{f1} = N_L \cdot t / N_{\text{Dir}} = 1.016$   
 $d_{fv} = d$  (figure 11.2, ACI 440) = 357.00  
 $f_{fe} ((11-5), \text{ACI } 440) = 259.312$   
 $E_f = 64828.00$   
 $f_e = 0.004$ , from (11.6a), ACI 440  
 with  $f_u = 0.01$   
 From (11-11), ACI 440:  $V_s + V_f \leq 134445.642$   
 $b_w = 200.00$

displacement\_ductility\_demand is calculated as  $\delta / y$

- Calculation of  $\delta / y$  for END B -  
 for rotation axis 3 and integ. section (b)

From analysis, chord rotation  $\theta = 0.00027223$   
 $y = (M_y \cdot L_s / 3) / E_{\text{eff}} = 0.00208411$  ((4.29), Biskinis Phd))  
 $M_y = 1.3657\text{E}+008$   
 $L_s = M/V$  (with  $L_s > 0.1 \cdot L$  and  $L_s < 2 \cdot L$ ) = 300.00  
 From table 10.5, ASCE 41\_17:  $E_{\text{eff}} = \text{factor} \cdot E_c \cdot I_g = 6.5531\text{E}+012$   
 factor = 0.30  
 $A_g = 120000.00$   
 $f_c' = 15.00$   
 $N = 4742.638$   
 $E_c \cdot I_g = 2.1844\text{E}+013$

Calculation of Yielding Moment  $M_y$

Calculation of  $\delta$  and  $M_y$  according to Annex 7 -

$y = \text{Min}(\delta_{\text{ten}}, \delta_{\text{com}})$   
 $\delta_{\text{ten}} = 5.8874430\text{E}-006$   
 with ((10.1), ASCE 41-17)  $f_y = \text{Min}(f_y, 1.25 \cdot f_y \cdot (I_b / I_d)^{2/3}) = 235.317$

```

d = 357.00
y = 0.44020587
A = 0.0724421
B = 0.04070795
with pt = 0.01724796
    pc = 0.01724796
    pv = 0.03766391
    N = 4742.638
    b = 200.00
    " = 0.12044818
y_comp = 1.0162879E-005
with fc* (12.3, (ACI 440)) = 16.12972
    fc = 15.00
    fl = 0.93147527
    b = bmax = 400.00
    h = hmax = 400.00
    Ag = 120000.00
    g = pt + pc + pv = 0.07215983
    rc = 40.00
    Ae/Ac = 0.38686758
    Effective FRP thickness, tf = NL*t*cos(b1) = 1.016
    effective strain from (12.5) and (12.12), efe = 0.004
    fu = 0.01
    Ef = 64828.00
    Ec = 18203.022
    y = 0.43961339
    A = 0.0719516
    B = 0.04042568
    with Es = 200000.00

```

-----

Calculation of ratio lb/l<sub>d</sub>

-----

Lap Length: l<sub>d</sub>/l<sub>d,min</sub> = 0.27567359

l<sub>b</sub> = 300.00

l<sub>d</sub> = 1088.244

Calculation of l according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

= 1

db = 18.00

Mean strength value of all re-bars: f<sub>y</sub> = 444.44

f<sub>c</sub>' = 15.00, but f<sub>c</sub>'<sup>0.5</sup> ≤ 8.3 MPa (22.5.3.1, ACI 318-14)

t = 1.00

s = 0.80

e = 1.00

cb = 24.02082

K<sub>tr</sub> = 0.82673491

A<sub>tr</sub> = Min(A<sub>tr\_x</sub>, A<sub>tr\_y</sub>) = 157.0796

where A<sub>tr\_x</sub>, A<sub>tr\_y</sub> are the sum of the area of all stirrup legs along X and Y local axis

s = 380.00

n = 20.00

-----

End Of Calculation of Shear Capacity for element: column TC1 of floor 1

At local axis: 2

Integration Section: (b)

-----

**Calculation No. 14**

column C1, Floor 1

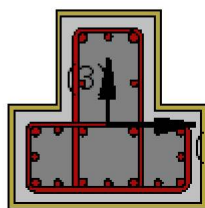
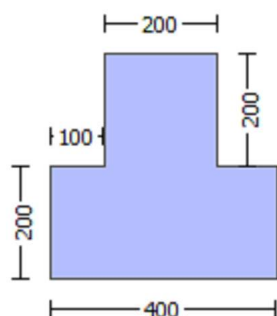
Limit State: Collapse Prevention (data interpolation between analysis steps 2 and 3)

Analysis: Uniform +X

Check: Chord rotation capacity (  $\phi$  )

Edge: End

Local Axis: (2)



Start Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1

At Shear local axis: 3

(Bending local axis: 2)

Section Type: rctcs

Constant Properties

Knowledge Factor,  $\gamma = 0.90$

Mean strength values are used for both shear and moment calculations.

Consequently:

Existing material of Primary Member: Concrete Strength,  $f_c = f_{cm} = 15.00$

Existing material of Primary Member: Steel Strength,  $f_s = f_{sm} = 444.44$

Concrete Elasticity,  $E_c = 18203.022$

Steel Elasticity,  $E_s = 200000.00$

#####

Note: Especially for the calculation of moment strengths,

the above steel re-bar strengths are multiplied by 1.25 according to R18.6.5, ACI 318-14

Existing material: Steel Strength,  $f_s = 1.25 \cdot f_{sm} = 555.55$

#####

Max Height,  $H_{max} = 400.00$

Min Height,  $H_{min} = 200.00$

Max Width,  $W_{max} = 400.00$

Min Width,  $W_{min} = 200.00$

Eccentricity,  $Ecc = 100.00$

Cover Thickness,  $c = 25.00$

Mean Confinement Factor overall section = 1.27578

Element Length,  $L = 3000.00$

Primary Member

Ribbed Bars

Ductile Steel

Without Detailing for Earthquake Resistance (including stirrups not closed at 135°)

Longitudinal Bars With Ends Lapped Starting at the End Sections

Lap Length  $l_o = 300.00$

FRP Wrapping Data

Type: Carbon

Cured laminate properties (design values)

Thickness,  $t = 1.016$

Tensile Strength,  $f_{fu} = 1055.00$

Tensile Modulus,  $E_f = 64828.00$

Elongation,  $\epsilon_{fu} = 0.01$   
Number of directions,  $NoDir = 1$   
Fiber orientations,  $bi = 0.00^\circ$   
Number of layers,  $NL = 1$   
Radius of rounding corners,  $R = 40.00$

#### Stepwise Properties

At local axis: 3  
EDGE -A-  
Shear Force,  $V_a = 0.01054019$   
EDGE -B-  
Shear Force,  $V_b = -0.01054019$   
BOTH EDGES  
Axial Force,  $F = -4737.328$   
Longitudinal Reinforcement Area Distribution (in 2 divisions)  
-Tension:  $As_t = 0.00$   
-Compression:  $As_c = 5152.212$   
Longitudinal Reinforcement Area Distribution (in 3 divisions)  
-Tension:  $As_{ten} = 2261.947$   
-Compression:  $As_{com} = 829.3805$   
-Middle:  $As_{mid} = 2060.885$

Calculation of Shear Capacity ratio,  $V_e/V_r = 0.82694402$   
Member Controlled by Flexure ( $V_e/V_r < 1$ )  
Calculation of Shear Demand from fig. R18.6.5, ACI 318-14  $V_e = (M_{pr1} + M_{pr2})/l_n = 162085.836$   
with  
 $M_{pr1} = \max(\mu_{u1+}, \mu_{u1-}) = 2.4313E+008$   
 $\mu_{u1+} = 2.4313E+008$ , is the ultimate moment strength at the edge 1 of the member in the actual moment direction which is defined for the static loading combination  
 $\mu_{u1-} = 1.2706E+008$ , is the ultimate moment strength at the edge 1 of the member in the opposite moment direction which is defined for the static loading combination  
 $M_{pr2} = \max(\mu_{u2+}, \mu_{u2-}) = 2.4313E+008$   
 $\mu_{u2+} = 2.4313E+008$ , is the ultimate moment strength at the edge 2 of the member in the actual moment direction which is defined for the static loading combination  
 $\mu_{u2-} = 1.2706E+008$ , is the ultimate moment strength at the edge 2 of the member in the opposite moment direction which is defined for the static loading combination

#### Calculation of $\mu_{u1+}$

Calculation of ultimate curvature  $\mu_u$  according to 4.1, Biskinis/Fardis 2013:  
 $\mu_u = 2.6161250E-005$   
 $\mu_u = 2.4313E+008$

with full section properties:

$b = 200.00$   
 $d = 357.00$   
 $d' = 43.00$   
 $v = 0.00442328$   
 $N = 4737.328$   
 $f_c = 15.00$   
 $\alpha_1(5A.5, TBDY) = 0.002$   
Final value of  $\alpha_1$ :  $\alpha_1^* = \text{shear\_factor} * \max(\alpha_c, \alpha_1) = 0.018$   
The Shear\_factor is considered equal to 1 (pure moment strength)  
From (5.4b), TBDY:  $\alpha_1 = 0.018$   
where  $\alpha_1 = \alpha_1^* \cdot \frac{f_{yk}}{f_{yk} + f_{yk} - f_{yk}} = 0.15303423$   
where  $f = \alpha_1 \cdot \frac{f_{yk}}{f_{yk} + f_{yk} - f_{yk}}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)  
 $f_x = 0.15303423$   
Expression ((15B.6), TBDY) is modified as  $\alpha_1 = 1 - (\text{Unconfined area})/(\text{total area})$

$$af = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 51733.333$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A4.4.3(6), } pf = 2tf/bw = 0.01016$$

$$bw = 200.00$$

$$\text{effective stress from (A.35), } ff,e = 524.0792$$

$$fy = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $af = 1 - (\text{Unconfined area})/(\text{total area})$

$$af = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 0.00$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A4.4.3(6), } pf = 2tf/bw = 0.01016$$

$$bw = 200.00$$

$$\text{effective stress from (A.35), } ff,e = 524.0792$$

$$R = 40.00$$

$$\text{Effective FRP thickness, } tf = NL * t * \cos(b1) = 1.016$$

$$fu,f = 1055.00$$

$$Ef = 64828.00$$

$$u,f = 0.015$$

$$ase = \text{Max}(((A_{\text{conf,max}} - A_{\text{noConf}})/A_{\text{conf,max}}) * (A_{\text{conf,min}}/A_{\text{conf,max}}), 0) = 0.00$$

The definitions of  $A_{\text{noConf}}$ ,  $A_{\text{conf,min}}$  and  $A_{\text{conf,max}}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{\text{conf,max}} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{\text{conf,min}} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{\text{conf,max}}$  by a length equal to half the clear spacing between hoops.

$A_{\text{noConf}} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$$psh_{\min} = \text{Min}(psh_x, psh_y) = 0.00165347$$

Expression ((5.4d), TBDY) for  $psh_{\min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$$psh_x \text{ ((5.4d), TBDY)} = L_{\text{stir}} * A_{\text{stir}} / (A_{\text{sec}} * s) = 0.00165347$$

$$L_{\text{stir}} \text{ (Length of stirrups along Y)} = 960.00$$

$$A_{\text{stir}} \text{ (stirrups area)} = 78.53982$$

$$A_{\text{sec}} \text{ (section area)} = 120000.00$$

$$psh_y \text{ ((5.4d), TBDY)} = L_{\text{stir}} * A_{\text{stir}} / (A_{\text{sec}} * s) = 0.00165347$$

$$L_{\text{stir}} \text{ (Length of stirrups along X)} = 960.00$$

$$A_{\text{stir}} \text{ (stirrups area)} = 78.53982$$

$$A_{\text{sec}} \text{ (section area)} = 120000.00$$

$$s = 380.00$$

$$fy_{we} = 555.55$$

$$f_{ce} = 15.00$$

$$\text{From ((5.A5), TBDY), TBDY: } cc = 0.00475778$$

$$c = \text{confinement factor} = 1.27578$$

$$y1 = 0.0010562$$

$$sh1 = 0.00365026$$

$$ft1 = 304.185$$

$$fy1 = 253.4875$$

$$su1 = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$$lo/lou_{\min} = lb/ld = 0.22053887$$

$$su1 = 0.4 * esu1_{\text{nominal}} \text{ ((5.5), TBDY)} = 0.032$$

From table 5A.1, TBDY:  $esu1_{\text{nominal}} = 0.08$ ,

For calculation of  $esu1_{\text{nominal}}$  and  $y1$ ,  $sh1$ ,  $ft1$ ,  $fy1$ , it is considered characteristic value  $fsy1 = fs1/1.2$ , from table 5.1, TBDY.

$y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fs1 = fs = 253.4875$   
 with  $Es1 = Es = 200000.00$   
 $y2 = 0.0010562$   
 $sh2 = 0.00365026$   
 $ft2 = 304.185$   
 $fy2 = 253.4875$   
 $su2 = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $lo/lou, min = lb/lb, min = 0.22053887$   
 $su2 = 0.4 \cdot esu2\_nominal ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esu2\_nominal = 0.08$ ,  
 For calculation of  $esu2\_nominal$  and  $y2, sh2, ft2, fy2$ , it is considered  
 characteristic value  $fsy2 = fs2/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fs2 = fs = 253.4875$   
 with  $Es2 = Es = 200000.00$   
 $yv = 0.0010562$   
 $shv = 0.00365026$   
 $ftv = 304.185$   
 $fyv = 253.4875$   
 $suv = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $lo/lou, min = lb/ld = 0.22053887$   
 $suv = 0.4 \cdot esuv\_nominal ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esuv\_nominal = 0.08$ ,  
 considering characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY  
 For calculation of  $esuv\_nominal$  and  $yv, shv, ftv, fyv$ , it is considered  
 characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fsv = fs = 253.4875$   
 with  $Esv = Es = 200000.00$   
 $1 = Asl, ten / (b \cdot d) \cdot (fs1 / fc) = 0.53536441$   
 $2 = Asl, com / (b \cdot d) \cdot (fs2 / fc) = 0.19630028$   
 $v = Asl, mid / (b \cdot d) \cdot (fsv / fc) = 0.48777647$

and confined core properties:

$b = 140.00$   
 $d = 327.00$   
 $d' = 13.00$   
 $fcc (5A.2, TBDY) = 19.13667$   
 $cc (5A.5, TBDY) = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $1 = Asl, ten / (b \cdot d) \cdot (fs1 / fc) = 0.83497202$   
 $2 = Asl, com / (b \cdot d) \cdot (fs2 / fc) = 0.30615641$   
 $v = Asl, mid / (b \cdot d) \cdot (fsv / fc) = 0.76075229$

Case/Assumption: Unconfined full section - Steel rupture

' satisfies Eq. (4.3)

----

$v < vs, y2$  - LHS eq.(4.5) is not satisfied

----

$v < vs, c$  - RHS eq.(4.5) is not satisfied

----

Case/Assumption Rejected.

----

New Case/Assumption: Unconfined full section - Spalling of concrete cover

' satisfies Eq. (4.4)

----

$v < s, y1$  - LHS eq.(4.7) is not satisfied

----

$v < vc, y1$  - RHS eq.(4.6) is satisfied

----

$cu (4.10) = 0.46564051$

$MRC (4.17) = 2.0934E+008$

```

--->
New Case/Assumption: Ultimate curvature of confined core after spalling of concrete cover
In expressions below, the following modifications have been made
- b, d, d' replaced by geometric parameters of the core: bo, do, d'o
- N,  $\epsilon_s$ ,  $\epsilon_c$  v normalised to bo*do, instead of b*d
-  $\epsilon_{cc}$ ,  $\epsilon_{cc}$  parameters of confined concrete,  $\epsilon_{cc}$ ,  $\epsilon_{cc}$  used in lieu of  $\epsilon_c$ ,  $\epsilon_{cc}$ 
--->
Subcase: Rupture of tension steel
--->
 $\epsilon_s^* < \epsilon_{sy}$  - LHS eq.(4.5) is not satisfied
--->
 $\epsilon_s^* < \epsilon_{sc}$  - LHS eq.(4.5) is not satisfied
--->
Subcase rejected
--->
New Subcase: Failure of compression zone
--->
 $\epsilon_c^* < \epsilon_{cy}$  - LHS eq.(4.6) is not satisfied
--->
 $\epsilon_c^* < \epsilon_{cy}$  - RHS eq.(4.6) is satisfied
--->
 $\epsilon_{cu}$  (4.10) = 0.55615794
MRo (4.17) = 2.4313E+008
--->
 $\epsilon_u = \epsilon_{cu}$  (4.2) = 2.6161250E-005
Mu = MRo
-----

Calculation of ratio lb/ld
-----
Lap Length: lb/ld = 0.22053887
lb = 300.00
ld = 1360.304
Calculation of lb,min according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.
= 1
db = 18.00
Mean strength value of all re-bars: fy = 555.55
fc' = 15.00, but  $f_c^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)
t = 1.00
s = 0.80
e = 1.00
cb = 24.02082
Ktr = 0.82673491
Atr = Min(Atr_x, Atr_y) = 157.0796
where Atr_x, Atr_y are the sum of the area of all stirrup legs along X and Y loxal axis
s = 380.00
n = 20.00
-----
-----
-----

Calculation of Mu1-
-----
-----

Calculation of ultimate curvature  $\epsilon_u$  according to 4.1, Biskinis/Fardis 2013:
 $\epsilon_u = 1.3353763E-005$ 
Mu = 1.2706E+008
-----

with full section properties:
b = 400.00
d = 357.00
d' = 43.00
v = 0.00221164
N = 4737.328
fc = 15.00
 $\epsilon_{co}$  (5A.5, TBDY) = 0.002
Final value of  $\epsilon_{cu}$ :  $\epsilon_{cu}^* = \text{shear\_factor} * \text{Max}(\epsilon_{cu}, \epsilon_{cc}) = 0.018$ 

```

The Shear\_factor is considered equal to 1 (pure moment strength)

From (5.4b), TBDY:  $c_u = 0.018$

we ((5.4c), TBDY) =  $ase * sh_{min} * fy_{we} / f_{ce} + \min(f_x, f_y) = 0.15303423$

where  $f = af * pf * f_{fe} / f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$f_x = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $af = 1 - (\text{Unconfined area}) / (\text{total area})$

$af = 0.43111111$

with Unconfined area =  $((b_{max} - 2R)^2 + (h_{max} - 2R)^2) / 3 = 51733.333$

$b_{max} = 400.00$

$h_{max} = 400.00$

From EC8 A4.4.3(6),  $pf = 2tf / bw = 0.01016$

$bw = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

$f_y = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $af = 1 - (\text{Unconfined area}) / (\text{total area})$

$af = 0.43111111$

with Unconfined area =  $((b_{max} - 2R)^2 + (h_{max} - 2R)^2) / 3 = 0.00$

$b_{max} = 400.00$

$h_{max} = 400.00$

From EC8 A4.4.3(6),  $pf = 2tf / bw = 0.01016$

$bw = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

$R = 40.00$

Effective FRP thickness,  $tf = NL * t * \cos(b1) = 1.016$

$f_{u,f} = 1055.00$

$E_f = 64828.00$

$u_{f} = 0.015$

$ase = \max((A_{conf,max} - A_{noConf}) / A_{conf,max}) * (A_{conf,min} / A_{conf,max}, 0) = 0.00$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2 / 6$  as defined at (A.2).

$psh_{min} = \min(psh_x, psh_y) = 0.00165347$

Expression ((5.4d), TBDY) for  $psh_{min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$psh_x$  ((5.4d), TBDY) =  $L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$

$L_{stir}$  (Length of stirrups along Y) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$psh_y$  ((5.4d), TBDY) =  $L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$

$L_{stir}$  (Length of stirrups along X) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$s = 380.00$

$fy_{we} = 555.55$

$f_{ce} = 15.00$

From ((5.A5), TBDY), TBDY:  $cc = 0.00475778$

$c$  = confinement factor = 1.27578

$y1 = 0.0010562$

$sh1 = 0.00365026$

$ft1 = 304.185$

$fy1 = 253.4875$

$su1 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor



and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $l_o/l_{ou,min} = l_b/l_d = 0.22053887$   
 $su_1 = 0.4 * esu_{1,nominal} ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esu_{1,nominal} = 0.08$ ,  
 For calculation of  $esu_{1,nominal}$  and  $y_1, sh_1, ft_1, fy_1$ , it is considered  
 characteristic value  $fsy_1 = fs_1/1.2$ , from table 5.1, TBDY.  
 $y_1, sh_1, ft_1, fy_1$ , are also multiplied by  $Min(1, 1.25 * (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fs_1 = fs = 253.4875$   
 with  $Es_1 = Es = 200000.00$   
 $y_2 = 0.0010562$   
 $sh_2 = 0.00365026$   
 $ft_2 = 304.185$   
 $fy_2 = 253.4875$   
 $su_2 = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $l_o/l_{ou,min} = l_b/l_{b,min} = 0.22053887$   
 $su_2 = 0.4 * esu_{2,nominal} ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esu_{2,nominal} = 0.08$ ,  
 For calculation of  $esu_{2,nominal}$  and  $y_2, sh_2, ft_2, fy_2$ , it is considered  
 characteristic value  $fsy_2 = fs_2/1.2$ , from table 5.1, TBDY.  
 $y_1, sh_1, ft_1, fy_1$ , are also multiplied by  $Min(1, 1.25 * (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fs_2 = fs = 253.4875$   
 with  $Es_2 = Es = 200000.00$   
 $y_v = 0.0010562$   
 $sh_v = 0.00365026$   
 $ft_v = 304.185$   
 $fy_v = 253.4875$   
 $suv = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $l_o/l_{ou,min} = l_b/l_d = 0.22053887$   
 $suv = 0.4 * esuv_{nominal} ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esuv_{nominal} = 0.08$ ,  
 considering characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY  
 For calculation of  $esuv_{nominal}$  and  $y_v, sh_v, ft_v, fy_v$ , it is considered  
 characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY.  
 $y_1, sh_1, ft_1, fy_1$ , are also multiplied by  $Min(1, 1.25 * (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fsv = fs = 253.4875$   
 with  $Esv = Es = 200000.00$   
 $1 = Asl_{ten}/(b*d) * (fs_1/fc) = 0.09815014$   
 $2 = Asl_{com}/(b*d) * (fs_2/fc) = 0.26768221$   
 $v = Asl_{mid}/(b*d) * (fsv/fc) = 0.24388823$   
 and confined core properties:  
 $b = 340.00$   
 $d = 327.00$   
 $d' = 13.00$   
 $f_{cc} (5A.2, TBDY) = 19.13667$   
 $cc (5A.5, TBDY) = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $1 = Asl_{ten}/(b*d) * (fs_1/fc) = 0.1260644$   
 $2 = Asl_{com}/(b*d) * (fs_2/fc) = 0.34381201$   
 $v = Asl_{mid}/(b*d) * (fsv/fc) = 0.31325094$   
 Case/Assumption: Unconfined full section - Steel rupture  
 ' satisfies Eq. (4.3)  
 --->  
 $v < v_{s,y2}$  - LHS eq.(4.5) is satisfied  
 --->  
 $su (4.9) = 0.23431248$   
 $Mu = MRc (4.14) = 1.2706E+008$   
 $u = su (4.1) = 1.3353763E-005$

-----  
 Calculation of ratio  $l_b/l_d$

Lap Length:  $l_b/l_d = 0.22053887$

$l_b = 300.00$

$l_d = 1360.304$

Calculation of  $l_b$ , min according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$= 1$

$d_b = 18.00$

Mean strength value of all re-bars:  $f_y = 555.55$

$f_c' = 15.00$ , but  $f_c'^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$t = 1.00$

$s = 0.80$

$e = 1.00$

$c_b = 24.02082$

$K_{tr} = 0.82673491$

$A_{tr} = \text{Min}(A_{tr_x}, A_{tr_y}) = 157.0796$

where  $A_{tr_x}$ ,  $A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis

$s = 380.00$

$n = 20.00$

Calculation of  $\mu_{2+}$

Calculation of ultimate curvature  $\mu$  according to 4.1, Biskinis/Fardis 2013:

$\mu = 2.6161250E-005$

$\mu = 2.4313E+008$

with full section properties:

$b = 200.00$

$d = 357.00$

$d' = 43.00$

$v = 0.00442328$

$N = 4737.328$

$f_c = 15.00$

$c_o$  (5A.5, TBDY) = 0.002

Final value of  $\mu$ :  $\mu^* = \text{shear\_factor} * \text{Max}(\mu, c_o) = 0.018$

The Shear\_factor is considered equal to 1 (pure moment strength)

From (5.4b), TBDY:  $\mu = 0.018$

we ((5.4c), TBDY) =  $a_s e^* \text{sh}_{\min} f_{ywe}/f_{ce} + \text{Min}(f_x, f_y) = 0.15303423$

where  $f = a_f p_f f_{fe}/f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$f_x = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area})/(\text{total area})$

$a_f = 0.43111111$

with Unconfined area =  $((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 51733.333$

$b_{\max} = 400.00$

$h_{\max} = 400.00$

From EC8 A.4.4.3(6),  $p_f = 2t_f/b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

$f_y = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area})/(\text{total area})$

$a_f = 0.43111111$

with Unconfined area =  $((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 0.00$

$b_{\max} = 400.00$

$h_{\max} = 400.00$

From EC8 A.4.4.3(6),  $p_f = 2t_f/b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

$R = 40.00$

Effective FRP thickness,  $t_f = N L^* t \cos(b_1) = 1.016$

$f_{u,f} = 1055.00$

$E_f = 64828.00$

$$u,f = 0.015$$

$$ase = \text{Max}(((A_{conf,max} - A_{noConf}) / A_{conf,max}) * (A_{conf,min} / A_{conf,max}), 0) = 0.00$$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$$psh,min = \text{Min}(psh,x, psh,y) = 0.00165347$$

Expression ((5.4d), TBDY) for  $psh,min$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$$psh,x \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$$

$$L_{stir} \text{ (Length of stirrups along Y)} = 960.00$$

$$A_{stir} \text{ (stirrups area)} = 78.53982$$

$$A_{sec} \text{ (section area)} = 120000.00$$

$$psh,y \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$$

$$L_{stir} \text{ (Length of stirrups along X)} = 960.00$$

$$A_{stir} \text{ (stirrups area)} = 78.53982$$

$$A_{sec} \text{ (section area)} = 120000.00$$

$$s = 380.00$$

$$f_{ywe} = 555.55$$

$$f_{ce} = 15.00$$

$$\text{From ((5.A5), TBDY), TBDY: } cc = 0.00475778$$

$$c = \text{confinement factor} = 1.27578$$

$$y1 = 0.0010562$$

$$sh1 = 0.00365026$$

$$ft1 = 304.185$$

$$fy1 = 253.4875$$

$$su1 = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$$l_o/l_{ou,min} = l_b/l_d = 0.22053887$$

$$su1 = 0.4 * esu1_{nominal} \text{ ((5.5), TBDY)} = 0.032$$

From table 5A.1, TBDY:  $esu1_{nominal} = 0.08$ ,

For calculation of  $esu1_{nominal}$  and  $y1$ ,  $sh1$ ,  $ft1$ ,  $fy1$ , it is considered characteristic value  $fsy1 = fs1/1.2$ , from table 5.1, TBDY.

$y1$ ,  $sh1$ ,  $ft1$ ,  $fy1$ , are also multiplied by  $\text{Min}(1, 1.25 * (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.

$$\text{with } fs1 = fs = 253.4875$$

$$\text{with } Es1 = Es = 200000.00$$

$$y2 = 0.0010562$$

$$sh2 = 0.00365026$$

$$ft2 = 304.185$$

$$fy2 = 253.4875$$

$$su2 = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$$l_o/l_{ou,min} = l_b/l_{b,min} = 0.22053887$$

$$su2 = 0.4 * esu2_{nominal} \text{ ((5.5), TBDY)} = 0.032$$

From table 5A.1, TBDY:  $esu2_{nominal} = 0.08$ ,

For calculation of  $esu2_{nominal}$  and  $y2$ ,  $sh2$ ,  $ft2$ ,  $fy2$ , it is considered characteristic value  $fsy2 = fs2/1.2$ , from table 5.1, TBDY.

$y1$ ,  $sh1$ ,  $ft1$ ,  $fy1$ , are also multiplied by  $\text{Min}(1, 1.25 * (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.

$$\text{with } fs2 = fs = 253.4875$$

$$\text{with } Es2 = Es = 200000.00$$

$$y_v = 0.0010562$$

$$sh_v = 0.00365026$$

$$ft_v = 304.185$$

```

fyv = 253.4875
suv = 0.00365026
    using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
    and also multiplied by the shear_factor according to 15.7.1.4, with
    Shear_factor = 1.00
    lo/lo,min = lb/ld = 0.22053887
    suv = 0.4*esuv_nominal ((5.5), TBDY) = 0.032
    From table 5A.1, TBDY: esuv_nominal = 0.08,
    considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY
    For calculation of esuv_nominal and yv, shv,ftv,fyv, it is considered
    characteristic value fsyv = fsv/1.2, from table 5.1, TBDY.
    y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/ld)^ 2/3), from 10.3.5, ASCE 41-17.
    with fsv = fs = 253.4875
    with Esv = Es = 200000.00
    1 = Asl,ten/(b*d)*(fs1/fc) = 0.53536441
    2 = Asl,com/(b*d)*(fs2/fc) = 0.19630028
    v = Asl,mid/(b*d)*(fsv/fc) = 0.48777647
and confined core properties:
b = 140.00
d = 327.00
d' = 13.00
fcc (5A.2, TBDY) = 19.13667
cc (5A.5, TBDY) = 0.00475778
    c = confinement factor = 1.27578
    1 = Asl,ten/(b*d)*(fs1/fc) = 0.83497202
    2 = Asl,com/(b*d)*(fs2/fc) = 0.30615641
    v = Asl,mid/(b*d)*(fsv/fc) = 0.76075229
Case/Assumption: Unconfined full section - Steel rupture
' satisfies Eq. (4.3)
--->
v < vs,y2 - LHS eq.(4.5) is not satisfied
--->
v < vs,c - RHS eq.(4.5) is not satisfied
--->
Case/Assumption Rejected.
--->
New Case/Assumption: Unconfined full section - Spalling of concrete cover
' satisfies Eq. (4.4)
--->
v < s,y1 - LHS eq.(4.7) is not satisfied
--->
v < vc,y1 - RHS eq.(4.6) is satisfied
--->
    cu (4.10) = 0.46564051
    MRc (4.17) = 2.0934E+008
--->
New Case/Assumption: Ultimate curvature of confined core after spalling of concrete cover
In expressions below, the following modifications have been made
- b, d, d' replaced by geometric parameters of the core: bo, do, d'o
- N, 1, 2, v normalised to bo*do, instead of b*d
- - parameters of confined concrete, fcc, cc, used in lieu of fc, ecu
--->
Subcase: Rupture of tension steel
--->
v* < v*s,y2 - LHS eq.(4.5) is not satisfied
--->
v* < v*s,c - LHS eq.(4.5) is not satisfied
--->
Subcase rejected
--->
New Subcase: Failure of compression zone
--->
v* < v*c,y2 - LHS eq.(4.6) is not satisfied
--->
v* < v*c,y1 - RHS eq.(4.6) is satisfied
--->
    *cu (4.10) = 0.55615794

```

$$M_{Ro} (4.17) = 2.4313E+008$$

--->

$$u = cu (4.2) = 2.6161250E-005$$

$$\mu = M_{Ro}$$

Calculation of ratio  $l_b/l_d$

$$\text{Lap Length: } l_b/l_d = 0.22053887$$

$$l_b = 300.00$$

$$l_d = 1360.304$$

Calculation of  $l_b, \min$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$$= 1$$

$$d_b = 18.00$$

Mean strength value of all re-bars:  $f_y = 555.55$

$$f_c' = 15.00, \text{ but } f_c'^{0.5} \leq 8.3 \text{ MPa (22.5.3.1, ACI 318-14)}$$

$$t = 1.00$$

$$s = 0.80$$

$$e = 1.00$$

$$c_b = 24.02082$$

$$K_{tr} = 0.82673491$$

$$A_{tr} = \min(A_{tr_x}, A_{tr_y}) = 157.0796$$

where  $A_{tr_x}, A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis

$$s = 380.00$$

$$n = 20.00$$

Calculation of  $\mu_2$ -

Calculation of ultimate curvature  $\mu$  according to 4.1, Biskinis/Fardis 2013:

$$u = 1.3353763E-005$$

$$\mu = 1.2706E+008$$

with full section properties:

$$b = 400.00$$

$$d = 357.00$$

$$d' = 43.00$$

$$v = 0.00221164$$

$$N = 4737.328$$

$$f_c = 15.00$$

$$c_o (5A.5, \text{ TBDY}) = 0.002$$

$$\text{Final value of } c_u: c_u^* = \text{shear\_factor} * \max(c_u, c_c) = 0.018$$

The Shear\_factor is considered equal to 1 (pure moment strength)

$$\text{From (5.4b), TBDY: } c_u = 0.018$$

$$w_e ((5.4c), \text{ TBDY}) = a_{se} * s_{h, \min} * f_{ywe} / f_{ce} + \min(f_x, f_y) = 0.15303423$$

where  $f = a_f * p_f * f_{fe} / f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$$f_x = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2) / 3 = 51733.333$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } p_f = 2t_f / b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$f_y = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2) / 3 = 0.00$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } p_f = 2t_f / b_w = 0.01016$$

bw = 200.00  
effective stress from (A.35),  $f_{f,e} = 524.0792$

R = 40.00  
Effective FRP thickness,  $t_f = N_L * t * \cos(b_1) = 1.016$   
 $f_{u,f} = 1055.00$   
 $E_f = 64828.00$   
 $u_{,f} = 0.015$

$a_{se} = \text{Max}(((A_{conf,max} - A_{noConf}) / A_{conf,max}) * (A_{conf,min} / A_{conf,max}), 0) = 0.00$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988) "Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$p_{sh,min} = \text{Min}(p_{sh,x}, p_{sh,y}) = 0.00165347$

Expression ((5.4d), TBDY) for  $p_{sh,min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$p_{sh,x} \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$

$L_{stir}$  (Length of stirrups along Y) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$p_{sh,y} \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$

$L_{stir}$  (Length of stirrups along X) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

s = 380.00

$f_{ywe} = 555.55$

$f_{ce} = 15.00$

From ((5.A5), TBDY), TBDY:  $cc = 0.00475778$

c = confinement factor = 1.27578

$y_1 = 0.0010562$

$sh_1 = 0.00365026$

$ft_1 = 304.185$

$fy_1 = 253.4875$

$su_1 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$l_o/l_{ou,min} = l_b/l_d = 0.22053887$

$su_1 = 0.4 * esu1_{nominal} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu1_{nominal} = 0.08$ ,

For calculation of  $esu1_{nominal}$  and  $y_1$ ,  $sh_1$ ,  $ft_1$ ,  $fy_1$ , it is considered characteristic value  $fsy_1 = fs_1/1.2$ , from table 5.1, TBDY.

$y_1$ ,  $sh_1$ ,  $ft_1$ ,  $fy_1$ , are also multiplied by  $\text{Min}(1, 1.25 * (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.

with  $fs_1 = fs = 253.4875$

with  $Es_1 = Es = 200000.00$

$y_2 = 0.0010562$

$sh_2 = 0.00365026$

$ft_2 = 304.185$

$fy_2 = 253.4875$

$su_2 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$l_o/l_{ou,min} = l_b/l_{b,min} = 0.22053887$

$su_2 = 0.4 * esu2_{nominal} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu2_{nominal} = 0.08$ ,

For calculation of  $esu2_{nominal}$  and  $y_2$ ,  $sh_2$ ,  $ft_2$ ,  $fy_2$ , it is considered

characteristic value  $fsy2 = fs2/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fs2 = fs = 253.4875$   
 with  $Es2 = Es = 200000.00$   
 $yv = 0.0010562$   
 $shv = 0.00365026$   
 $ftv = 304.185$   
 $fyv = 253.4875$   
 $suv = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $lo/lo_{u,min} = lb/ld = 0.22053887$   
 $suv = 0.4 \cdot esuv_{nominal} ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esuv_{nominal} = 0.08$ ,  
 considering characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY  
 For calculation of  $esuv_{nominal}$  and  $yv, shv, ftv, fyv$ , it is considered  
 characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fsv = fs = 253.4875$   
 with  $Esv = Es = 200000.00$   
 $1 = Asl_{ten}/(b \cdot d) \cdot (fs1/fc) = 0.09815014$   
 $2 = Asl_{com}/(b \cdot d) \cdot (fs2/fc) = 0.26768221$   
 $v = Asl_{mid}/(b \cdot d) \cdot (fsv/fc) = 0.24388823$

and confined core properties:

$b = 340.00$   
 $d = 327.00$   
 $d' = 13.00$   
 $fcc (5A.2, TBDY) = 19.13667$   
 $cc (5A.5, TBDY) = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $1 = Asl_{ten}/(b \cdot d) \cdot (fs1/fc) = 0.1260644$   
 $2 = Asl_{com}/(b \cdot d) \cdot (fs2/fc) = 0.34381201$   
 $v = Asl_{mid}/(b \cdot d) \cdot (fsv/fc) = 0.31325094$

Case/Assumption: Unconfined full section - Steel rupture

' satisfies Eq. (4.3)

--->

$v < v_{s,y2}$  - LHS eq.(4.5) is satisfied

--->

$su (4.9) = 0.23431248$   
 $Mu = MRc (4.14) = 1.2706E+008$   
 $u = su (4.1) = 1.3353763E-005$

Calculation of ratio  $lb/ld$

Lap Length:  $lb/ld = 0.22053887$

$lb = 300.00$

$ld = 1360.304$

Calculation of  $lb_{min}$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

= 1

$db = 18.00$

Mean strength value of all re-bars:  $fy = 555.55$

$fc' = 15.00$ , but  $fc^{0.5} \leq 8.3 \text{ MPa}$  (22.5.3.1, ACI 318-14)

$t = 1.00$

$s = 0.80$

$e = 1.00$

$cb = 24.02082$

$Ktr = 0.82673491$

$Atr = \text{Min}(Atr_x, Atr_y) = 157.0796$

where  $Atr_x, Atr_y$  are the sum of the area of all stirrup legs along X and Y loxal axis

$s = 380.00$

$n = 20.00$

Calculation of Shear Strength  $V_r = \text{Min}(V_{r1}, V_{r2}) = 196005.816$

Calculation of Shear Strength at edge 1,  $V_{r1} = 227350.021$

$V_{r1} = V_{Col} ((10.3), \text{ASCE } 41-17) = k_{nl} * V_{Col0}$

$V_{Col0} = 227350.021$

$k_{nl} = 1$  (zero step-static loading)

NOTE: In expression (10-3) ' $V_s$ ' is replaced by ' $V_s + f * V_f$ ' where  $V_f$  is the contribution of FRPs (11.3), ACI 440).

$= 1$  (normal-weight concrete)

$f'_c = 15.00$ , but  $f'_c^{0.5} \leq 8.3 \text{ MPa}$  (22.5.3.1, ACI 318-14)

$M/Vd = 2.00$

$\mu_u = 3.21769$

$\nu_u = 0.01054019$

$d = 0.8 * h = 320.00$

$N_u = 4737.328$

$A_g = 80000.00$

From (11.5.4.8), ACI 318-14:  $V_s = V_{s1} + V_{s2} = 0.00$

where:

$V_{s1} = 0.00$  is calculated for section web, with:

$d = 320.00$

$A_v = 157079.633$

$f_y = 444.44$

$s = 380.00$

$V_{s1}$  is multiplied by  $\text{Col1} = 0.00$

$s/d = 1.1875$

$V_{s2} = 0.00$  is calculated for section flange, with:

$d = 160.00$

$A_v = 157079.633$

$f_y = 444.44$

$s = 380.00$

$V_{s2}$  is multiplied by  $\text{Col2} = 0.00$

$s/d = 2.375$

$V_f ((11-3)-(11.4), \text{ACI } 440) = 188111.148$

$f = 0.95$ , for fully-wrapped sections

$w_f/s_f = 1$  (FRP strips adjacent to one another).

In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot a) \sin a$  which is more a generalised expression, where  $a$  is the angle of the crack direction (see KANEPE).

This later relation, considered as a function  $V_f(, )$ , is implemented for every different fiber orientation  $a_i$ , as well as for 2 crack directions,  $a = 45^\circ$  and  $a = -45^\circ$  to take into consideration the cyclic seismic loading.

orientation 1:  $\theta = b1 + 90^\circ = 90.00$

$V_f = \text{Min}(|V_f(45, \theta)|, |V_f(-45, a1)|)$ , with:

total thickness per orientation,  $t_{f1} = N_L * t / N_{oDir} = 1.016$

$d_{fv} = d$  (figure 11.2, ACI 440) = 357.00

$f_{fe} ((11-5), \text{ACI } 440) = 259.312$

$E_f = 64828.00$

$f_e = 0.004$ , from (11.6a), ACI 440

with  $f_u = 0.01$

From (11-11), ACI 440:  $V_s + V_f \leq 164661.611$

$b_w = 200.00$

Calculation of Shear Strength at edge 2,  $V_{r2} = 196005.816$

$V_{r2} = V_{Col} ((10.3), \text{ASCE } 41-17) = k_{nl} * V_{Col0}$

$V_{Col0} = 196005.816$

$k_{nl} = 1$  (zero step-static loading)

NOTE: In expression (10-3) ' $V_s$ ' is replaced by ' $V_s + f * V_f$ ' where  $V_f$  is the contribution of FRPs (11.3), ACI 440).

$= 1$  (normal-weight concrete)

$f'_c = 15.00$ , but  $f'_c^{0.5} \leq 8.3 \text{ MPa}$  (22.5.3.1, ACI 318-14)

$M/Vd = 4.00$

$\mu_u = 23.99609$

$\nu_u = 0.01054019$

$d = 0.8 * h = 320.00$



$N_u = 4737.328$   
 $A_g = 80000.00$   
 From (11.5.4.8), ACI 318-14:  $V_s = V_{s1} + V_{s2} = 0.00$   
 where:  
 $V_{s1} = 0.00$  is calculated for section web, with:  
 $d = 320.00$   
 $A_v = 157079.633$   
 $f_y = 444.44$   
 $s = 380.00$   
 $V_{s1}$  is multiplied by  $Col1 = 0.00$   
 $s/d = 1.1875$   
 $V_{s2} = 0.00$  is calculated for section flange, with:  
 $d = 160.00$   
 $A_v = 157079.633$   
 $f_y = 444.44$   
 $s = 380.00$   
 $V_{s2}$  is multiplied by  $Col2 = 0.00$   
 $s/d = 2.375$   
 $V_f ((11-3)-(11.4), ACI 440) = 188111.148$   
 $f = 0.95$ , for fully-wrapped sections  
 $wf/sf = 1$  (FRP strips adjacent to one another).  
 In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot a) \sin a$  which is more a generalised expression,  
 where  $a$  is the angle of the crack direction (see KANEPE).  
 This later relation, considered as a function  $V_f( , )$ , is implemented for every different fiber orientation  $a_i$ ,  
 as well as for 2 crack directions,  $a = 45^\circ$  and  $a = -45^\circ$  to take into consideration the cyclic seismic loading.  
 orientation 1:  $a_1 = b_1 + 90^\circ = 90.00$   
 $V_f = \text{Min}(|V_f(45, 1)|, |V_f(-45, a_1)|)$ , with:  
 total thickness per orientation,  $t_{f1} = N_L * t / N_{oDir} = 1.016$   
 $d_{fv} = d$  (figure 11.2, ACI 440) = 357.00  
 $f_{fe} ((11-5), ACI 440) = 259.312$   
 $E_f = 64828.00$   
 $f_e = 0.004$ , from (11.6a), ACI 440  
 with  $f_u = 0.01$   
 From (11-11), ACI 440:  $V_s + V_f \leq 164661.611$   
 $b_w = 200.00$

-----  
 End Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1  
 At local axis: 3  
 -----

-----  
 Start Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1  
 At Shear local axis: 2  
 (Bending local axis: 3)  
 Section Type: rctcs

Constant Properties

-----  
 Knowledge Factor,  $\phi = 0.90$   
 Mean strength values are used for both shear and moment calculations.  
 Consequently:  
 Existing material of Primary Member: Concrete Strength,  $f_c = f_{cm} = 15.00$   
 Existing material of Primary Member: Steel Strength,  $f_s = f_{sm} = 444.44$   
 Concrete Elasticity,  $E_c = 18203.022$   
 Steel Elasticity,  $E_s = 200000.00$   
 #####  
 Note: Especially for the calculation of moment strengths,  
 the above steel re-bar strengths are multiplied by 1.25 according to R18.6.5, ACI 318-14  
 Existing material: Steel Strength,  $f_s = 1.25 * f_{sm} = 555.55$   
 #####  
 Max Height,  $H_{max} = 400.00$   
 Min Height,  $H_{min} = 200.00$   
 Max Width,  $W_{max} = 400.00$   
 Min Width,  $W_{min} = 200.00$   
 Eccentricity,  $E_{cc} = 100.00$

Cover Thickness,  $c = 25.00$   
 Mean Confinement Factor overall section = 1.27578  
 Element Length,  $L = 3000.00$   
 Primary Member  
 Ribbed Bars  
 Ductile Steel  
 Without Detailing for Earthquake Resistance (including stirrups not closed at 135°)  
 Longitudinal Bars With Ends Lapped Starting at the End Sections  
 Lap Length  $l_o = 300.00$   
 FRP Wrapping Data  
 Type: Carbon  
 Cured laminate properties (design values)  
 Thickness,  $t = 1.016$   
 Tensile Strength,  $f_{fu} = 1055.00$   
 Tensile Modulus,  $E_f = 64828.00$   
 Elongation,  $\epsilon_{fu} = 0.01$   
 Number of directions,  $NoDir = 1$   
 Fiber orientations,  $b_i: 0.00^\circ$   
 Number of layers,  $NL = 1$   
 Radius of rounding corners,  $R = 40.00$   
 -----  
 Stepwise Properties  
 -----  
 At local axis: 2  
 EDGE -A-  
 Shear Force,  $V_a = 1.5456333E-009$   
 EDGE -B-  
 Shear Force,  $V_b = -1.5456333E-009$   
 BOTH EDGES  
 Axial Force,  $F = -4737.328$   
 Longitudinal Reinforcement Area Distribution (in 2 divisions)  
     -Tension:  $As_t = 0.00$   
     -Compression:  $As_c = 5152.212$   
 Longitudinal Reinforcement Area Distribution (in 3 divisions)  
     -Tension:  $As_{t,ten} = 1231.504$   
     -Compression:  $As_{c,com} = 1231.504$   
     -Middle:  $As_{l,mid} = 2689.203$   
 -----  
 -----  
 Calculation of Shear Capacity ratio ,  $V_e/V_r = 0.55718248$   
 Member Controlled by Flexure ( $V_e/V_r < 1$ )  
 Calculation of Shear Demand from fig. R18.6.5, ACI 318-14  $V_e = (M_{pr1} + M_{pr2})/l_n = 126675.449$   
 with  
 $M_{pr1} = \text{Max}(\mu_{u1+}, \mu_{u1-}) = 1.9001E+008$   
      $\mu_{u1+} = 1.9001E+008$ , is the ultimate moment strength at the edge 1 of the member in the actual moment direction  
     which is defined for the static loading combination  
      $\mu_{u1-} = 1.9001E+008$ , is the ultimate moment strength at the edge 1 of the member in the opposite moment  
     direction which is defined for the static loading combination  
 $M_{pr2} = \text{Max}(\mu_{u2+}, \mu_{u2-}) = 1.9001E+008$   
      $\mu_{u2+} = 1.9001E+008$ , is the ultimate moment strength at the edge 2 of the member in the actual moment direction  
     which is defined for the the static loading combination  
      $\mu_{u2-} = 1.9001E+008$ , is the ultimate moment strength at the edge 2 of the member in the opposite moment  
     direction which is defined for the the static loading combination  
 -----  
 Calculation of  $\mu_{u1+}$   
 -----  
 -----  
 Calculation of ultimate curvature  $\phi_u$  according to 4.1, Biskinis/Fardis 2013:  
      $\phi_u = 1.7086748E-005$   
      $\mu_u = 1.9001E+008$   
 -----  
 with full section properties:

b = 200.00  
d = 357.00  
d' = 43.00  
v = 0.00442328  
N = 4737.328

fc = 15.00

co (5A.5, TBDY) = 0.002

Final value of cu:  $cu^* = \text{shear\_factor} * \text{Max}(cu, cc) = 0.018$

The Shear\_factor is considered equal to 1 (pure moment strength)

From (5.4b), TBDY:  $cu = 0.018$

we ((5.4c), TBDY) =  $ase * sh_{min} * fy_{we} / f_{ce} + \text{Min}(fx, fy) = 0.15303423$

where  $f = af * pf * f_{fe} / f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

fx = 0.15303423

Expression ((15B.6), TBDY) is modified as  $af = 1 - (\text{Unconfined area}) / (\text{total area})$

af = 0.43111111

with Unconfined area =  $((b_{max} - 2R)^2 + (h_{max} - 2R)^2) / 3 = 51733.333$

bmax = 400.00

hmax = 400.00

From EC8 A4.4.3(6),  $pf = 2tf / bw = 0.01016$

bw = 200.00

effective stress from (A.35),  $f_{fe} = 524.0792$

fy = 0.15303423

Expression ((15B.6), TBDY) is modified as  $af = 1 - (\text{Unconfined area}) / (\text{total area})$

af = 0.43111111

with Unconfined area =  $((b_{max} - 2R)^2 + (h_{max} - 2R)^2) / 3 = 0.00$

bmax = 400.00

hmax = 400.00

From EC8 A4.4.3(6),  $pf = 2tf / bw = 0.01016$

bw = 200.00

effective stress from (A.35),  $f_{fe} = 524.0792$

R = 40.00

Effective FRP thickness,  $tf = NL * t * \cos(b1) = 1.016$

fu,f = 1055.00

Ef = 64828.00

u,f = 0.015

$ase = \text{Max}(((A_{conf,max} - A_{noConf}) / A_{conf,max}) * (A_{conf,min} / A_{conf,max}), 0) = 0.00$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2 / 6$  as defined at (A.2).

$psh_{min} = \text{Min}(psh_x, psh_y) = 0.00165347$

Expression ((5.4d), TBDY) for  $psh_{min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$psh_x$  ((5.4d), TBDY) =  $L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$

$L_{stir}$  (Length of stirrups along Y) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$psh_y$  ((5.4d), TBDY) =  $L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$

$L_{stir}$  (Length of stirrups along X) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

s = 380.00

$fy_{we} = 555.55$

$f_{ce} = 15.00$

```

From ((5.A.5), TBDY), TBDY: cc = 0.00475778
c = confinement factor = 1.27578
y1 = 0.0010562
sh1 = 0.00365026
ft1 = 304.185
fy1 = 253.4875
su1 = 0.00365026
using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
and also multiplied by the shear_factor according to 15.7.1.4, with
Shear_factor = 1.00
lo/lou,min = lb/ld = 0.22053887
su1 = 0.4*esu1_nominal ((5.5), TBDY) = 0.032
From table 5A.1, TBDY: esu1_nominal = 0.08,
For calculation of esu1_nominal and y1, sh1,ft1,fy1, it is considered
characteristic value fsy1 = fs1/1.2, from table 5.1, TBDY.
y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/ld)^2/3), from 10.3.5, ASCE 41-17.
with fs1 = fs = 253.4875
with Es1 = Es = 200000.00
y2 = 0.0010562
sh2 = 0.00365026
ft2 = 304.185
fy2 = 253.4875
su2 = 0.00365026
using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
and also multiplied by the shear_factor according to 15.7.1.4, with
Shear_factor = 1.00
lo/lou,min = lb/lb,min = 0.22053887
su2 = 0.4*esu2_nominal ((5.5), TBDY) = 0.032
From table 5A.1, TBDY: esu2_nominal = 0.08,
For calculation of esu2_nominal and y2, sh2,ft2,fy2, it is considered
characteristic value fsy2 = fs2/1.2, from table 5.1, TBDY.
y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/ld)^2/3), from 10.3.5, ASCE 41-17.
with fs2 = fs = 253.4875
with Es2 = Es = 200000.00
yv = 0.0010562
shv = 0.00365026
ftv = 304.185
fyv = 253.4875
suv = 0.00365026
using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
and also multiplied by the shear_factor according to 15.7.1.4, with
Shear_factor = 1.00
lo/lou,min = lb/ld = 0.22053887
suv = 0.4*esuv_nominal ((5.5), TBDY) = 0.032
From table 5A.1, TBDY: esuv_nominal = 0.08,
considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY
For calculation of esuv_nominal and yv, shv,ftv,fyv, it is considered
characteristic value fsyv = fsv/1.2, from table 5.1, TBDY.
y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/ld)^2/3), from 10.3.5, ASCE 41-17.
with fsv = fs = 253.4875
with Esv = Es = 200000.00
1 = Asl,ten/(b*d)*(fs1/fc) = 0.29147618
2 = Asl,com/(b*d)*(fs2/fc) = 0.29147618
v = Asl,mid/(b*d)*(fsv/fc) = 0.6364888
and confined core properties:
b = 140.00
d = 327.00
d' = 13.00
fcc (5A.2, TBDY) = 19.13667
cc (5A.5, TBDY) = 0.00475778
c = confinement factor = 1.27578
1 = Asl,ten/(b*d)*(fs1/fc) = 0.45459588
2 = Asl,com/(b*d)*(fs2/fc) = 0.45459588
v = Asl,mid/(b*d)*(fsv/fc) = 0.99268896
Case/Assumption: Unconfined full section - Steel rupture
'satisfies Eq. (4.3)
--->

```

$v < v_{s,y2}$  - LHS eq.(4.5) is not satisfied

---->

$v < v_{s,c}$  - RHS eq.(4.5) is satisfied

---->

$\mu_u (4.8) = 0.40159417$

$\mu_u = M_{Rc} (4.15) = 1.9001E+008$

$u = \mu_u (4.1) = 1.7086748E-005$

Calculation of ratio  $I_b/I_d$

Lap Length:  $I_b/I_d = 0.22053887$

$I_b = 300.00$

$I_d = 1360.304$

Calculation of  $I_b$ ,min according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.  
 $= 1$

$d_b = 18.00$

Mean strength value of all re-bars:  $f_y = 555.55$

$f_c' = 15.00$ , but  $f_c'^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$t = 1.00$

$s = 0.80$

$e = 1.00$

$c_b = 24.02082$

$K_{tr} = 0.82673491$

$A_{tr} = \text{Min}(A_{tr,x}, A_{tr,y}) = 157.0796$

where  $A_{tr,x}$ ,  $A_{tr,y}$  are the sum of the area of all stirrup legs along X and Y loxal axis

$s = 380.00$

$n = 20.00$

Calculation of  $\mu_{u1}$ -

Calculation of ultimate curvature  $\mu_u$  according to 4.1, Biskinis/Fardis 2013:

$u = 1.7086748E-005$

$\mu_u = 1.9001E+008$

with full section properties:

$b = 200.00$

$d = 357.00$

$d' = 43.00$

$v = 0.00442328$

$N = 4737.328$

$f_c = 15.00$

$\alpha_{co} (5A.5, \text{TB DY}) = 0.002$

Final value of  $\mu_u$ :  $\mu_u^* = \text{shear\_factor} * \text{Max}(\mu_u, \alpha_{co}) = 0.018$

The Shear\_factor is considered equal to 1 (pure moment strength)

From (5.4b), TB DY:  $\mu_u = 0.018$

we ((5.4c), TB DY) =  $\alpha_{se} * \text{sh}_{\min} * f_{ywe}/f_{ce} + \text{Min}(f_x, f_y) = 0.15303423$

where  $f = \alpha_f * p_f * f_{fe}/f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$f_x = 0.15303423$

Expression ((15B.6), TB DY) is modified as  $\alpha_f = 1 - (\text{Unconfined area})/(\text{total area})$

$\alpha_f = 0.43111111$

with Unconfined area =  $((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 51733.333$

$b_{\max} = 400.00$

$h_{\max} = 400.00$

From EC8 A.4.4.3(6),  $p_f = 2t_f/b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

$f_y = 0.15303423$

Expression ((15B.6), TB DY) is modified as  $\alpha_f = 1 - (\text{Unconfined area})/(\text{total area})$

$\alpha_f = 0.43111111$

with Unconfined area =  $((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 0.00$

bmax = 400.00  
hmax = 400.00  
From EC8 A4.4.3(6),  $pf = 2tf/bw = 0.01016$   
bw = 200.00  
effective stress from (A.35),  $ff,e = 524.0792$

R = 40.00  
Effective FRP thickness,  $tf = NL*t*Cos(b1) = 1.016$   
 $f_{u,f} = 1055.00$   
 $E_f = 64828.00$   
 $u_{,f} = 0.015$

$ase = \text{Max}(((A_{conf,max} - A_{noConf}) / A_{conf,max}) * (A_{conf,min} / A_{conf,max}), 0) = 0.00$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988) "Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$psh,min = \text{Min}(psh,x, psh,y) = 0.00165347$

Expression ((5.4d), TBDY) for  $psh,min$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$psh,x \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$   
 $L_{stir}$  (Length of stirrups along Y) = 960.00  
 $A_{stir}$  (stirrups area) = 78.53982  
 $A_{sec}$  (section area) = 120000.00

$psh,y \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$   
 $L_{stir}$  (Length of stirrups along X) = 960.00  
 $A_{stir}$  (stirrups area) = 78.53982  
 $A_{sec}$  (section area) = 120000.00

s = 380.00  
 $f_{ywe} = 555.55$   
 $f_{ce} = 15.00$

From ((5.A5), TBDY), TBDY:  $cc = 0.00475778$   
c = confinement factor = 1.27578

$y1 = 0.0010562$   
 $sh1 = 0.00365026$

$ft1 = 304.185$

$fy1 = 253.4875$

$su1 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$lo/lo_{u,min} = lb/ld = 0.22053887$

$su1 = 0.4 * esu1_{nominal} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu1_{nominal} = 0.08$ ,

For calculation of  $esu1_{nominal}$  and  $y1, sh1, ft1, fy1$ , it is considered characteristic value  $fsy1 = fs1/1.2$ , from table 5.1, TBDY.

$y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 * (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.

with  $fs1 = fs = 253.4875$

with  $Es1 = Es = 200000.00$

$y2 = 0.0010562$   
 $sh2 = 0.00365026$

$ft2 = 304.185$

$fy2 = 253.4875$

$su2 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$lo/lo_{u,min} = lb/lb_{,min} = 0.22053887$

```

su2 = 0.4*esu2_nominal ((5.5), TBDY) = 0.032
From table 5A.1, TBDY: esu2_nominal = 0.08,
For calculation of esu2_nominal and y2, sh2,ft2,fy2, it is considered
characteristic value fsy2 = fs2/1.2, from table 5.1, TBDY.
y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/ld)^ 2/3), from 10.3.5, ASCE 41-17.
with fs2 = fs = 253.4875
with Es2 = Es = 200000.00
yv = 0.0010562
shv = 0.00365026
ftv = 304.185
fyv = 253.4875
suv = 0.00365026
using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
and also multiplied by the shear_factor according to 15.7.1.4, with
Shear_factor = 1.00
lo/lou,min = lb/ld = 0.22053887
suv = 0.4*esuv_nominal ((5.5), TBDY) = 0.032
From table 5A.1, TBDY: esuv_nominal = 0.08,
considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY
For calculation of esuv_nominal and yv, shv,ftv,fyv, it is considered
characteristic value fsyv = fsv/1.2, from table 5.1, TBDY.
y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/ld)^ 2/3), from 10.3.5, ASCE 41-17.
with fsv = fs = 253.4875
with Esv = Es = 200000.00
1 = Asl,ten/(b*d)*(fs1/fc) = 0.29147618
2 = Asl,com/(b*d)*(fs2/fc) = 0.29147618
v = Asl,mid/(b*d)*(fsv/fc) = 0.6364888
and confined core properties:
b = 140.00
d = 327.00
d' = 13.00
fcc (5A.2, TBDY) = 19.13667
cc (5A.5, TBDY) = 0.00475778
c = confinement factor = 1.27578
1 = Asl,ten/(b*d)*(fs1/fc) = 0.45459588
2 = Asl,com/(b*d)*(fs2/fc) = 0.45459588
v = Asl,mid/(b*d)*(fsv/fc) = 0.99268896
Case/Assumption: Unconfined full section - Steel rupture
' satisfies Eq. (4.3)
--->
v < vs,y2 - LHS eq.(4.5) is not satisfied
--->
v < vs,c - RHS eq.(4.5) is satisfied
--->
su (4.8) = 0.40159417
Mu = MRc (4.15) = 1.9001E+008
u = su (4.1) = 1.7086748E-005

```

#### Calculation of ratio lb/ld

```

Lap Length: lb/ld = 0.22053887
lb = 300.00
ld = 1360.304
Calculation of lb,min according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.
= 1
db = 18.00
Mean strength value of all re-bars: fy = 555.55
fc' = 15.00, but fc'^0.5 <= 8.3 MPa (22.5.3.1, ACI 318-14)
t = 1.00
s = 0.80
e = 1.00
cb = 24.02082
Ktr = 0.82673491
Atr = Min(Atr_x,Atr_y) = 157.0796
where Atr_x, Atr_y are the sum of the area of all stirrup legs along X and Y loxal axis
s = 380.00

```

n = 20.00

Calculation of  $\mu_{2+}$

Calculation of ultimate curvature  $\mu$  according to 4.1, Biskinis/Fardis 2013:

$\mu = 1.7086748E-005$

$\mu_u = 1.9001E+008$

with full section properties:

b = 200.00

d = 357.00

d' = 43.00

v = 0.00442328

N = 4737.328

f<sub>c</sub> = 15.00

c<sub>0</sub> (5A.5, TBDY) = 0.002

Final value of  $\mu_u$ :  $\mu_u^* = \text{shear\_factor} * \text{Max}(\mu_u, c_0) = 0.018$

The Shear\_factor is considered equal to 1 (pure moment strength)

From (5.4b), TBDY:  $\mu_u = 0.018$

where ((5.4c), TBDY) =  $a_{se} * \mu_{u,min} * f_{ywe} / f_{ce} + \text{Min}(f_x, f_y) = 0.15303423$

where  $f = a_f * p_f * f_{fe} / f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$f_x = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$a_f = 0.43111111$

with Unconfined area =  $((b_{max} - 2R)^2 + (h_{max} - 2R)^2) / 3 = 51733.333$

$b_{max} = 400.00$

$h_{max} = 400.00$

From EC8 A4.4.3(6),  $p_f = 2t_f / b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

$f_y = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$a_f = 0.43111111$

with Unconfined area =  $((b_{max} - 2R)^2 + (h_{max} - 2R)^2) / 3 = 0.00$

$b_{max} = 400.00$

$h_{max} = 400.00$

From EC8 A4.4.3(6),  $p_f = 2t_f / b_w = 0.01016$

$b_w = 200.00$

effective stress from (A.35),  $f_{fe} = 524.0792$

R = 40.00

Effective FRP thickness,  $t_f = N L * t * \cos(b_1) = 1.016$

$f_{u,f} = 1055.00$

$E_f = 64828.00$

$u_{f} = 0.015$

$a_{se} = \text{Max}(((A_{conf,max} - A_{noConf}) / A_{conf,max}) * (A_{conf,min} / A_{conf,max}), 0) = 0.00$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2 / 6$  as defined at (A.2).

$p_{sh,min} = \text{Min}(p_{sh,x}, p_{sh,y}) = 0.00165347$

Expression ((5.4d), TBDY) for  $p_{sh,min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)



$$psh,x ((5.4d), TBDY) = Lstir * Astir / (Asec * s) = 0.00165347$$

$$Lstir \text{ (Length of stirrups along Y)} = 960.00$$

$$Astir \text{ (stirrups area)} = 78.53982$$

$$Asec \text{ (section area)} = 120000.00$$

$$psh,y ((5.4d), TBDY) = Lstir * Astir / (Asec * s) = 0.00165347$$

$$Lstir \text{ (Length of stirrups along X)} = 960.00$$

$$Astir \text{ (stirrups area)} = 78.53982$$

$$Asec \text{ (section area)} = 120000.00$$

$$s = 380.00$$

$$fywe = 555.55$$

$$fce = 15.00$$

$$\text{From } ((5.A5), TBDY), TBDY: cc = 0.00475778$$

$$c = \text{confinement factor} = 1.27578$$

$$y1 = 0.0010562$$

$$sh1 = 0.00365026$$

$$ft1 = 304.185$$

$$fy1 = 253.4875$$

$$su1 = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00

$$lo/lou,min = lb/ld = 0.22053887$$

$$su1 = 0.4 * esu1\_nominal ((5.5), TBDY) = 0.032$$

$$\text{From table 5A.1, TBDY: } esu1\_nominal = 0.08,$$

For calculation of esu1\_nominal and y1, sh1,ft1,fy1, it is considered  
characteristic value fsy1 = fs1/1.2, from table 5.1, TBDY.

$$y1, sh1,ft1,fy1, \text{ are also multiplied by } \text{Min}(1, 1.25 * (lb/ld)^{2/3}), \text{ from 10.3.5, ASCE 41-17.}$$

$$\text{with } fs1 = fs = 253.4875$$

$$\text{with } Es1 = Es = 200000.00$$

$$y2 = 0.0010562$$

$$sh2 = 0.00365026$$

$$ft2 = 304.185$$

$$fy2 = 253.4875$$

$$su2 = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00

$$lo/lou,min = lb/lb,min = 0.22053887$$

$$su2 = 0.4 * esu2\_nominal ((5.5), TBDY) = 0.032$$

$$\text{From table 5A.1, TBDY: } esu2\_nominal = 0.08,$$

For calculation of esu2\_nominal and y2, sh2,ft2,fy2, it is considered  
characteristic value fsy2 = fs2/1.2, from table 5.1, TBDY.

$$y1, sh1,ft1,fy1, \text{ are also multiplied by } \text{Min}(1, 1.25 * (lb/ld)^{2/3}), \text{ from 10.3.5, ASCE 41-17.}$$

$$\text{with } fs2 = fs = 253.4875$$

$$\text{with } Es2 = Es = 200000.00$$

$$yv = 0.0010562$$

$$shv = 0.00365026$$

$$ftv = 304.185$$

$$fyv = 253.4875$$

$$suv = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00

$$lo/lou,min = lb/ld = 0.22053887$$

$$suv = 0.4 * esuv\_nominal ((5.5), TBDY) = 0.032$$

$$\text{From table 5A.1, TBDY: } esuv\_nominal = 0.08,$$

considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY

For calculation of esuv\_nominal and yv, shv,ftv,fyv, it is considered  
characteristic value fsyv = fsv/1.2, from table 5.1, TBDY.

$$y1, sh1,ft1,fy1, \text{ are also multiplied by } \text{Min}(1, 1.25 * (lb/ld)^{2/3}), \text{ from 10.3.5, ASCE 41-17.}$$

$$\text{with } fsv = fs = 253.4875$$

$$\text{with } Esv = Es = 200000.00$$

$$1 = Asl,ten/(b*d)*(fs1/fc) = 0.29147618$$

$$2 = Asl,com/(b*d)*(fs2/fc) = 0.29147618$$

$$v = Asl,mid/(b*d)*(fsv/fc) = 0.6364888$$

and confined core properties:

$$b = 140.00$$

$$d = 327.00$$

$$d' = 13.00$$

$$fcc(5A.2, TBDY) = 19.13667$$

$$cc(5A.5, TBDY) = 0.00475778$$

$$c = \text{confinement factor} = 1.27578$$

$$1 = A_{sl,ten}/(b*d)*(f_{s1}/f_c) = 0.45459588$$

$$2 = A_{sl,com}/(b*d)*(f_{s2}/f_c) = 0.45459588$$

$$v = A_{sl,mid}/(b*d)*(f_{sv}/f_c) = 0.99268896$$

Case/Assumption: Unconfined full section - Steel rupture

' satisfies Eq. (4.3)

--->

$v < v_{s,y2}$  - LHS eq.(4.5) is not satisfied

--->

$v < v_{s,c}$  - RHS eq.(4.5) is satisfied

--->

$$s_u(4.8) = 0.40159417$$

$$Mu = MR_c(4.15) = 1.9001E+008$$

$$u = s_u(4.1) = 1.7086748E-005$$

Calculation of ratio  $l_b/d$

Lap Length:  $l_b/d = 0.22053887$

$$l_b = 300.00$$

$$l_d = 1360.304$$

Calculation of  $l_b, \min$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$$= 1$$

$$d_b = 18.00$$

Mean strength value of all re-bars:  $f_y = 555.55$

$$f_c' = 15.00, \text{ but } f_c^{0.5} \leq 8.3 \text{ MPa (22.5.3.1, ACI 318-14)}$$

$$t = 1.00$$

$$s = 0.80$$

$$e = 1.00$$

$$c_b = 24.02082$$

$$K_{tr} = 0.82673491$$

$$A_{tr} = \min(A_{tr_x}, A_{tr_y}) = 157.0796$$

where  $A_{tr_x}$ ,  $A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis

$$s = 380.00$$

$$n = 20.00$$

Calculation of  $Mu_2$ -

Calculation of ultimate curvature  $u$  according to 4.1, Biskinis/Fardis 2013:

$$u = 1.7086748E-005$$

$$Mu = 1.9001E+008$$

with full section properties:

$$b = 200.00$$

$$d = 357.00$$

$$d' = 43.00$$

$$v = 0.00442328$$

$$N = 4737.328$$

$$f_c = 15.00$$

$$co(5A.5, TBDY) = 0.002$$

$$\text{Final value of } cu: cu^* = \text{shear\_factor} * \max(cu, cc) = 0.018$$

The Shear\_factor is considered equal to 1 (pure moment strength)

$$\text{From (5.4b), TBDY: } cu = 0.018$$

$$w_e((5.4c), TBDY) = a_s * p_f * f_{fe}/f_{ce} + \min(f_x, f_y) = 0.15303423$$

where  $f = a_f * p_f * f_{fe}/f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$$f_x = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $af = 1 - (\text{Unconfined area})/(\text{total area})$

$af = 0.43111111$

with Unconfined area =  $((b_{max}-2R)^2 + (h_{max}-2R)^2)/3 = 51733.333$

$b_{max} = 400.00$

$h_{max} = 400.00$

From EC8 A.4.4.3(6),  $pf = 2tf/bw = 0.01016$

$bw = 200.00$

effective stress from (A.35),  $ff_e = 524.0792$

$f_y = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $af = 1 - (\text{Unconfined area})/(\text{total area})$

$af = 0.43111111$

with Unconfined area =  $((b_{max}-2R)^2 + (h_{max}-2R)^2)/3 = 0.00$

$b_{max} = 400.00$

$h_{max} = 400.00$

From EC8 A.4.4.3(6),  $pf = 2tf/bw = 0.01016$

$bw = 200.00$

effective stress from (A.35),  $ff_e = 524.0792$

$R = 40.00$

Effective FRP thickness,  $tf = NL * t * \cos(b_1) = 1.016$

$f_{u,f} = 1055.00$

$E_f = 64828.00$

$u_f = 0.015$

$ase = \text{Max}(((A_{conf,max} - A_{noConf})/A_{conf,max}) * (A_{conf,min}/A_{conf,max}), 0) = 0.00$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$p_{sh,min} = \text{Min}(p_{sh,x}, p_{sh,y}) = 0.00165347$

Expression ((5.4d), TBDY) for  $p_{sh,min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$p_{sh,x} \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$

$L_{stir}$  (Length of stirrups along Y) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$p_{sh,y} \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$

$L_{stir}$  (Length of stirrups along X) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$s = 380.00$

$f_{ywe} = 555.55$

$f_{ce} = 15.00$

From ((5.A5), TBDY), TBDY:  $cc = 0.00475778$

$c$  = confinement factor = 1.27578

$y_1 = 0.0010562$

$sh_1 = 0.00365026$

$ft_1 = 304.185$

$fy_1 = 253.4875$

$su_1 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00

$lo/lo_{u,min} = lb/ld = 0.22053887$

$su_1 = 0.4 * esu_{1,nominal} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu_{1,nominal} = 0.08$ ,

For calculation of  $esu_{1,nominal}$  and  $y_1$ ,  $sh_1$ ,  $ft_1$ ,  $fy_1$ , it is considered

characteristic value  $f_{sy1} = f_{s1}/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
with  $f_{s1} = f_s = 253.4875$   
with  $E_{s1} = E_s = 200000.00$   
 $y2 = 0.0010562$   
 $sh2 = 0.00365026$   
 $ft2 = 304.185$   
 $fy2 = 253.4875$   
 $su2 = 0.00365026$   
using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00  
 $l_o/l_{o,min} = l_b/l_{b,min} = 0.22053887$   
 $su2 = 0.4 \cdot esu2_{nominal} ((5.5), TBDY) = 0.032$   
From table 5A.1, TBDY:  $esu2_{nominal} = 0.08$ ,  
For calculation of  $esu2_{nominal}$  and  $y2, sh2, ft2, fy2$ , it is considered  
characteristic value  $f_{sy2} = f_{s2}/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
with  $f_{s2} = f_s = 253.4875$   
with  $E_{s2} = E_s = 200000.00$   
 $yv = 0.0010562$   
 $shv = 0.00365026$   
 $ftv = 304.185$   
 $fyv = 253.4875$   
 $suv = 0.00365026$   
using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00  
 $l_o/l_{o,min} = l_b/l_d = 0.22053887$   
 $suv = 0.4 \cdot esuv_{nominal} ((5.5), TBDY) = 0.032$   
From table 5A.1, TBDY:  $esuv_{nominal} = 0.08$ ,  
considering characteristic value  $f_{syv} = f_{sv}/1.2$ , from table 5.1, TBDY  
For calculation of  $esuv_{nominal}$  and  $yv, shv, ftv, fyv$ , it is considered  
characteristic value  $f_{syv} = f_{sv}/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
with  $f_{sv} = f_s = 253.4875$   
with  $E_{sv} = E_s = 200000.00$   
 $1 = A_{sl,ten}/(b \cdot d) \cdot (f_{s1}/f_c) = 0.29147618$   
 $2 = A_{sl,com}/(b \cdot d) \cdot (f_{s2}/f_c) = 0.29147618$   
 $v = A_{sl,mid}/(b \cdot d) \cdot (f_{sv}/f_c) = 0.6364888$   
and confined core properties:  
 $b = 140.00$   
 $d = 327.00$   
 $d' = 13.00$   
 $f_{cc} (5A.2, TBDY) = 19.13667$   
 $cc (5A.5, TBDY) = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $1 = A_{sl,ten}/(b \cdot d) \cdot (f_{s1}/f_c) = 0.45459588$   
 $2 = A_{sl,com}/(b \cdot d) \cdot (f_{s2}/f_c) = 0.45459588$   
 $v = A_{sl,mid}/(b \cdot d) \cdot (f_{sv}/f_c) = 0.99268896$   
Case/Assumption: Unconfined full section - Steel rupture  
' satisfies Eq. (4.3)  
--->  
 $v < v_{s,y2}$  - LHS eq.(4.5) is not satisfied  
--->  
 $v < v_{s,c}$  - RHS eq.(4.5) is satisfied  
--->  
 $su (4.8) = 0.40159417$   
 $Mu = MRc (4.15) = 1.9001E+008$   
 $u = su (4.1) = 1.7086748E-005$

Calculation of ratio  $l_b/l_d$

Lap Length:  $l_b/l_d = 0.22053887$   
 $l_b = 300.00$   
 $l_d = 1360.304$

Calculation of  $I_{b,min}$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$$= 1$$

$$d_b = 18.00$$

Mean strength value of all re-bars:  $f_y = 555.55$

$$f'_c = 15.00, \text{ but } f_c^{0.5} \leq 8.3 \text{ MPa (22.5.3.1, ACI 318-14)}$$

$$t = 1.00$$

$$s = 0.80$$

$$e = 1.00$$

$$c_b = 24.02082$$

$$K_{tr} = 0.82673491$$

$$A_{tr} = \min(A_{tr_x}, A_{tr_y}) = 157.0796$$

where  $A_{tr_x}$ ,  $A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y local axis

$$s = 380.00$$

$$n = 20.00$$

Calculation of Shear Strength  $V_r = \min(V_{r1}, V_{r2}) = 227350.021$

Calculation of Shear Strength at edge 1,  $V_{r1} = 227350.021$

$$V_{r1} = V_{Col} \text{ ((10.3), ASCE 41-17)} = k_n I * V_{Col0}$$

$$V_{Col0} = 227350.021$$

$$k_n I = 1 \text{ (zero step-static loading)}$$

NOTE: In expression (10-3) ' $V_s$ ' is replaced by ' $V_s + f * V_f$ '

where  $V_f$  is the contribution of FRPs (11.3), ACI 440).

$$= 1 \text{ (normal-weight concrete)}$$

$$f'_c = 15.00, \text{ but } f_c^{0.5} \leq 8.3 \text{ MPa (22.5.3.1, ACI 318-14)}$$

$$M/Vd = 2.00$$

$$\mu_u = 0.00988804$$

$$V_u = 1.5456333E-009$$

$$d = 0.8 * h = 320.00$$

$$N_u = 4737.328$$

$$A_g = 80000.00$$

$$\text{From (11.5.4.8), ACI 318-14: } V_s = V_{s1} + V_{s2} = 0.00$$

where:

$V_{s1} = 0.00$  is calculated for section web, with:

$$d = 160.00$$

$$A_v = 157079.633$$

$$f_y = 444.44$$

$$s = 380.00$$

$V_{s1}$  is multiplied by  $Col1 = 0.00$

$$s/d = 2.375$$

$V_{s2} = 0.00$  is calculated for section flange, with:

$$d = 320.00$$

$$A_v = 157079.633$$

$$f_y = 444.44$$

$$s = 380.00$$

$V_{s2}$  is multiplied by  $Col2 = 0.00$

$$s/d = 1.1875$$

$$V_f \text{ ((11-3)-(11.4), ACI 440)} = 188111.148$$

$$f = 0.95, \text{ for fully-wrapped sections}$$

$w_f/s_f = 1$  (FRP strips adjacent to one another).

In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot a) \sin a$  which is more a generalised expression,

where  $a$  is the angle of the crack direction (see KANEPE).

This later relation, considered as a function  $V_f(, )$ , is implemented for every different fiber orientation  $a_i$ , as well as for 2 crack directions,  $a = 45^\circ$  and  $a = -45^\circ$  to take into consideration the cyclic seismic loading.

orientation 1:  $a_1 = b_1 + 90^\circ = 90.00$

$$V_f = \min(|V_f(45, 1)|, |V_f(-45, a_1)|), \text{ with:}$$

$$\text{total thickness per orientation, } t_{f1} = N_L * t / N_{oDir} = 1.016$$

$$d_{fv} = d \text{ (figure 11.2, ACI 440)} = 357.00$$

$$f_{fe} \text{ ((11-5), ACI 440)} = 259.312$$

$$E_f = 64828.00$$

$$f_e = 0.004, \text{ from (11.6a), ACI 440}$$

$$\text{with } f_u = 0.01$$

From (11-11), ACI 440:  $V_s + V_f \leq 164661.611$   
 $bw = 200.00$

Calculation of Shear Strength at edge 2,  $V_{r2} = 227350.021$   
 $V_{r2} = V_{Col} ((10.3), ASCE 41-17) = knl * V_{Col0}$   
 $V_{Col0} = 227350.021$   
 $knl = 1$  (zero step-static loading)

NOTE: In expression (10-3) ' $V_s$ ' is replaced by ' $V_s + f * V_f$ '  
where  $V_f$  is the contribution of FRPs (11.3), ACI 440).

$= 1$  (normal-weight concrete)  
 $f'_c = 15.00$ , but  $f'_c^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$M/Vd = 2.00$

$\mu_u = 0.00525978$

$V_u = 1.5456333E-009$

$d = 0.8 * h = 320.00$

$N_u = 4737.328$

$A_g = 80000.00$

From (11.5.4.8), ACI 318-14:  $V_s = V_{s1} + V_{s2} = 0.00$

where:

$V_{s1} = 0.00$  is calculated for section web, with:

$d = 160.00$

$A_v = 157079.633$

$f_y = 444.44$

$s = 380.00$

$V_{s1}$  is multiplied by  $Col1 = 0.00$

$s/d = 2.375$

$V_{s2} = 0.00$  is calculated for section flange, with:

$d = 320.00$

$A_v = 157079.633$

$f_y = 444.44$

$s = 380.00$

$V_{s2}$  is multiplied by  $Col2 = 0.00$

$s/d = 1.1875$

$V_f ((11-3)-(11.4), ACI 440) = 188111.148$

$f = 0.95$ , for fully-wrapped sections

$w_f/s_f = 1$  (FRP strips adjacent to one another).

In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot a) \sin a$  which is more a generalised expression,  
where  $a$  is the angle of the crack direction (see KANEPE).

This later relation, considered as a function  $V_f(, )$ , is implemented for every different fiber orientation  $a_i$ ,  
as well as for 2 crack directions,  $a = 45^\circ$  and  $a = -45^\circ$  to take into consideration the cyclic seismic loading.

orientation 1:  $a_1 = b_1 + 90^\circ = 90.00$

$V_f = \text{Min}(|V_f(45, 1)|, |V_f(-45, a_1)|)$ , with:

total thickness per orientation,  $t_{f1} = NL * t / NoDir = 1.016$

$d_{fv} = d$  (figure 11.2, ACI 440) = 357.00

$f_{fe} ((11-5), ACI 440) = 259.312$

$E_f = 64828.00$

$f_e = 0.004$ , from (11.6a), ACI 440

with  $f_u = 0.01$

From (11-11), ACI 440:  $V_s + V_f \leq 164661.611$

$bw = 200.00$

End Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1  
At local axis: 2

Start Of Calculation of Chord Rotation Capacity for element: column TC1 of floor 1  
At local axis: 2  
Integration Section: (b)  
Section Type: rctcs

Constant Properties

Knowledge Factor,  $\phi = 0.90$   
 Chord Rotation is generally considered as Deformation-Controlled Action according to Table C7-1, ASCE 41-17.  
 Mean strengths are used for Deformation-Controlled Actions according to 7.5.1.3, ASCE 41-17  
 Consequently:  
 Existing material of Primary Member: Concrete Strength,  $f_c = f_{cm} = 15.00$   
 Existing material of Primary Member: Steel Strength,  $f_s = f_{sm} = 444.44$   
 Concrete Elasticity,  $E_c = 18203.022$   
 Steel Elasticity,  $E_s = 200000.00$   
 Max Height,  $H_{max} = 400.00$   
 Min Height,  $H_{min} = 200.00$   
 Max Width,  $W_{max} = 400.00$   
 Min Width,  $W_{min} = 200.00$   
 Eccentricity,  $Ecc = 100.00$   
 Cover Thickness,  $c = 25.00$   
 Element Length,  $L = 3000.00$   
 Primary Member  
 Ribbed Bars  
 Ductile Steel  
 Without Detailing for Earthquake Resistance (including stirrups not closed at 135°)  
 Longitudinal Bars With Ends Lapped Starting at the End Sections  
 Lap Length  $l_b = 300.00$   
 FRP Wrapping Data  
 Type: Carbon  
 Cured laminate properties (design values)  
 Thickness,  $t = 1.016$   
 Tensile Strength,  $f_{fu} = 1055.00$   
 Tensile Modulus,  $E_f = 64828.00$   
 Elongation,  $\epsilon_{fu} = 0.01$   
 Number of directions,  $N_{oDir} = 1$   
 Fiber orientations,  $b_i: 0.00^\circ$   
 Number of layers,  $N_L = 1$   
 Radius of rounding corners,  $R = 40.00$

#### Stepwise Properties

Bending Moment,  $M = -853.8761$   
 Shear Force,  $V_2 = 3961.043$   
 Shear Force,  $V_3 = -0.77690092$   
 Axial Force,  $F = -4742.638$   
 Longitudinal Reinforcement Area Distribution (in 2 divisions)  
   -Tension:  $A_{st} = 0.00$   
   -Compression:  $A_{sc} = 5152.212$   
 Longitudinal Reinforcement Area Distribution (in 3 divisions)  
   -Tension:  $A_{st,ten} = 2261.947$   
   -Compression:  $A_{st,com} = 829.3805$   
   -Middle:  $A_{st,mid} = 2060.885$   
 Mean Diameter of Tension Reinforcement,  $D_{bL} = 17.77778$

Existing component: From table 7-7, ASCE 41\_17: Final chord rotation Capacity  $u_{,R} = \phi \cdot u = 0.04562592$   
 $u = y + p = 0.05069546$

- Calculation of  $y$  -

$y = (M_y \cdot L_s / 3) / E_{eff} = 0.00869546$  ((4.29), Biskinis Phd))  
 $M_y = 1.9010E+008$   
 $L_s = M/V$  (with  $L_s > 0.1 \cdot L$  and  $L_s < 2 \cdot L$ ) = 1099.08  
 From table 10.5, ASCE 41\_17:  $E_{eff} = factor \cdot E_c \cdot I_g = 8.0093E+012$   
 factor = 0.30  
 $A_g = 120000.00$   
 $f_c' = 15.00$   
 $N = 4742.638$

$$E_c I_g = 2.6698E+013$$

Calculation of Yielding Moment  $M_y$

Calculation of  $\rho_y$  and  $M_y$  according to Annex 7 -

$$y = \text{Min}(y_{\text{ten}}, y_{\text{com}})$$

$$y_{\text{ten}} = 6.8135163E-006$$

$$\text{with } ((10.1), \text{ASCE 41-17}) f_y = \text{Min}(f_y, 1.25 * f_y * (l_b / l_d)^{2/3}) = 235.317$$

$$d = 357.00$$

$$y = 0.51629147$$

$$A = 0.0724421$$

$$B = 0.04953159$$

$$\text{with } p_t = 0.0075814$$

$$p_c = 0.01161597$$

$$p_v = 0.02886393$$

$$N = 4742.638$$

$$b = 200.00$$

$$" = 0.12044818$$

$$y_{\text{comp}} = 8.6576116E-006$$

$$\text{with } f_c^* (12.3, (\text{ACI 440})) = 16.12972$$

$$f_c = 15.00$$

$$f_l = 0.93147527$$

$$b = b_{\text{max}} = 400.00$$

$$h = h_{\text{max}} = 400.00$$

$$A_g = 120000.00$$

$$g = p_t + p_c + p_v = 0.07215983$$

$$r_c = 40.00$$

$$A_e / A_c = 0.38686758$$

$$\text{Effective FRP thickness, } t_f = N L * t * \cos(b_1) = 1.016$$

$$\text{effective strain from (12.5) and (12.12), } \epsilon_{fe} = 0.004$$

$$f_u = 0.01$$

$$E_f = 64828.00$$

$$E_c = 18203.022$$

$$y = 0.51604736$$

$$A = 0.0719516$$

$$B = 0.04924932$$

$$\text{with } E_s = 200000.00$$

Calculation of ratio  $l_b / l_d$

$$\text{Lap Length: } l_d / l_d, \text{min} = 0.27567359$$

$$l_b = 300.00$$

$$l_d = 1088.244$$

Calculation of  $I$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$$= 1$$

$$d_b = 18.00$$

$$\text{Mean strength value of all re-bars: } f_y = 444.44$$

$$f_c' = 15.00, \text{ but } f_c'^{0.5} \leq 8.3 \text{ MPa (22.5.3.1, ACI 318-14)}$$

$$t = 1.00$$

$$s = 0.80$$

$$e = 1.00$$

$$c_b = 24.02082$$

$$K_{tr} = 0.82673491$$

$$A_{tr} = \text{Min}(A_{tr_x}, A_{tr_y}) = 157.0796$$

where  $A_{tr_x}$ ,  $A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis

$$s = 380.00$$

$$n = 20.00$$

- Calculation of  $\rho_p$  -

From table 10-8:  $\rho_p = 0.042$



with:

- Columns controlled by inadequate development or splicing along the clear height because  $l_b/l_d < 1$

shear control ratio  $V_{yE}/V_{ColOE} = 0.82694402$

$d = 357.00$

$s = 0.00$

$t = A_v/(b_w*s) + 2*t_f/b_w*(f_{fe}/f_s) = A_v*L_{stir}/(A_g*s) + 2*t_f/b_w*(f_{fe}/f_s) = 0.0075814$

$A_v = 78.53982$ , is the area of every stirrup

$L_{stir} = 960.00$ , is the total Length of all stirrups parallel to loading (shear) direction

The term  $2*t_f/b_w*(f_{fe}/f_s)$  is implemented to account for FRP contribution

where  $f = 2*t_f/b_w$  is FRP ratio (EC8 - 3, A.4.4.3(6)) and  $f_{fe}/f_s$  normalises  $f$  to steel strength

All these variables have already been given in Shear control ratio calculation.

$NUD = 4742.638$

$A_g = 120000.00$

$f_{cE} = 15.00$

$f_{ytE} = f_{yle} = 444.44$

$\rho_l = \text{Area\_Tot\_Long\_Rein}/(b*d) = 0.07215983$

$b = 200.00$

$d = 357.00$

$f_{cE} = 15.00$

-----  
End Of Calculation of Chord Rotation Capacity for element: column TC1 of floor 1

At local axis: 2

Integration Section: (b)

-----

## Calculation No. 15

column C1, Floor 1

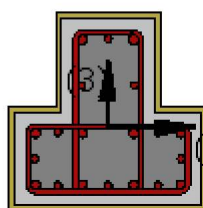
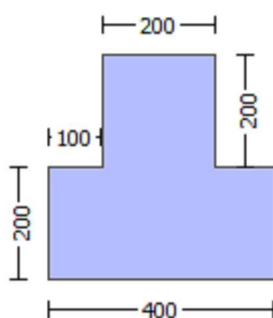
Limit State: Collapse Prevention (data interpolation between analysis steps 2 and 3)

Analysis: Uniform +X

Check: Shear capacity  $V_{Rd}$

Edge: End

Local Axis: (3)



Start Of Calculation of Shear Capacity for element: column TC1 of floor 1

At local axis: 3  
Integration Section: (b)  
Section Type: rctcs

#### Constant Properties

-----  
Knowledge Factor,  $\gamma = 0.90$   
Member Shear Force is generally considered as Force-Controlled Action according to Table C7-1, ASCE 41-17.  
Lower-bound strengths are used for Force-Controlled Actions according to 7.5.1.3, ASCE 41-17  
Consequently:  
Existing material of Primary Member: Concrete Strength,  $f_c = f_{c\_lower\_bound} = 10.00$   
Existing material of Primary Member: Steel Strength,  $f_s = f_{s\_lower\_bound} = 400.00$   
Concrete Elasticity,  $E_c = 18203.022$   
Steel Elasticity,  $E_s = 200000.00$   
#####  
Note: Especially for the calculation of  $\gamma$  for displacement ductility demand,  
the expected (mean value) strengths are used (7.5.1.3, ASCE 41-17) because bending is considered as  
Deformation-Controlled Action (Table C7-1, ASCE 41-17).  
Existing material: Concrete Strength,  $f_c = f_{cm} = 15.00$   
Existing material: Steel Strength,  $f_s = f_{sm} = 444.44$   
#####  
Max Height,  $H_{max} = 400.00$   
Min Height,  $H_{min} = 200.00$   
Max Width,  $W_{max} = 400.00$   
Min Width,  $W_{min} = 200.00$   
Eccentricity,  $Ecc = 100.00$   
Cover Thickness,  $c = 25.00$   
Element Length,  $L = 3000.00$   
Primary Member  
Ribbed Bars  
Ductile Steel  
Without Detailing for Earthquake Resistance (including stirrups not closed at 135°)  
Longitudinal Bars With Ends Lapped Starting at the End Sections  
Lap Length  $l_o = l_b = 300.00$   
FRP Wrapping Data  
Type: Carbon  
Cured laminate properties (design values)  
Thickness,  $t = 1.016$   
Tensile Strength,  $f_{fu} = 1055.00$   
Tensile Modulus,  $E_f = 64828.00$   
Elongation,  $ef_u = 0.01$   
Number of directions,  $NoDir = 1$   
Fiber orientations,  $bi: 0.00^\circ$   
Number of layers,  $NL = 1$   
Radius of rounding corners,  $R = 40.00$   
-----

#### Stepwise Properties

-----  
EDGE -A-  
Bending Moment,  $M_a = -1284.318$   
Shear Force,  $V_a = 0.77690092$   
EDGE -B-  
Bending Moment,  $M_b = -853.8761$   
Shear Force,  $V_b = -0.77690092$   
BOTH EDGES  
Axial Force,  $F = -4742.638$   
Longitudinal Reinforcement Area Distribution (in 2 divisions)  
-Tension:  $As_t = 0.00$   
-Compression:  $As_c = 5152.212$   
Longitudinal Reinforcement Area Distribution (in 3 divisions)  
-Tension:  $As_{t,ten} = 2261.947$   
-Compression:  $As_{l,com} = 829.3805$   
-Middle:  $As_{l,mid} = 2060.885$   
Mean Diameter of Tension Reinforcement,  $Db_{L,ten} = 17.77778$   
-----  
-----

Existing component: From table 7-7, ASCE 41\_17: Final Shear Capacity  $V_R = V_n = 147915.927$

$V_n$  ((10.3), ASCE 41-17) =  $k_n \cdot V_{CoIO} = 164351.03$

$V_{CoI} = 164351.03$

$k_n = 1.00$

$\text{displacement\_ductility\_demand} = 3.6025723E-005$

NOTE: In expression (10-3) ' $V_s$ ' is replaced by ' $V_s + f \cdot V_f$ '  
where  $V_f$  is the contribution of FRPs (11.3), ACI 440).

$= 1$  (normal-weight concrete)

$f'_c = 10.00$ , but  $f'_c^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$M/Vd = 3.43462$

$\mu_u = 853.8761$

$V_u = 0.77690092$

$d = 0.8 \cdot h = 320.00$

$N_u = 4742.638$

$A_g = 80000.00$

From (11.5.4.8), ACI 318-14:  $V_s = V_{s1} + V_{s2} = 0.00$

where:

$V_{s1} = 0.00$  is calculated for section web, with:

$d = 320.00$

$A_v = 157079.633$

$f_y = 400.00$

$s = 380.00$

$V_{s1}$  is multiplied by  $\text{Col1} = 0.00$

$s/d = 1.1875$

$V_{s2} = 0.00$  is calculated for section flange, with:

$d = 160.00$

$A_v = 157079.633$

$f_y = 400.00$

$s = 380.00$

$V_{s2}$  is multiplied by  $\text{Col2} = 0.00$

$s/d = 2.375$

$V_f$  ((11-3)-(11.4), ACI 440) = 188111.148

$f = 0.95$ , for fully-wrapped sections

$w_f/s_f = 1$  (FRP strips adjacent to one another).

In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot a) \sin a$  which is more a generalised expression,

where  $a$  is the angle of the crack direction (see KANEPE).

This later relation, considered as a function  $V_f(a)$ , is implemented for every different fiber orientation  $a_i$ , as well as for 2 crack directions,  $a = 45^\circ$  and  $a = -45^\circ$  to take into consideration the cyclic seismic loading.

orientation 1:  $a = b1 + 90^\circ = 90.00$

$V_f = \text{Min}(|V_f(45, a)|, |V_f(-45, a)|)$ , with:

total thickness per orientation,  $t_{f1} = N_L \cdot t / N_{oDir} = 1.016$

$d_{fv} = d$  (figure 11.2, ACI 440) = 357.00

$f_{fe}$  ((11-5), ACI 440) = 259.312

$E_f = 64828.00$

$f_{fe} = 0.004$ , from (11.6a), ACI 440

with  $f_u = 0.01$

From (11-11), ACI 440:  $V_s + V_f \leq 134445.642$

$b_w = 200.00$

$\text{displacement\_ductility\_demand}$  is calculated as  $\Delta / y$

- Calculation of  $\Delta / y$  for END B -

for rotation axis 2 and integ. section (b)

From analysis, chord rotation  $\theta = 3.1326036E-007$

$y = (M_y \cdot L_s / 3) / E_{eff} = 0.00869546$  ((4.29), Biskinis Phd))

$M_y = 1.9010E+008$

$L_s = M/V$  (with  $L_s > 0.1 \cdot L$  and  $L_s < 2 \cdot L$ ) = 1099.08

From table 10.5, ASCE 41\_17:  $E_{eff} = \text{factor} \cdot E_c \cdot I_g = 8.0093E+012$

$\text{factor} = 0.30$

$A_g = 120000.00$

$f_c' = 15.00$   
 $N = 4742.638$   
 $E_c \cdot I_g = 2.6698E+013$

Calculation of Yielding Moment  $M_y$

Calculation of  $y$  and  $M_y$  according to Annex 7 -

$y = \text{Min}(y_{\text{ten}}, y_{\text{com}})$   
 $y_{\text{ten}} = 6.8135163E-006$   
with  $((10.1), \text{ASCE } 41-17)$   $f_y = \text{Min}(f_y, 1.25 \cdot f_y \cdot (l_b/d)^{2/3}) = 235.317$   
 $d = 357.00$   
 $y = 0.51629147$   
 $A = 0.0724421$   
 $B = 0.04953159$   
with  $pt = 0.03167993$   
 $pc = 0.01161597$   
 $pv = 0.02886393$   
 $N = 4742.638$   
 $b = 200.00$   
 $" = 0.12044818$   
 $y_{\text{comp}} = 8.6576116E-006$   
with  $f_c' (12.3, (\text{ACI } 440)) = 16.12972$   
 $f_c = 15.00$   
 $fl = 0.93147527$   
 $b = b_{\text{max}} = 400.00$   
 $h = h_{\text{max}} = 400.00$   
 $Ag = 120000.00$   
 $g = pt + pc + pv = 0.07215983$   
 $rc = 40.00$   
 $A_e/A_c = 0.38686758$   
Effective FRP thickness,  $t_f = NL \cdot t \cdot \cos(b1) = 1.016$   
effective strain from (12.5) and (12.12),  $\epsilon_{fe} = 0.004$   
 $f_u = 0.01$   
 $E_f = 64828.00$   
 $E_c = 18203.022$   
 $y = 0.51604736$   
 $A = 0.0719516$   
 $B = 0.04924932$   
with  $E_s = 200000.00$

Calculation of ratio  $l_b/d$

Lap Length:  $l_d/l_d, \text{min} = 0.27567359$

$l_b = 300.00$   
 $l_d = 1088.244$

Calculation of  $I$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$= 1$   
 $d_b = 18.00$   
Mean strength value of all re-bars:  $f_y = 444.44$   
 $f_c' = 15.00$ , but  $f_c'^{0.5} \leq 8.3 \text{ MPa}$  (22.5.3.1, ACI 318-14)  
 $t = 1.00$   
 $s = 0.80$   
 $e = 1.00$   
 $cb = 24.02082$   
 $K_{tr} = 0.82673491$   
 $A_{tr} = \text{Min}(A_{tr\_x}, A_{tr\_y}) = 157.0796$   
where  $A_{tr\_x}, A_{tr\_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis  
 $s = 380.00$   
 $n = 20.00$

End Of Calculation of Shear Capacity for element: column TC1 of floor 1

At local axis: 3

## Calculation No. 16

column C1, Floor 1

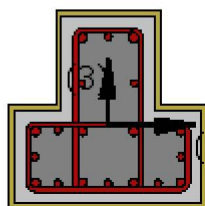
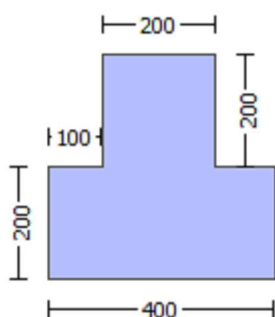
Limit State: Collapse Prevention (data interpolation between analysis steps 2 and 3)

Analysis: Uniform +X

Check: Chord rotation capacity (  $\mu$  )

Edge: End

Local Axis: (3)



Start Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1

At Shear local axis: 3

(Bending local axis: 2)

Section Type: rctcs

Constant Properties

Knowledge Factor,  $\gamma = 0.90$

Mean strength values are used for both shear and moment calculations.

Consequently:

Existing material of Primary Member: Concrete Strength,  $f_c = f_{cm} = 15.00$

Existing material of Primary Member: Steel Strength,  $f_s = f_{sm} = 444.44$

Concrete Elasticity,  $E_c = 18203.022$

Steel Elasticity,  $E_s = 200000.00$

#####

Note: Especially for the calculation of moment strengths,

the above steel re-bar strengths are multiplied by 1.25 according to R18.6.5, ACI 318-14

Existing material: Steel Strength,  $f_s = 1.25 \cdot f_{sm} = 555.55$

#####

Max Height,  $H_{max} = 400.00$

Min Height,  $H_{min} = 200.00$

Max Width,  $W_{max} = 400.00$

Min Width,  $W_{min} = 200.00$

Eccentricity,  $E_{cc} = 100.00$

Cover Thickness,  $c = 25.00$

Mean Confinement Factor overall section = 1.27578

Element Length,  $L = 3000.00$   
 Primary Member  
 Ribbed Bars  
 Ductile Steel  
 Without Detailing for Earthquake Resistance (including stirrups not closed at  $135^\circ$ )  
 Longitudinal Bars With Ends Lapped Starting at the End Sections  
 Lap Length  $l_o = 300.00$   
 FRP Wrapping Data  
 Type: Carbon  
 Cured laminate properties (design values)  
 Thickness,  $t = 1.016$   
 Tensile Strength,  $f_{fu} = 1055.00$   
 Tensile Modulus,  $E_f = 64828.00$   
 Elongation,  $\epsilon_{fu} = 0.01$   
 Number of directions,  $NoDir = 1$   
 Fiber orientations,  $b_i: 0.00^\circ$   
 Number of layers,  $NL = 1$   
 Radius of rounding corners,  $R = 40.00$

#### Stepwise Properties

At local axis: 3  
 EDGE -A-  
 Shear Force,  $V_a = 0.01054019$   
 EDGE -B-  
 Shear Force,  $V_b = -0.01054019$   
 BOTH EDGES  
 Axial Force,  $F = -4737.328$   
 Longitudinal Reinforcement Area Distribution (in 2 divisions)  
   -Tension:  $As_t = 0.00$   
   -Compression:  $As_c = 5152.212$   
 Longitudinal Reinforcement Area Distribution (in 3 divisions)  
   -Tension:  $As_{t,ten} = 2261.947$   
   -Compression:  $As_{l,com} = 829.3805$   
   -Middle:  $As_{l,mid} = 2060.885$

Calculation of Shear Capacity ratio,  $V_e/V_r = 0.82694402$   
 Member Controlled by Flexure ( $V_e/V_r < 1$ )  
 Calculation of Shear Demand from fig. R18.6.5, ACI 318-14  $V_e = (M_{pr1} + M_{pr2})/l_n = 162085.836$   
 with  
 $M_{pr1} = \max(\mu_{u1+}, \mu_{u1-}) = 2.4313E+008$   
 $\mu_{u1+} = 2.4313E+008$ , is the ultimate moment strength at the edge 1 of the member in the actual moment direction which is defined for the static loading combination  
 $\mu_{u1-} = 1.2706E+008$ , is the ultimate moment strength at the edge 1 of the member in the opposite moment direction which is defined for the static loading combination  
 $M_{pr2} = \max(\mu_{u2+}, \mu_{u2-}) = 2.4313E+008$   
 $\mu_{u2+} = 2.4313E+008$ , is the ultimate moment strength at the edge 2 of the member in the actual moment direction which is defined for the the static loading combination  
 $\mu_{u2-} = 1.2706E+008$ , is the ultimate moment strength at the edge 2 of the member in the opposite moment direction which is defined for the the static loading combination

#### Calculation of $\mu_{u1+}$

Calculation of ultimate curvature  $\mu_u$  according to 4.1, Biskinis/Fardis 2013:  
 $\mu_u = 2.6161250E-005$   
 $M_u = 2.4313E+008$

with full section properties:  
 $b = 200.00$   
 $d = 357.00$

$$d' = 43.00$$

$$v = 0.00442328$$

$$N = 4737.328$$

$$f_c = 15.00$$

$$c_o(5A.5, \text{TBDY}) = 0.002$$

$$\text{Final value of } c_u: c_u^* = \text{shear\_factor} * \text{Max}(c_u, c_c) = 0.018$$

The Shear\_factor is considered equal to 1 (pure moment strength)

$$\text{From (5.4b), TBDY: } c_u = 0.018$$

$$w_e(5.4c, \text{TBDY}) = a_{se} * s_{h,min} * f_{ywe}/f_{ce} + \text{Min}(f_x, f_y) = 0.15303423$$

where  $f = a_f * p_f * f_{fe}/f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$$f_x = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area})/(\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 51733.333$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } p_f = 2t_f/b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$f_y = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area})/(\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 0.00$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } p_f = 2t_f/b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$R = 40.00$$

$$\text{Effective FRP thickness, } t_f = N L * t * \cos(b_1) = 1.016$$

$$f_{u,f} = 1055.00$$

$$E_f = 64828.00$$

$$u_{,f} = 0.015$$

$$a_{se} = \text{Max}(((A_{\text{conf,max}} - A_{\text{noConf}})/A_{\text{conf,max}}) * (A_{\text{conf,min}}/A_{\text{conf,max}}), 0) = 0.00$$

The definitions of  $A_{\text{noConf}}$ ,  $A_{\text{conf,min}}$  and  $A_{\text{conf,max}}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{\text{conf,max}} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{\text{conf,min}} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{\text{conf,max}}$  by a length equal to half the clear spacing between hoops.

$A_{\text{noConf}} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$$p_{sh,min} = \text{Min}(p_{sh,x}, p_{sh,y}) = 0.00165347$$

Expression ((5.4d), TBDY) for  $p_{sh,min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$$p_{sh,x}((5.4d), \text{TBDY}) = L_{\text{stir}} * A_{\text{stir}} / (A_{\text{sec}} * s) = 0.00165347$$

$$L_{\text{stir}} (\text{Length of stirrups along Y}) = 960.00$$

$$A_{\text{stir}} (\text{stirrups area}) = 78.53982$$

$$A_{\text{sec}} (\text{section area}) = 120000.00$$

$$p_{sh,y}((5.4d), \text{TBDY}) = L_{\text{stir}} * A_{\text{stir}} / (A_{\text{sec}} * s) = 0.00165347$$

$$L_{\text{stir}} (\text{Length of stirrups along X}) = 960.00$$

$$A_{\text{stir}} (\text{stirrups area}) = 78.53982$$

$$A_{\text{sec}} (\text{section area}) = 120000.00$$

$$s = 380.00$$

$$f_{ywe} = 555.55$$

$$f_{ce} = 15.00$$

$$\text{From ((5.A5), TBDY), TBDY: } c_c = 0.00475778$$

$$c = \text{confinement factor} = 1.27578$$

```

y1 = 0.0010562
sh1 = 0.00365026
ft1 = 304.185
fy1 = 253.4875
su1 = 0.00365026
    using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
    and also multiplied by the shear_factor according to 15.7.1.4, with
    Shear_factor = 1.00
    lo/lou,min = lb/lb = 0.22053887
    su1 = 0.4*esu1_nominal ((5.5), TBDY) = 0.032
    From table 5A.1, TBDY: esu1_nominal = 0.08,
    For calculation of esu1_nominal and y1, sh1,ft1,fy1, it is considered
    characteristic value fsy1 = fs1/1.2, from table 5.1, TBDY.
    y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/lb)^ 2/3), from 10.3.5, ASCE 41-17.
    with fs1 = fs = 253.4875
    with Es1 = Es = 200000.00
y2 = 0.0010562
sh2 = 0.00365026
ft2 = 304.185
fy2 = 253.4875
su2 = 0.00365026
    using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
    and also multiplied by the shear_factor according to 15.7.1.4, with
    Shear_factor = 1.00
    lo/lou,min = lb/lb,min = 0.22053887
    su2 = 0.4*esu2_nominal ((5.5), TBDY) = 0.032
    From table 5A.1, TBDY: esu2_nominal = 0.08,
    For calculation of esu2_nominal and y2, sh2,ft2,fy2, it is considered
    characteristic value fsy2 = fs2/1.2, from table 5.1, TBDY.
    y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/lb)^ 2/3), from 10.3.5, ASCE 41-17.
    with fs2 = fs = 253.4875
    with Es2 = Es = 200000.00
yv = 0.0010562
shv = 0.00365026
ftv = 304.185
fyv = 253.4875
suv = 0.00365026
    using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
    and also multiplied by the shear_factor according to 15.7.1.4, with
    Shear_factor = 1.00
    lo/lou,min = lb/lb = 0.22053887
    suv = 0.4*esuv_nominal ((5.5), TBDY) = 0.032
    From table 5A.1, TBDY: esuv_nominal = 0.08,
    considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY
    For calculation of esuv_nominal and yv, shv,ftv,fyv, it is considered
    characteristic value fsyv = fsv/1.2, from table 5.1, TBDY.
    y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/lb)^ 2/3), from 10.3.5, ASCE 41-17.
    with fsv = fs = 253.4875
    with Esv = Es = 200000.00
1 = Asl,ten/(b*d)*(fs1/fc) = 0.53536441
2 = Asl,com/(b*d)*(fs2/fc) = 0.19630028
v = Asl,mid/(b*d)*(fsv/fc) = 0.48777647
and confined core properties:
b = 140.00
d = 327.00
d' = 13.00
fcc (5A.2, TBDY) = 19.13667
cc (5A.5, TBDY) = 0.00475778
c = confinement factor = 1.27578
1 = Asl,ten/(b*d)*(fs1/fc) = 0.83497202
2 = Asl,com/(b*d)*(fs2/fc) = 0.30615641
v = Asl,mid/(b*d)*(fsv/fc) = 0.76075229
Case/Assumption: Unconfined full section - Steel rupture
' satisfies Eq. (4.3)
---->
v < vs,y2 - LHS eq.(4.5) is not satisfied
---->

```



$v < v_{s,c}$  - RHS eq.(4.5) is not satisfied

--->

Case/Assumption Rejected.

--->

New Case/Assumption: Unconfined full section - Spalling of concrete cover

' satisfies Eq. (4.4)

--->

$v < s_y1$  - LHS eq.(4.7) is not satisfied

--->

$v < v_{c,y1}$  - RHS eq.(4.6) is satisfied

--->

$\epsilon_{cu}$  (4.10) = 0.46564051

$M_{Rc}$  (4.17) = 2.0934E+008

--->

New Case/Assumption: Ultimate curvature of confined core after spalling of concrete cover

In expressions below, the following modifications have been made

- $b, d, d'$  replaced by geometric parameters of the core:  $b_o, d_o, d'_o$
- $N, 1, 2, v$  normalised to  $b_o*d_o$ , instead of  $b*d$
- $f_{cc}, \epsilon_{cc}$  parameters of confined concrete,  $f_{cc}, \epsilon_{cc}$  used in lieu of  $f_c, \epsilon_{cu}$

--->

Subcase: Rupture of tension steel

--->

$v^* < v^*_{s,y2}$  - LHS eq.(4.5) is not satisfied

--->

$v^* < v^*_{s,c}$  - LHS eq.(4.5) is not satisfied

--->

Subcase rejected

--->

New Subcase: Failure of compression zone

--->

$v^* < v^*_{c,y2}$  - LHS eq.(4.6) is not satisfied

--->

$v^* < v^*_{c,y1}$  - RHS eq.(4.6) is satisfied

--->

$\epsilon^*_{cu}$  (4.10) = 0.55615794

$M_{Ro}$  (4.17) = 2.4313E+008

--->

$u = \epsilon_{cu}$  (4.2) = 2.6161250E-005

$\mu = M_{Ro}$

-----  
Calculation of ratio  $l_b/l_d$

-----  
Lap Length:  $l_b/l_d = 0.22053887$

$l_b = 300.00$

$l_d = 1360.304$

Calculation of  $l_{b,min}$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$\gamma = 1$

$d_b = 18.00$

Mean strength value of all re-bars:  $f_y = 555.55$

$f'_c = 15.00$ , but  $f_c^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$t = 1.00$

$s = 0.80$

$e = 1.00$

$c_b = 24.02082$

$K_{tr} = 0.82673491$

$A_{tr} = \min(A_{tr_x}, A_{tr_y}) = 157.0796$

where  $A_{tr_x}, A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y local axis

$s = 380.00$

$n = 20.00$

-----  
Calculation of  $\mu_{u1}$ -  
-----  
-----

Calculation of ultimate curvature  $\phi_u$  according to 4.1, Biskinis/Fardis 2013:

$$u = 1.3353763E-005$$

$$\mu = 1.2706E+008$$

with full section properties:

$$b = 400.00$$

$$d = 357.00$$

$$d' = 43.00$$

$$v = 0.00221164$$

$$N = 4737.328$$

$$f_c = 15.00$$

$$\omega (5A.5, \text{TBDY}) = 0.002$$

$$\text{Final value of } \phi_u^* = \text{shear\_factor} * \text{Max}(\phi_u, \phi_c) = 0.018$$

The Shear\_factor is considered equal to 1 (pure moment strength)

$$\text{From (5.4b), TBDY: } \phi_u = 0.018$$

$$\omega_e ((5.4c), \text{TBDY}) = a_s e * \phi_{u, \min} * f_{ywe} / f_{ce} + \text{Min}(\phi_{ux}, \phi_{uy}) = 0.15303423$$

where  $\phi = a_f * \phi_f * f_{fe} / f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$$\phi_{ux} = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2) / 3 = 51733.333$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } \phi_f = 2t_f / b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$\phi_{uy} = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2) / 3 = 0.00$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } \phi_f = 2t_f / b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$R = 40.00$$

$$\text{Effective FRP thickness, } t_f = N L * t * \cos(b_1) = 1.016$$

$$f_{u,f} = 1055.00$$

$$E_f = 64828.00$$

$$u_{f} = 0.015$$

$$a_s e = \text{Max}(((A_{\text{conf,max}} - A_{\text{noConf}}) / A_{\text{conf,max}}) * (A_{\text{conf,min}} / A_{\text{conf,max}}), 0) = 0.00$$

The definitions of  $A_{\text{noConf}}$ ,  $A_{\text{conf,min}}$  and  $A_{\text{conf,max}}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{\text{conf,max}} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{\text{conf,min}} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{\text{conf,max}}$  by a length equal to half the clear spacing between hoops.

$A_{\text{noConf}} = 33066.667$  is the unconfined core area which is equal to  $b_i^2 / 6$  as defined at (A.2).

$$\phi_{sh, \min} = \text{Min}(\phi_{sh,x}, \phi_{sh,y}) = 0.00165347$$

Expression ((5.4d), TBDY) for  $\phi_{sh, \min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$$\phi_{sh,x} ((5.4d), \text{TBDY}) = L_{\text{stir}} * A_{\text{stir}} / (A_{\text{sec}} * s) = 0.00165347$$

$$L_{\text{stir}} (\text{Length of stirrups along Y}) = 960.00$$

$$A_{\text{stir}} (\text{stirrups area}) = 78.53982$$

$$A_{\text{sec}} (\text{section area}) = 120000.00$$

$$\phi_{sh,y} ((5.4d), \text{TBDY}) = L_{\text{stir}} * A_{\text{stir}} / (A_{\text{sec}} * s) = 0.00165347$$

$$L_{\text{stir}} (\text{Length of stirrups along X}) = 960.00$$

$$A_{\text{stir}} (\text{stirrups area}) = 78.53982$$

Asec (section area) = 120000.00

s = 380.00

fywe = 555.55

fce = 15.00

From ((5.A.5), TBDY), TBDY: cc = 0.00475778

c = confinement factor = 1.27578

y1 = 0.0010562

sh1 = 0.00365026

ft1 = 304.185

fy1 = 253.4875

su1 = 0.00365026

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00

lo/lou,min = lb/lb = 0.22053887

su1 = 0.4\*esu1\_nominal ((5.5), TBDY) = 0.032

From table 5A.1, TBDY: esu1\_nominal = 0.08,

For calculation of esu1\_nominal and y1, sh1,ft1,fy1, it is considered  
characteristic value fsy1 = fs1/1.2, from table 5.1, TBDY.

y1, sh1,ft1,fy1, are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/lb)^{2/3})$ , from 10.3.5, ASCE 41-17.

with fs1 = fs = 253.4875

with Es1 = Es = 200000.00

y2 = 0.0010562

sh2 = 0.00365026

ft2 = 304.185

fy2 = 253.4875

su2 = 0.00365026

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00

lo/lou,min = lb/lb,min = 0.22053887

su2 = 0.4\*esu2\_nominal ((5.5), TBDY) = 0.032

From table 5A.1, TBDY: esu2\_nominal = 0.08,

For calculation of esu2\_nominal and y2, sh2,ft2,fy2, it is considered  
characteristic value fsy2 = fs2/1.2, from table 5.1, TBDY.

y1, sh1,ft1,fy1, are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/lb)^{2/3})$ , from 10.3.5, ASCE 41-17.

with fs2 = fs = 253.4875

with Es2 = Es = 200000.00

yv = 0.0010562

shv = 0.00365026

ftv = 304.185

fyv = 253.4875

suv = 0.00365026

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00

lo/lou,min = lb/lb = 0.22053887

suv = 0.4\*esuv\_nominal ((5.5), TBDY) = 0.032

From table 5A.1, TBDY: esuv\_nominal = 0.08,

considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY

For calculation of esuv\_nominal and yv, shv,ftv,fyv, it is considered  
characteristic value fsyv = fsv/1.2, from table 5.1, TBDY.

y1, sh1,ft1,fy1, are also multiplied by  $\text{Min}(1, 1.25 \cdot (lb/lb)^{2/3})$ , from 10.3.5, ASCE 41-17.

with fsv = fs = 253.4875

with Esv = Es = 200000.00

1 = Asl,ten/(b\*d)\*(fs1/fc) = 0.09815014

2 = Asl,com/(b\*d)\*(fs2/fc) = 0.26768221

v = Asl,mid/(b\*d)\*(fsv/fc) = 0.24388823

and confined core properties:

b = 340.00

d = 327.00

d' = 13.00

fcc (5A.2, TBDY) = 19.13667

cc (5A.5, TBDY) = 0.00475778

c = confinement factor = 1.27578

1 = Asl,ten/(b\*d)\*(fs1/fc) = 0.1260644

$$2 = A_{sl,com}/(b*d)*(f_{s2}/f_c) = 0.34381201$$

$$v = A_{sl,mid}/(b*d)*(f_{sv}/f_c) = 0.31325094$$

Case/Assumption: Unconfined full section - Steel rupture

' satisfies Eq. (4.3)

---->

$v < v_{s,y2}$  - LHS eq.(4.5) is satisfied

---->

$$s_u(4.9) = 0.23431248$$

$$M_u = M_{Rc}(4.14) = 1.2706E+008$$

$$u = s_u(4.1) = 1.3353763E-005$$

Calculation of ratio  $l_b/l_d$

$$\text{Lap Length: } l_b/l_d = 0.22053887$$

$$l_b = 300.00$$

$$l_d = 1360.304$$

Calculation of  $l_b, \min$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$$= 1$$

$$d_b = 18.00$$

Mean strength value of all re-bars:  $f_y = 555.55$

$$f'_c = 15.00, \text{ but } f_c^{0.5} \leq 8.3 \text{ MPa (22.5.3.1, ACI 318-14)}$$

$$t = 1.00$$

$$s = 0.80$$

$$e = 1.00$$

$$c_b = 24.02082$$

$$K_{tr} = 0.82673491$$

$$A_{tr} = \min(A_{tr_x}, A_{tr_y}) = 157.0796$$

where  $A_{tr_x}, A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y local axis

$$s = 380.00$$

$$n = 20.00$$

Calculation of  $M_{u2+}$

Calculation of ultimate curvature  $u$  according to 4.1, Biskinis/Fardis 2013:

$$u = 2.6161250E-005$$

$$M_u = 2.4313E+008$$

with full section properties:

$$b = 200.00$$

$$d = 357.00$$

$$d' = 43.00$$

$$v = 0.00442328$$

$$N = 4737.328$$

$$f_c = 15.00$$

$$c_o(5A.5, \text{TB DY}) = 0.002$$

$$\text{Final value of } c_u: c_u^* = \text{shear\_factor} * \max(c_u, c_c) = 0.018$$

The Shear\_factor is considered equal to 1 (pure moment strength)

$$\text{From (5.4b), TB DY: } c_u = 0.018$$

$$w_e((5.4c), \text{TB DY}) = a_{se} * s_{h, \min} * f_{ywe}/f_{ce} + \min(f_x, f_y) = 0.15303423$$

where  $f = a_f * p_f * f_{fe}/f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$$f_x = 0.15303423$$

Expression ((15B.6), TB DY) is modified as  $a_f = 1 - (\text{Unconfined area})/(\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 51733.333$$

$$b_{\max} = 400.00$$

$$h_{\max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } p_f = 2t_f/b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$f_y = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $af = 1 - (\text{Unconfined area})/(\text{total area})$

$af = 0.43111111$

with  $\text{Unconfined area} = ((b_{\max} - 2R)^2 + (h_{\max} - 2R)^2)/3 = 0.00$

$b_{\max} = 400.00$

$h_{\max} = 400.00$

From EC8 A.4.4.3(6),  $pf = 2tf/bw = 0.01016$

$bw = 200.00$

effective stress from (A.35),  $ff_e = 524.0792$

$R = 40.00$

Effective FRP thickness,  $tf = NL * t * \cos(b1) = 1.016$

$f_{u,f} = 1055.00$

$E_f = 64828.00$

$u_f = 0.015$

$ase = \text{Max}(((A_{\text{conf,max}} - A_{\text{noConf}})/A_{\text{conf,max}}) * (A_{\text{conf,min}}/A_{\text{conf,max}}), 0) = 0.00$

The definitions of  $A_{\text{noConf}}$ ,  $A_{\text{conf,min}}$  and  $A_{\text{conf,max}}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988) "Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{\text{conf,max}} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{\text{conf,min}} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{\text{conf,max}}$  by a length equal to half the clear spacing between hoops.

$A_{\text{noConf}} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$p_{sh,min} = \text{Min}(p_{sh,x}, p_{sh,y}) = 0.00165347$

Expression ((5.4d), TBDY) for  $p_{sh,min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$p_{sh,x} \text{ ((5.4d), TBDY)} = L_{\text{stir}} * A_{\text{stir}} / (A_{\text{sec}} * s) = 0.00165347$

$L_{\text{stir}}$  (Length of stirrups along Y) = 960.00

$A_{\text{stir}}$  (stirrups area) = 78.53982

$A_{\text{sec}}$  (section area) = 120000.00

$p_{sh,y} \text{ ((5.4d), TBDY)} = L_{\text{stir}} * A_{\text{stir}} / (A_{\text{sec}} * s) = 0.00165347$

$L_{\text{stir}}$  (Length of stirrups along X) = 960.00

$A_{\text{stir}}$  (stirrups area) = 78.53982

$A_{\text{sec}}$  (section area) = 120000.00

$s = 380.00$

$f_{ywe} = 555.55$

$f_{ce} = 15.00$

From ((5.A5), TBDY), TBDY:  $cc = 0.00475778$

$c$  = confinement factor = 1.27578

$y1 = 0.0010562$

$sh1 = 0.00365026$

$ft1 = 304.185$

$fy1 = 253.4875$

$su1 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with  $\text{Shear\_factor} = 1.00$

$l_o/l_{o,min} = l_b/l_d = 0.22053887$

$su1 = 0.4 * esu1_{\text{nominal}} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu1_{\text{nominal}} = 0.08$ ,

For calculation of  $esu1_{\text{nominal}}$  and  $y1, sh1, ft1, fy1$ , it is considered characteristic value  $fsy1 = fs1/1.2$ , from table 5.1, TBDY.

$y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 * (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.

with  $fs1 = fs = 253.4875$

with  $Es1 = Es = 200000.00$

$y2 = 0.0010562$

$sh2 = 0.00365026$

$ft2 = 304.185$

$fy2 = 253.4875$

$su2 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor

and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00  
 $l_o/l_{ou,min} = l_b/l_{b,min} = 0.22053887$   
 $su_2 = 0.4 * esu_{2,nominal} ((5.5), TBDY) = 0.032$   
From table 5A.1, TBDY:  $esu_{2,nominal} = 0.08$ ,  
For calculation of  $esu_{2,nominal}$  and  $y_2, sh_2, ft_2, fy_2$ , it is considered  
characteristic value  $fsy_2 = fs_2/1.2$ , from table 5.1, TBDY.  
 $y_1, sh_1, ft_1, fy_1$ , are also multiplied by  $Min(1, 1.25 * (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
with  $fs_2 = fs = 253.4875$   
with  $Es_2 = Es = 200000.00$   
 $y_v = 0.0010562$   
 $sh_v = 0.00365026$   
 $ft_v = 304.185$   
 $fy_v = 253.4875$   
 $suv = 0.00365026$   
using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00  
 $l_o/l_{ou,min} = l_b/l_d = 0.22053887$   
 $suv = 0.4 * esuv_{nominal} ((5.5), TBDY) = 0.032$   
From table 5A.1, TBDY:  $esuv_{nominal} = 0.08$ ,  
considering characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY  
For calculation of  $esuv_{nominal}$  and  $y_v, sh_v, ft_v, fy_v$ , it is considered  
characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY.  
 $y_1, sh_1, ft_1, fy_1$ , are also multiplied by  $Min(1, 1.25 * (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
with  $fsv = fs = 253.4875$   
with  $Es_v = Es = 200000.00$   
 $1 = A_{sl,ten}/(b*d) * (fs_1/f_c) = 0.53536441$   
 $2 = A_{sl,com}/(b*d) * (fs_2/f_c) = 0.19630028$   
 $v = A_{sl,mid}/(b*d) * (fsv/f_c) = 0.48777647$   
and confined core properties:  
 $b = 140.00$   
 $d = 327.00$   
 $d' = 13.00$   
 $f_{cc} (5A.2, TBDY) = 19.13667$   
 $cc (5A.5, TBDY) = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $1 = A_{sl,ten}/(b*d) * (fs_1/f_c) = 0.83497202$   
 $2 = A_{sl,com}/(b*d) * (fs_2/f_c) = 0.30615641$   
 $v = A_{sl,mid}/(b*d) * (fsv/f_c) = 0.76075229$   
Case/Assumption: Unconfined full section - Steel rupture  
'satisfies Eq. (4.3)  
--->  
 $v < v_{s,y2}$  - LHS eq.(4.5) is not satisfied  
--->  
 $v < v_{s,c}$  - RHS eq.(4.5) is not satisfied  
--->  
Case/Assumption Rejected.  
--->  
New Case/Assumption: Unconfined full section - Spalling of concrete cover  
'satisfies Eq. (4.4)  
--->  
 $v < s_{y1}$  - LHS eq.(4.7) is not satisfied  
--->  
 $v < v_{c,y1}$  - RHS eq.(4.6) is satisfied  
--->  
 $cu (4.10) = 0.46564051$   
 $M_{Rc} (4.17) = 2.0934E+008$   
--->  
New Case/Assumption: Ultimate curvature of confined core after spalling of concrete cover  
In expressions below, the following modifications have been made  
-  $b, d, d'$  replaced by geometric parameters of the core:  $bo, do, d'o$   
-  $N, 1, 2, v$  normalised to  $bo*do$ , instead of  $b*d$   
- parameters of confined concrete,  $f_{cc}, cc$ , used in lieu of  $f_c, ec_u$   
--->  
Subcase: Rupture of tension steel  
--->

$v^* < v^*_{s,y2}$  - LHS eq.(4.5) is not satisfied

--->

$v^* < v^*_{s,c}$  - LHS eq.(4.5) is not satisfied

--->

Subcase rejected

--->

New Subcase: Failure of compression zone

--->

$v^* < v^*_{c,y2}$  - LHS eq.(4.6) is not satisfied

--->

$v^* < v^*_{c,y1}$  - RHS eq.(4.6) is satisfied

--->

$*c_u$  (4.10) = 0.55615794

$M_{Ro}$  (4.17) = 2.4313E+008

--->

$u = c_u$  (4.2) = 2.6161250E-005

$\mu = M_{Ro}$

Calculation of ratio  $l_b/l_d$

Lap Length:  $l_b/l_d = 0.22053887$

$l_b = 300.00$

$l_d = 1360.304$

Calculation of  $l_{b,min}$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

= 1

$d_b = 18.00$

Mean strength value of all re-bars:  $f_y = 555.55$

$f'_c = 15.00$ , but  $f'_c^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$t = 1.00$

$s = 0.80$

$e = 1.00$

$c_b = 24.02082$

$K_{tr} = 0.82673491$

$A_{tr} = \min(A_{tr_x}, A_{tr_y}) = 157.0796$

where  $A_{tr_x}, A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis

$s = 380.00$

$n = 20.00$

Calculation of  $\mu_2$ -

Calculation of ultimate curvature  $\mu$  according to 4.1, Biskinis/Fardis 2013:

$u = 1.3353763E-005$

$\mu = 1.2706E+008$

with full section properties:

$b = 400.00$

$d = 357.00$

$d' = 43.00$

$v = 0.00221164$

$N = 4737.328$

$f_c = 15.00$

$\alpha$  (5A.5, TBDY) = 0.002

Final value of  $\alpha$ :  $\alpha^* = \text{shear\_factor} * \max(\alpha, \alpha_c) = 0.018$

The Shear\_factor is considered equal to 1 (pure moment strength)

From (5.4b), TBDY:  $\alpha = 0.018$

$\alpha_{we}$  ((5.4c), TBDY) =  $\alpha_{se} * \min(f_{ywe}/f_{ce} + \min(f_x, f_y)) = 0.15303423$

where  $f = \alpha_f * \rho_f * f_{fe}/f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$f_x = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $\alpha_f = 1 - (\text{Unconfined area})/(\text{total area})$

$\alpha_f = 0.43111111$

with Unconfined area =  $((b_{max}-2R)^2 + (h_{max}-2R)^2)/3 = 51733.333$

bmax = 400.00  
hmax = 400.00  
From EC8 A.4.4.3(6),  $pf = 2tf/bw = 0.01016$   
bw = 200.00  
effective stress from (A.35),  $ff,e = 524.0792$

fy = 0.15303423  
Expression ((15B.6), TBDY) is modified as  $af = 1 - (\text{Unconfined area})/(\text{total area})$   
af = 0.43111111  
with Unconfined area =  $((bmax-2R)^2 + (hmax-2R)^2)/3 = 0.00$   
bmax = 400.00  
hmax = 400.00  
From EC8 A.4.4.3(6),  $pf = 2tf/bw = 0.01016$   
bw = 200.00  
effective stress from (A.35),  $ff,e = 524.0792$

R = 40.00  
Effective FRP thickness,  $tf = NL*t*\cos(b1) = 1.016$   
fu,f = 1055.00  
Ef = 64828.00  
u,f = 0.015  
 $ase = \text{Max}(((Aconf,max - AnoConf)/Aconf,max) * (Aconf,min/Aconf,max), 0) = 0.00$   
The definitions of AnoConf, Aconf,min and Aconf,max are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).  
The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988) "Theoretical Stress-Strain Model for Confined Concrete."  
J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.  
Aconf,max = 75600.00 is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.  
Aconf,min = 0.00 is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area Aconf,max by a length equal to half the clear spacing between hoops.  
AnoConf = 33066.667 is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).  
 $psh,min = \text{Min}(psh,x, psh,y) = 0.00165347$   
Expression ((5.4d), TBDY) for psh,min has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$psh,x \text{ ((5.4d), TBDY)} = Lstir * Astir / (Asec * s) = 0.00165347$   
Lstir (Length of stirrups along Y) = 960.00  
Astir (stirrups area) = 78.53982  
Asec (section area) = 120000.00

$psh,y \text{ ((5.4d), TBDY)} = Lstir * Astir / (Asec * s) = 0.00165347$   
Lstir (Length of stirrups along X) = 960.00  
Astir (stirrups area) = 78.53982  
Asec (section area) = 120000.00

s = 380.00  
fywe = 555.55  
fce = 15.00  
From ((5.A5), TBDY), TBDY:  $cc = 0.00475778$   
c = confinement factor = 1.27578  
y1 = 0.0010562  
sh1 = 0.00365026  
ft1 = 304.185  
fy1 = 253.4875  
su1 = 0.00365026  
using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with Shear\_factor = 1.00  
 $lo/lou,min = lb/ld = 0.22053887$   
 $su1 = 0.4 * esu1\_nominal \text{ ((5.5), TBDY)} = 0.032$   
From table 5A.1, TBDY:  $esu1\_nominal = 0.08$ ,  
For calculation of  $esu1\_nominal$  and y1, sh1, ft1, fy1, it is considered characteristic value  $fsy1 = fs1/1.2$ , from table 5.1, TBDY.  
y1, sh1, ft1, fy1, are also multiplied by  $\text{Min}(1, 1.25 * (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
with  $fs1 = fs = 253.4875$



with  $E_s = E_s = 200000.00$   
 $y_2 = 0.0010562$   
 $sh_2 = 0.00365026$   
 $ft_2 = 304.185$   
 $fy_2 = 253.4875$   
 $su_2 = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $lo/lo_{min} = lb/lb_{min} = 0.22053887$   
 $su_2 = 0.4 * esu_{nominal} ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esu_{nominal} = 0.08$ ,  
 For calculation of  $esu_{nominal}$  and  $y_2, sh_2, ft_2, fy_2$ , it is considered  
 characteristic value  $fsy_2 = fs_2/1.2$ , from table 5.1, TBDY.  
 $y_1, sh_1, ft_1, fy_1$ , are also multiplied by  $Min(1, 1.25 * (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fs_2 = fs = 253.4875$   
 with  $E_s = E_s = 200000.00$   
 $y_v = 0.0010562$   
 $sh_v = 0.00365026$   
 $ft_v = 304.185$   
 $fy_v = 253.4875$   
 $suv = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $lo/lo_{min} = lb/ld = 0.22053887$   
 $suv = 0.4 * esuv_{nominal} ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esuv_{nominal} = 0.08$ ,  
 considering characteristic value  $fsyv = fs_v/1.2$ , from table 5.1, TBDY  
 For calculation of  $esuv_{nominal}$  and  $y_v, sh_v, ft_v, fy_v$ , it is considered  
 characteristic value  $fsyv = fs_v/1.2$ , from table 5.1, TBDY.  
 $y_1, sh_1, ft_1, fy_1$ , are also multiplied by  $Min(1, 1.25 * (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fs_v = fs = 253.4875$   
 with  $E_s = E_s = 200000.00$   
 $1 = Asl_{ten}/(b*d) * (fs_1/f_c) = 0.09815014$   
 $2 = Asl_{com}/(b*d) * (fs_2/f_c) = 0.26768221$   
 $v = Asl_{mid}/(b*d) * (fs_v/f_c) = 0.24388823$   
 and confined core properties:  
 $b = 340.00$   
 $d = 327.00$   
 $d' = 13.00$   
 $f_{cc} (5A.2, TBDY) = 19.13667$   
 $cc (5A.5, TBDY) = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $1 = Asl_{ten}/(b*d) * (fs_1/f_c) = 0.1260644$   
 $2 = Asl_{com}/(b*d) * (fs_2/f_c) = 0.34381201$   
 $v = Asl_{mid}/(b*d) * (fs_v/f_c) = 0.31325094$   
 Case/Assumption: Unconfined full section - Steel rupture  
 ' satisfies Eq. (4.3)  
 --->  
 $v < v_{s,y_2}$  - LHS eq.(4.5) is satisfied  
 --->  
 $su (4.9) = 0.23431248$   
 $Mu = MRc (4.14) = 1.2706E+008$   
 $u = su (4.1) = 1.3353763E-005$

#### Calculation of ratio $lb/ld$

Lap Length:  $lb/ld = 0.22053887$   
 $lb = 300.00$   
 $ld = 1360.304$   
 Calculation of  $lb_{min}$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.  
 $= 1$   
 $db = 18.00$   
 Mean strength value of all re-bars:  $fy = 555.55$   
 $fc' = 15.00$ , but  $fc^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$t = 1.00$   
 $s = 0.80$   
 $e = 1.00$   
 $cb = 24.02082$   
 $K_{tr} = 0.82673491$   
 $A_{tr} = \text{Min}(A_{tr\_x}, A_{tr\_y}) = 157.0796$   
 where  $A_{tr\_x}$ ,  $A_{tr\_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis  
 $s = 380.00$   
 $n = 20.00$

Calculation of Shear Strength  $V_r = \text{Min}(V_{r1}, V_{r2}) = 196005.816$

Calculation of Shear Strength at edge 1,  $V_{r1} = 227350.021$

$V_{r1} = V_{Col} \text{ ((10.3), ASCE 41-17)} = k_{nl} * V_{Col0}$

$V_{Col0} = 227350.021$

$k_{nl} = 1$  (zero step-static loading)

NOTE: In expression (10-3) ' $V_s$ ' is replaced by ' $V_s + f * V_f$ '  
 where  $V_f$  is the contribution of FRPs (11.3), ACI 440).

$= 1$  (normal-weight concrete)

$f'_c = 15.00$ , but  $f'_c \leq 8.3 \text{ MPa}$  (22.5.3.1, ACI 318-14)

$M/Vd = 2.00$

$\mu_u = 3.21769$

$V_u = 0.01054019$

$d = 0.8 * h = 320.00$

$N_u = 4737.328$

$A_g = 80000.00$

From (11.5.4.8), ACI 318-14:  $V_s = V_{s1} + V_{s2} = 0.00$

where:

$V_{s1} = 0.00$  is calculated for section web, with:

$d = 320.00$

$A_v = 157079.633$

$f_y = 444.44$

$s = 380.00$

$V_{s1}$  is multiplied by  $Col1 = 0.00$

$s/d = 1.1875$

$V_{s2} = 0.00$  is calculated for section flange, with:

$d = 160.00$

$A_v = 157079.633$

$f_y = 444.44$

$s = 380.00$

$V_{s2}$  is multiplied by  $Col2 = 0.00$

$s/d = 2.375$

$V_f \text{ ((11-3)-(11.4), ACI 440)} = 188111.148$

$f = 0.95$ , for fully-wrapped sections

$w_f/s_f = 1$  (FRP strips adjacent to one another).

In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot a) \sin a$  which is more a generalised expression,  
 where  $a$  is the angle of the crack direction (see KANEPE).

This later relation, considered as a function  $V_f(, )$ , is implemented for every different fiber orientation  $a_i$ ,  
 as well as for 2 crack directions,  $a = 45^\circ$  and  $a = -45^\circ$  to take into consideration the cyclic seismic loading.

orientation 1:  $a_1 = b_1 + 90^\circ = 90.00$

$V_f = \text{Min}(|V_f(45, 1)|, |V_f(-45, a_1)|)$ , with:

total thickness per orientation,  $t_{f1} = N_L * t / N_{oDir} = 1.016$

$d_{fv} = d$  (figure 11.2, ACI 440) = 357.00

$f_{fe} \text{ ((11-5), ACI 440)} = 259.312$

$E_f = 64828.00$

$f_e = 0.004$ , from (11.6a), ACI 440

with  $f_u = 0.01$

From (11-11), ACI 440:  $V_s + V_f \leq 164661.611$

$bw = 200.00$

Calculation of Shear Strength at edge 2,  $V_{r2} = 196005.816$

$V_{r2} = V_{Col} ((10.3), ASCE 41-17) = k_{nl} * V_{Col0}$   
 $V_{Col0} = 196005.816$   
 $k_{nl} = 1$  (zero step-static loading)

NOTE: In expression (10-3) 'Vs' is replaced by 'Vs+ f\*Vf'  
where Vf is the contribution of FRPs (11.3), ACI 440).

= 1 (normal-weight concrete)  
 $f_c' = 15.00$ , but  $f_c'^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)  
 $M/Vd = 4.00$   
 $\mu_u = 23.99609$   
 $V_u = 0.01054019$   
 $d = 0.8 * h = 320.00$   
 $N_u = 4737.328$   
 $A_g = 80000.00$   
From (11.5.4.8), ACI 318-14:  $V_s = V_{s1} + V_{s2} = 0.00$   
where:  
 $V_{s1} = 0.00$  is calculated for section web, with:  
 $d = 320.00$   
 $A_v = 157079.633$   
 $f_y = 444.44$   
 $s = 380.00$   
 $V_{s1}$  is multiplied by  $Col1 = 0.00$   
 $s/d = 1.1875$   
 $V_{s2} = 0.00$  is calculated for section flange, with:  
 $d = 160.00$   
 $A_v = 157079.633$   
 $f_y = 444.44$   
 $s = 380.00$   
 $V_{s2}$  is multiplied by  $Col2 = 0.00$   
 $s/d = 2.375$   
 $V_f ((11-3)-(11.4), ACI 440) = 188111.148$   
 $f = 0.95$ , for fully-wrapped sections  
 $w_f/s_f = 1$  (FRP strips adjacent to one another).  
In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot a) \sin a$  which is more a generalised expression,  
where  $a$  is the angle of the crack direction (see KANEPE).  
This later relation, considered as a function  $V_f( , )$ , is implemented for every different fiber orientation  $a_i$ ,  
as well as for 2 crack directions,  $a = 45^\circ$  and  $a = -45^\circ$  to take into consideration the cyclic seismic loading.  
orientation 1:  $a = b1 + 90^\circ = 90.00$   
 $V_f = \text{Min}(|V_f(45, 1)|, |V_f(-45, a1)|)$ , with:  
total thickness per orientation,  $t_{f1} = N_L * t / N_{oDir} = 1.016$   
 $d_{fv} = d$  (figure 11.2, ACI 440) = 357.00  
 $f_{fe} ((11-5), ACI 440) = 259.312$   
 $E_f = 64828.00$   
 $f_e = 0.004$ , from (11.6a), ACI 440  
with  $f_u = 0.01$   
From (11-11), ACI 440:  $V_s + V_f \leq 164661.611$   
 $b_w = 200.00$

End Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1  
At local axis: 3

Start Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1  
At Shear local axis: 2  
(Bending local axis: 3)  
Section Type: rctcs

Constant Properties

Knowledge Factor,  $\gamma = 0.90$   
Mean strength values are used for both shear and moment calculations.  
Consequently:  
Existing material of Primary Member: Concrete Strength,  $f_c = f_{cm} = 15.00$

Existing material of Primary Member: Steel Strength,  $f_s = f_{sm} = 444.44$   
Concrete Elasticity,  $E_c = 18203.022$   
Steel Elasticity,  $E_s = 200000.00$   
#####  
Note: Especially for the calculation of moment strengths,  
the above steel re-bar strengths are multiplied by 1.25 according to R18.6.5, ACI 318-14  
Existing material: Steel Strength,  $f_s = 1.25 \cdot f_{sm} = 555.55$   
#####  
Max Height,  $H_{max} = 400.00$   
Min Height,  $H_{min} = 200.00$   
Max Width,  $W_{max} = 400.00$   
Min Width,  $W_{min} = 200.00$   
Eccentricity,  $Ecc = 100.00$   
Cover Thickness,  $c = 25.00$   
Mean Confinement Factor overall section = 1.27578  
Element Length,  $L = 3000.00$   
Primary Member  
Ribbed Bars  
Ductile Steel  
Without Detailing for Earthquake Resistance (including stirrups not closed at 135°)  
Longitudinal Bars With Ends Lapped Starting at the End Sections  
Lap Length  $l_o = 300.00$   
FRP Wrapping Data  
Type: Carbon  
Cured laminate properties (design values)  
Thickness,  $t = 1.016$   
Tensile Strength,  $f_{fu} = 1055.00$   
Tensile Modulus,  $E_f = 64828.00$   
Elongation,  $\epsilon_{fu} = 0.01$   
Number of directions,  $N_{oDir} = 1$   
Fiber orientations,  $b_i: 0.00^\circ$   
Number of layers,  $N_L = 1$   
Radius of rounding corners,  $R = 40.00$

#### Stepwise Properties

At local axis: 2  
EDGE -A-  
Shear Force,  $V_a = 1.5456333E-009$   
EDGE -B-  
Shear Force,  $V_b = -1.5456333E-009$   
BOTH EDGES  
Axial Force,  $F = -4737.328$   
Longitudinal Reinforcement Area Distribution (in 2 divisions)  
-Tension:  $A_{sl,t} = 0.00$   
-Compression:  $A_{sl,c} = 5152.212$   
Longitudinal Reinforcement Area Distribution (in 3 divisions)  
-Tension:  $A_{sl,ten} = 1231.504$   
-Compression:  $A_{sl,com} = 1231.504$   
-Middle:  $A_{sl,mid} = 2689.203$

Calculation of Shear Capacity ratio,  $V_e/V_r = 0.55718248$   
Member Controlled by Flexure ( $V_e/V_r < 1$ )  
Calculation of Shear Demand from fig. R18.6.5, ACI 318-14  $V_e = (M_{pr1} + M_{pr2})/l_n = 126675.449$   
with  
 $M_{pr1} = \max(\mu_{u1+}, \mu_{u1-}) = 1.9001E+008$   
 $\mu_{u1+} = 1.9001E+008$ , is the ultimate moment strength at the edge 1 of the member in the actual moment direction  
which is defined for the static loading combination  
 $\mu_{u1-} = 1.9001E+008$ , is the ultimate moment strength at the edge 1 of the member in the opposite moment  
direction which is defined for the static loading combination  
 $M_{pr2} = \max(\mu_{u2+}, \mu_{u2-}) = 1.9001E+008$   
 $\mu_{u2+} = 1.9001E+008$ , is the ultimate moment strength at the edge 2 of the member in the actual moment direction  
which is defined for the static loading combination

Mu2- = 1.9001E+008, is the ultimate moment strength at the edge 2 of the member in the opposite moment direction which is defined for the static loading combination

#### Calculation of Mu1+

Calculation of ultimate curvature  $\phi_u$  according to 4.1, Biskinis/Fardis 2013:

$$\phi_u = 1.7086748E-005$$

$$M_u = 1.9001E+008$$

with full section properties:

$$b = 200.00$$

$$d = 357.00$$

$$d' = 43.00$$

$$v = 0.00442328$$

$$N = 4737.328$$

$$f_c = 15.00$$

$$\phi_{co} \text{ (5A.5, TBDY)} = 0.002$$

$$\text{Final value of } \phi_u: \phi_u^* = \text{shear\_factor} * \text{Max}(\phi_u, \phi_{co}) = 0.018$$

The Shear\_factor is considered equal to 1 (pure moment strength)

$$\text{From (5.4b), TBDY: } \phi_u = 0.018$$

$$\phi_{we} \text{ ((5.4c), TBDY)} = a_{se} * \phi_{sh,min} * f_{ywe} / f_{ce} + \text{Min}(\phi_{fx}, \phi_{fy}) = 0.15303423$$

where  $\phi_{fx} = a_f * \phi_{pf} * f_{fe} / f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$$\phi_{fx} = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{max} - 2R)^2 + (h_{max} - 2R)^2) / 3 = 51733.333$$

$$b_{max} = 400.00$$

$$h_{max} = 400.00$$

$$\text{From EC8 A4.4.3(6), } \phi_{pf} = 2t_f / b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$\phi_{fy} = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area}) / (\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{max} - 2R)^2 + (h_{max} - 2R)^2) / 3 = 0.00$$

$$b_{max} = 400.00$$

$$h_{max} = 400.00$$

$$\text{From EC8 A4.4.3(6), } \phi_{pf} = 2t_f / b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$R = 40.00$$

$$\text{Effective FRP thickness, } t_f = N L^* t \cos(b_1) = 1.016$$

$$f_{u,f} = 1055.00$$

$$E_f = 64828.00$$

$$\phi_{u,f} = 0.015$$

$$a_{se} = \text{Max}(((A_{conf,max} - A_{noConf}) / A_{conf,max}) * (A_{conf,min} / A_{conf,max}), 0) = 0.00$$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2 / 6$  as defined at (A.2).

$$\phi_{sh,min} = \text{Min}(\phi_{sh,x}, \phi_{sh,y}) = 0.00165347$$

Expression ((5.4d), TBDY) for  $\phi_{sh,min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$$psh,x ((5.4d), TBDY) = Lstir * Astir / (Asec * s) = 0.00165347$$

$$Lstir \text{ (Length of stirrups along Y)} = 960.00$$

$$Astir \text{ (stirrups area)} = 78.53982$$

$$Asec \text{ (section area)} = 120000.00$$

$$psh,y ((5.4d), TBDY) = Lstir * Astir / (Asec * s) = 0.00165347$$

$$Lstir \text{ (Length of stirrups along X)} = 960.00$$

$$Astir \text{ (stirrups area)} = 78.53982$$

$$Asec \text{ (section area)} = 120000.00$$

$$s = 380.00$$

$$fywe = 555.55$$

$$fce = 15.00$$

$$\text{From } ((5.A5), TBDY), TBDY: cc = 0.00475778$$

$$c = \text{confinement factor} = 1.27578$$

$$y1 = 0.0010562$$

$$sh1 = 0.00365026$$

$$ft1 = 304.185$$

$$fy1 = 253.4875$$

$$su1 = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00

$$lo/lou,min = lb/ld = 0.22053887$$

$$su1 = 0.4 * esu1\_nominal ((5.5), TBDY) = 0.032$$

$$\text{From table 5A.1, TBDY: } esu1\_nominal = 0.08,$$

For calculation of esu1\_nominal and y1, sh1,ft1,fy1, it is considered  
characteristic value fsy1 = fs1/1.2, from table 5.1, TBDY.

$$y1, sh1,ft1,fy1, \text{ are also multiplied by } \text{Min}(1, 1.25 * (lb/ld)^{2/3}), \text{ from 10.3.5, ASCE 41-17.}$$

$$\text{with } fs1 = fs = 253.4875$$

$$\text{with } Es1 = Es = 200000.00$$

$$y2 = 0.0010562$$

$$sh2 = 0.00365026$$

$$ft2 = 304.185$$

$$fy2 = 253.4875$$

$$su2 = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00

$$lo/lou,min = lb/lb,min = 0.22053887$$

$$su2 = 0.4 * esu2\_nominal ((5.5), TBDY) = 0.032$$

$$\text{From table 5A.1, TBDY: } esu2\_nominal = 0.08,$$

For calculation of esu2\_nominal and y2, sh2,ft2,fy2, it is considered  
characteristic value fsy2 = fs2/1.2, from table 5.1, TBDY.

$$y1, sh1,ft1,fy1, \text{ are also multiplied by } \text{Min}(1, 1.25 * (lb/ld)^{2/3}), \text{ from 10.3.5, ASCE 41-17.}$$

$$\text{with } fs2 = fs = 253.4875$$

$$\text{with } Es2 = Es = 200000.00$$

$$yv = 0.0010562$$

$$shv = 0.00365026$$

$$ftv = 304.185$$

$$fyv = 253.4875$$

$$suv = 0.00365026$$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
Shear\_factor = 1.00

$$lo/lou,min = lb/ld = 0.22053887$$

$$suv = 0.4 * esuv\_nominal ((5.5), TBDY) = 0.032$$

$$\text{From table 5A.1, TBDY: } esuv\_nominal = 0.08,$$

considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY

For calculation of esuv\_nominal and yv, shv,ftv,fyv, it is considered  
characteristic value fsyv = fsv/1.2, from table 5.1, TBDY.

$$y1, sh1,ft1,fy1, \text{ are also multiplied by } \text{Min}(1, 1.25 * (lb/ld)^{2/3}), \text{ from 10.3.5, ASCE 41-17.}$$

$$\text{with } fsv = fs = 253.4875$$

$$\text{with } Esv = Es = 200000.00$$

$$1 = Asl,ten / (b * d) * (fs1 / fc) = 0.29147618$$

$$2 = Asl,com / (b * d) * (fs2 / fc) = 0.29147618$$

$$v = Asl,mid / (b * d) * (fsv / fc) = 0.6364888$$

and confined core properties:

$$b = 140.00$$

$$d = 327.00$$

$$d' = 13.00$$

$$fcc(5A.2, TBDY) = 19.13667$$

$$cc(5A.5, TBDY) = 0.00475778$$

$$c = \text{confinement factor} = 1.27578$$

$$1 = A_{s1,ten}/(b*d)*(f_{s1}/f_c) = 0.45459588$$

$$2 = A_{s2,com}/(b*d)*(f_{s2}/f_c) = 0.45459588$$

$$v = A_{s,mid}/(b*d)*(f_{sv}/f_c) = 0.99268896$$

Case/Assumption: Unconfined full section - Steel rupture

' satisfies Eq. (4.3)

--->

$v < v_{s,y2}$  - LHS eq.(4.5) is not satisfied

--->

$v < v_{s,c}$  - RHS eq.(4.5) is satisfied

--->

$$s_u(4.8) = 0.40159417$$

$$Mu = MR_c(4.15) = 1.9001E+008$$

$$u = s_u(4.1) = 1.7086748E-005$$

Calculation of ratio  $l_b/d$

Lap Length:  $l_b/d = 0.22053887$

$$l_b = 300.00$$

$$l_d = 1360.304$$

Calculation of  $l_b, \min$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$$= 1$$

$$d_b = 18.00$$

Mean strength value of all re-bars:  $f_y = 555.55$

$$f_c' = 15.00, \text{ but } f_c'^{0.5} \leq 8.3 \text{ MPa (22.5.3.1, ACI 318-14)}$$

$$t = 1.00$$

$$s = 0.80$$

$$e = 1.00$$

$$c_b = 24.02082$$

$$K_{tr} = 0.82673491$$

$$A_{tr} = \min(A_{tr_x}, A_{tr_y}) = 157.0796$$

where  $A_{tr_x}$ ,  $A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis

$$s = 380.00$$

$$n = 20.00$$

Calculation of  $Mu1$ -

Calculation of ultimate curvature  $u$  according to 4.1, Biskinis/Fardis 2013:

$$u = 1.7086748E-005$$

$$Mu = 1.9001E+008$$

with full section properties:

$$b = 200.00$$

$$d = 357.00$$

$$d' = 43.00$$

$$v = 0.00442328$$

$$N = 4737.328$$

$$f_c = 15.00$$

$$co(5A.5, TBDY) = 0.002$$

$$\text{Final value of } cu: cu^* = \text{shear\_factor} * \max(cu, cc) = 0.018$$

The Shear\_factor is considered equal to 1 (pure moment strength)

$$\text{From (5.4b), TBDY: } cu = 0.018$$

$$we((5.4c), TBDY) = a_{se} * sh_{min} * f_{ywe}/f_{ce} + \min(f_x, f_y) = 0.15303423$$

where  $f = a_f * p_f * f_{fe}/f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$$f_x = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $af = 1 - (\text{Unconfined area})/(\text{total area})$

$af = 0.43111111$

with Unconfined area =  $((b_{\max}-2R)^2 + (h_{\max}-2R)^2)/3 = 51733.333$

$b_{\max} = 400.00$

$h_{\max} = 400.00$

From EC8 A.4.4.3(6),  $pf = 2tf/bw = 0.01016$

$bw = 200.00$

effective stress from (A.35),  $ff_e = 524.0792$

$f_y = 0.15303423$

Expression ((15B.6), TBDY) is modified as  $af = 1 - (\text{Unconfined area})/(\text{total area})$

$af = 0.43111111$

with Unconfined area =  $((b_{\max}-2R)^2 + (h_{\max}-2R)^2)/3 = 0.00$

$b_{\max} = 400.00$

$h_{\max} = 400.00$

From EC8 A.4.4.3(6),  $pf = 2tf/bw = 0.01016$

$bw = 200.00$

effective stress from (A.35),  $ff_e = 524.0792$

$R = 40.00$

Effective FRP thickness,  $tf = NL \cdot t \cdot \cos(b_1) = 1.016$

$f_{u,f} = 1055.00$

$E_f = 64828.00$

$u_f = 0.015$

$ase = \text{Max}(((A_{\text{conf,max}} - A_{\text{noConf}})/A_{\text{conf,max}}) \cdot (A_{\text{conf,min}}/A_{\text{conf,max}}), 0) = 0.00$

The definitions of  $A_{\text{noConf}}$ ,  $A_{\text{conf,min}}$  and  $A_{\text{conf,max}}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{\text{conf,max}} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{\text{conf,min}} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{\text{conf,max}}$  by a length equal to half the clear spacing between hoops.

$A_{\text{noConf}} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$p_{sh,min} = \text{Min}(p_{sh,x}, p_{sh,y}) = 0.00165347$

Expression ((5.4d), TBDY) for  $p_{sh,min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$p_{sh,x} \text{ ((5.4d), TBDY)} = L_{stir} \cdot A_{stir} / (A_{sec} \cdot s) = 0.00165347$

$L_{stir}$  (Length of stirrups along Y) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$p_{sh,y} \text{ ((5.4d), TBDY)} = L_{stir} \cdot A_{stir} / (A_{sec} \cdot s) = 0.00165347$

$L_{stir}$  (Length of stirrups along X) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$s = 380.00$

$f_{ywe} = 555.55$

$f_{ce} = 15.00$

From ((5.A5), TBDY), TBDY:  $cc = 0.00475778$

$c$  = confinement factor = 1.27578

$y_1 = 0.0010562$

$sh_1 = 0.00365026$

$ft_1 = 304.185$

$fy_1 = 253.4875$

$su_1 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor and also multiplied by the shear\_factor according to 15.7.1.4, with

Shear\_factor = 1.00

$lo/lo_{u,min} = lb/ld = 0.22053887$

$su_1 = 0.4 \cdot esu_{1,nominal} \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu_{1,nominal} = 0.08$ ,

For calculation of  $esu_{1,nominal}$  and  $y_1$ ,  $sh_1$ ,  $ft_1$ ,  $fy_1$ , it is considered



characteristic value  $f_{sy1} = f_{s1}/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $f_{s1} = f_s = 253.4875$   
 with  $E_{s1} = E_s = 200000.00$   
 $y2 = 0.0010562$   
 $sh2 = 0.00365026$   
 $ft2 = 304.185$   
 $fy2 = 253.4875$   
 $su2 = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $l_o/l_{ou,min} = l_b/l_{b,min} = 0.22053887$   
 $su2 = 0.4 \cdot esu2_{nominal} ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esu2_{nominal} = 0.08$ ,  
 For calculation of  $esu2_{nominal}$  and  $y2, sh2, ft2, fy2$ , it is considered  
 characteristic value  $f_{sy2} = f_{s2}/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $f_{s2} = f_s = 253.4875$   
 with  $E_{s2} = E_s = 200000.00$   
 $yv = 0.0010562$   
 $shv = 0.00365026$   
 $ftv = 304.185$   
 $fyv = 253.4875$   
 $suv = 0.00365026$   
 using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
 and also multiplied by the shear\_factor according to 15.7.1.4, with  
 Shear\_factor = 1.00  
 $l_o/l_{ou,min} = l_b/l_d = 0.22053887$   
 $suv = 0.4 \cdot esuv_{nominal} ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esuv_{nominal} = 0.08$ ,  
 considering characteristic value  $f_{syv} = f_{sv}/1.2$ , from table 5.1, TBDY  
 For calculation of  $esuv_{nominal}$  and  $yv, shv, ftv, fyv$ , it is considered  
 characteristic value  $f_{syv} = f_{sv}/1.2$ , from table 5.1, TBDY.  
 $y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 \cdot (l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $f_{sv} = f_s = 253.4875$   
 with  $E_{sv} = E_s = 200000.00$   
 $1 = A_{sl,ten}/(b \cdot d) \cdot (f_{s1}/f_c) = 0.29147618$   
 $2 = A_{sl,com}/(b \cdot d) \cdot (f_{s2}/f_c) = 0.29147618$   
 $v = A_{sl,mid}/(b \cdot d) \cdot (f_{sv}/f_c) = 0.6364888$   
 and confined core properties:  
 $b = 140.00$   
 $d = 327.00$   
 $d' = 13.00$   
 $f_{cc} (5A.2, TBDY) = 19.13667$   
 $cc (5A.5, TBDY) = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $1 = A_{sl,ten}/(b \cdot d) \cdot (f_{s1}/f_c) = 0.45459588$   
 $2 = A_{sl,com}/(b \cdot d) \cdot (f_{s2}/f_c) = 0.45459588$   
 $v = A_{sl,mid}/(b \cdot d) \cdot (f_{sv}/f_c) = 0.99268896$   
 Case/Assumption: Unconfined full section - Steel rupture  
 ' satisfies Eq. (4.3)  
 --->  
 $v < v_{s,y2}$  - LHS eq.(4.5) is not satisfied  
 --->  
 $v < v_{s,c}$  - RHS eq.(4.5) is satisfied  
 --->  
 $su (4.8) = 0.40159417$   
 $Mu = MRc (4.15) = 1.9001E+008$   
 $u = su (4.1) = 1.7086748E-005$

Calculation of ratio  $l_b/l_d$

Lap Length:  $l_b/l_d = 0.22053887$   
 $l_b = 300.00$   
 $l_d = 1360.304$

Calculation of  $l_{b,min}$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.

$$= 1$$

$$d_b = 18.00$$

Mean strength value of all re-bars:  $f_y = 555.55$

$$f'_c = 15.00, \text{ but } f_c^{0.5} \leq 8.3 \text{ MPa (22.5.3.1, ACI 318-14)}$$

$$t = 1.00$$

$$s = 0.80$$

$$e = 1.00$$

$$c_b = 24.02082$$

$$K_{tr} = 0.82673491$$

$$A_{tr} = \text{Min}(A_{tr_x}, A_{tr_y}) = 157.0796$$

where  $A_{tr_x}$ ,  $A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis

$$s = 380.00$$

$$n = 20.00$$

Calculation of  $\mu_{2+}$

Calculation of ultimate curvature  $\mu$  according to 4.1, Biskinis/Fardis 2013:

$$\mu = 1.7086748E-005$$

$$\mu_u = 1.9001E+008$$

with full section properties:

$$b = 200.00$$

$$d = 357.00$$

$$d' = 43.00$$

$$v = 0.00442328$$

$$N = 4737.328$$

$$f'_c = 15.00$$

$$\alpha (5A.5, \text{ TBDY}) = 0.002$$

$$\text{Final value of } \mu_u: \mu_u^* = \text{shear\_factor} * \text{Max}(\mu_u, \mu_c) = 0.018$$

The Shear\_factor is considered equal to 1 (pure moment strength)

$$\text{From (5.4b), TBDY: } \mu_u = 0.018$$

$$\mu_{ue} ((5.4c), \text{ TBDY}) = a_{se} * \mu_{u,min} * f_{y,ue} / f_{c,e} + \text{Min}(\mu_{fx}, \mu_{fy}) = 0.15303423$$

where  $\mu_{fx} = a_{sf} * \mu_{pf} * f_{fe} / f_{c,e}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$$\mu_{fx} = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_{sf} = 1 - (\text{Unconfined area}) / (\text{total area})$

$$a_{sf} = 0.43111111$$

$$\text{with Unconfined area} = ((b_{max} - 2R)^2 + (h_{max} - 2R)^2) / 3 = 51733.333$$

$$b_{max} = 400.00$$

$$h_{max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } \mu_{pf} = 2t_f / b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$f_y = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_{sf} = 1 - (\text{Unconfined area}) / (\text{total area})$

$$a_{sf} = 0.43111111$$

$$\text{with Unconfined area} = ((b_{max} - 2R)^2 + (h_{max} - 2R)^2) / 3 = 0.00$$

$$b_{max} = 400.00$$

$$h_{max} = 400.00$$

$$\text{From EC8 A.4.4.3(6), } \mu_{pf} = 2t_f / b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$R = 40.00$$

$$\text{Effective FRP thickness, } t_f = N L * t * \cos(b_1) = 1.016$$

$$f_{u,f} = 1055.00$$

$$E_f = 64828.00$$

$$\mu_{u,f} = 0.015$$

$$a_{se} = \text{Max}(((A_{conf,max} - A_{noConf}) / A_{conf,max}) * (A_{conf,min} / A_{conf,max}), 0) = 0.00$$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)  
"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and  
is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and  
is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length  
equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$psh,min = \text{Min}(psh,x, psh,y) = 0.00165347$

Expression ((5.4d), TBDY) for  $psh,min$  has been multiplied by 0.3 according to 15.7.1.3 for members without  
earthquake detailing (90° closed stirrups)

$psh,x \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$

$L_{stir}$  (Length of stirrups along Y) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$psh,y \text{ ((5.4d), TBDY)} = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$

$L_{stir}$  (Length of stirrups along X) = 960.00

$A_{stir}$  (stirrups area) = 78.53982

$A_{sec}$  (section area) = 120000.00

$s = 380.00$

$f_{ywe} = 555.55$

$f_{ce} = 15.00$

From ((5.A5), TBDY), TBDY:  $cc = 0.00475778$

$c = \text{confinement factor} = 1.27578$

$y1 = 0.0010562$

$sh1 = 0.00365026$

$ft1 = 304.185$

$fy1 = 253.4875$

$su1 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
 $\text{Shear\_factor} = 1.00$

$lo/lou,min = lb/ld = 0.22053887$

$su1 = 0.4 * esu1\_nominal \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu1\_nominal = 0.08$ ,

For calculation of  $esu1\_nominal$  and  $y1, sh1, ft1, fy1$ , it is considered  
characteristic value  $fsy1 = fs1/1.2$ , from table 5.1, TBDY.

$y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 * (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.

with  $fs1 = fs = 253.4875$

with  $Es1 = Es = 200000.00$

$y2 = 0.0010562$

$sh2 = 0.00365026$

$ft2 = 304.185$

$fy2 = 253.4875$

$su2 = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with  
 $\text{Shear\_factor} = 1.00$

$lo/lou,min = lb/lb,min = 0.22053887$

$su2 = 0.4 * esu2\_nominal \text{ ((5.5), TBDY)} = 0.032$

From table 5A.1, TBDY:  $esu2\_nominal = 0.08$ ,

For calculation of  $esu2\_nominal$  and  $y2, sh2, ft2, fy2$ , it is considered  
characteristic value  $fsy2 = fs2/1.2$ , from table 5.1, TBDY.

$y1, sh1, ft1, fy1$ , are also multiplied by  $\text{Min}(1, 1.25 * (lb/ld)^{2/3})$ , from 10.3.5, ASCE 41-17.

with  $fs2 = fs = 253.4875$

with  $Es2 = Es = 200000.00$

$yv = 0.0010562$

$shv = 0.00365026$

$ftv = 304.185$

$fyv = 253.4875$

$suv = 0.00365026$

using (30) in Biskinis/Fardis (2013) multiplied with shear\_factor  
and also multiplied by the shear\_factor according to 15.7.1.4, with

Shear\_factor = 1.00  
 $l_o/l_{ou,min} = l_b/l_d = 0.22053887$   
 $suv = 0.4 * esuv_{nominal} ((5.5), TBDY) = 0.032$   
 From table 5A.1, TBDY:  $esuv_{nominal} = 0.08$ ,  
 considering characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY  
 For calculation of  $esuv_{nominal}$  and  $yv$ ,  $shv,ftv,fyv$ , it is considered  
 characteristic value  $fsyv = fsv/1.2$ , from table 5.1, TBDY.  
 $y1, sh1,ft1,fy1$ , are also multiplied by  $Min(1,1.25*(l_b/l_d)^{2/3})$ , from 10.3.5, ASCE 41-17.  
 with  $fsv = fs = 253.4875$   
 with  $Esv = Es = 200000.00$   
 $1 = Asl_{ten}/(b*d)*(fs1/fc) = 0.29147618$   
 $2 = Asl_{com}/(b*d)*(fs2/fc) = 0.29147618$   
 $v = Asl_{mid}/(b*d)*(fsv/fc) = 0.6364888$

and confined core properties:

$b = 140.00$   
 $d = 327.00$   
 $d' = 13.00$   
 $f_{cc} (5A.2, TBDY) = 19.13667$   
 $cc (5A.5, TBDY) = 0.00475778$   
 $c = \text{confinement factor} = 1.27578$   
 $1 = Asl_{ten}/(b*d)*(fs1/fc) = 0.45459588$   
 $2 = Asl_{com}/(b*d)*(fs2/fc) = 0.45459588$   
 $v = Asl_{mid}/(b*d)*(fsv/fc) = 0.99268896$

Case/Assumption: Unconfined full section - Steel rupture  
 ' satisfies Eq. (4.3)

---->  
 $v < v_{s,y2}$  - LHS eq.(4.5) is not satisfied  
 ---->  
 $v < v_{s,c}$  - RHS eq.(4.5) is satisfied  
 ---->  
 $su (4.8) = 0.40159417$   
 $Mu = MRc (4.15) = 1.9001E+008$   
 $u = su (4.1) = 1.7086748E-005$

Calculation of ratio  $l_b/l_d$

Lap Length:  $l_b/l_d = 0.22053887$   
 $l_b = 300.00$   
 $l_d = 1360.304$   
 Calculation of  $l_b,min$  according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.  
 $= 1$   
 $db = 18.00$   
 Mean strength value of all re-bars:  $f_y = 555.55$   
 $fc' = 15.00$ , but  $fc'^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)  
 $t = 1.00$   
 $s = 0.80$   
 $e = 1.00$   
 $cb = 24.02082$   
 $K_{tr} = 0.82673491$   
 $A_{tr} = Min(A_{tr_x}, A_{tr_y}) = 157.0796$   
 where  $A_{tr_x}, A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y loxal axis  
 $s = 380.00$   
 $n = 20.00$

Calculation of  $Mu2$ -

Calculation of ultimate curvature  $u$  according to 4.1, Biskinis/Fardis 2013:  
 $u = 1.7086748E-005$   
 $Mu = 1.9001E+008$

with full section properties:  
 $b = 200.00$

$$d = 357.00$$

$$d' = 43.00$$

$$v = 0.00442328$$

$$N = 4737.328$$

$$f_c = 15.00$$

$$c_o(5A.5, TBDY) = 0.002$$

$$\text{Final value of } c_u: c_u^* = \text{shear\_factor} * \text{Max}(c_u, c_c) = 0.018$$

The Shear\_factor is considered equal to 1 (pure moment strength)

$$\text{From (5.4b), TBDY: } c_u = 0.018$$

$$w_e(5.4c, TBDY) = a_s e^* s_{h,min} * f_{ywe}/f_{ce} + \text{Min}(f_x, f_y) = 0.15303423$$

where  $f = a_f * p_f * f_{fe}/f_{ce}$  is accounting for FRP contribution like EC8-part3 A.4.4.3(6)

$$f_x = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area})/(\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{max} - 2R)^2 + (h_{max} - 2R)^2)/3 = 51733.333$$

$$b_{max} = 400.00$$

$$h_{max} = 400.00$$

$$\text{From EC8 A4.4.3(6), } p_f = 2t_f/b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$f_y = 0.15303423$$

Expression ((15B.6), TBDY) is modified as  $a_f = 1 - (\text{Unconfined area})/(\text{total area})$

$$a_f = 0.43111111$$

$$\text{with Unconfined area} = ((b_{max} - 2R)^2 + (h_{max} - 2R)^2)/3 = 0.00$$

$$b_{max} = 400.00$$

$$h_{max} = 400.00$$

$$\text{From EC8 A4.4.3(6), } p_f = 2t_f/b_w = 0.01016$$

$$b_w = 200.00$$

$$\text{effective stress from (A.35), } f_{fe} = 524.0792$$

$$R = 40.00$$

$$\text{Effective FRP thickness, } t_f = N L^* t \cos(b_1) = 1.016$$

$$f_{u,f} = 1055.00$$

$$E_f = 64828.00$$

$$u_{f,f} = 0.015$$

$$a_s e = \text{Max}(((A_{conf,max} - A_{noConf})/A_{conf,max}) * (A_{conf,min}/A_{conf,max}), 0) = 0.00$$

The definitions of  $A_{noConf}$ ,  $A_{conf,min}$  and  $A_{conf,max}$  are derived from generalization of the rectangular sections confinement, which is expressed by (5.4d).

The generalization is done according to Mander, J., Priestley, M., and Park, R. (1988)

"Theoretical Stress-Strain Model for Confined Concrete."

J. Struct. Eng., 10.1061/(ASCE)0733-9445(1988)114:8(1804), 1804-1826.

$A_{conf,max} = 75600.00$  is the confined core area at levels of member with hoops and is calculated as the area of core enclosed by the center lines of the perimeter hoops.

$A_{conf,min} = 0.00$  is the confined core area at midway between the levels of hoops and is calculated by reducing all the dimensions of the area  $A_{conf,max}$  by a length equal to half the clear spacing between hoops.

$A_{noConf} = 33066.667$  is the unconfined core area which is equal to  $b_i^2/6$  as defined at (A.2).

$$p_{sh,min} = \text{Min}(p_{sh,x}, p_{sh,y}) = 0.00165347$$

Expression ((5.4d), TBDY) for  $p_{sh,min}$  has been multiplied by 0.3 according to 15.7.1.3 for members without earthquake detailing (90° closed stirrups)

$$p_{sh,x}((5.4d), TBDY) = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$$

$$L_{stir} (\text{Length of stirrups along Y}) = 960.00$$

$$A_{stir} (\text{stirrups area}) = 78.53982$$

$$A_{sec} (\text{section area}) = 120000.00$$

$$p_{sh,y}((5.4d), TBDY) = L_{stir} * A_{stir} / (A_{sec} * s) = 0.00165347$$

$$L_{stir} (\text{Length of stirrups along X}) = 960.00$$

$$A_{stir} (\text{stirrups area}) = 78.53982$$

$$A_{sec} (\text{section area}) = 120000.00$$

$$s = 380.00$$

$$f_{ywe} = 555.55$$

$$f_{ce} = 15.00$$

$$\text{From ((5A5), TBDY), TBDY: } c_c = 0.00475778$$

```

c = confinement factor = 1.27578
y1 = 0.0010562
sh1 = 0.00365026
ft1 = 304.185
fy1 = 253.4875
su1 = 0.00365026
using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
and also multiplied by the shear_factor according to 15.7.1.4, with
Shear_factor = 1.00
lo/lou,min = lb/ld = 0.22053887
su1 = 0.4*esu1_nominal ((5.5), TBDY) = 0.032
From table 5A.1, TBDY: esu1_nominal = 0.08,
For calculation of esu1_nominal and y1, sh1,ft1,fy1, it is considered
characteristic value fsy1 = fs1/1.2, from table 5.1, TBDY.
y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/ld)^ 2/3), from 10.3.5, ASCE 41-17.
with fs1 = fs = 253.4875
with Es1 = Es = 200000.00
y2 = 0.0010562
sh2 = 0.00365026
ft2 = 304.185
fy2 = 253.4875
su2 = 0.00365026
using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
and also multiplied by the shear_factor according to 15.7.1.4, with
Shear_factor = 1.00
lo/lou,min = lb/lb,min = 0.22053887
su2 = 0.4*esu2_nominal ((5.5), TBDY) = 0.032
From table 5A.1, TBDY: esu2_nominal = 0.08,
For calculation of esu2_nominal and y2, sh2,ft2,fy2, it is considered
characteristic value fsy2 = fs2/1.2, from table 5.1, TBDY.
y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/ld)^ 2/3), from 10.3.5, ASCE 41-17.
with fs2 = fs = 253.4875
with Es2 = Es = 200000.00
yv = 0.0010562
shv = 0.00365026
ftv = 304.185
fyv = 253.4875
suv = 0.00365026
using (30) in Biskinis/Fardis (2013) multiplied with shear_factor
and also multiplied by the shear_factor according to 15.7.1.4, with
Shear_factor = 1.00
lo/lou,min = lb/ld = 0.22053887
suv = 0.4*esuv_nominal ((5.5), TBDY) = 0.032
From table 5A.1, TBDY: esuv_nominal = 0.08,
considering characteristic value fsyv = fsv/1.2, from table 5.1, TBDY
For calculation of esuv_nominal and yv, shv,ftv,fyv, it is considered
characteristic value fsyv = fsv/1.2, from table 5.1, TBDY.
y1, sh1,ft1,fy1, are also multiplied by Min(1,1.25*(lb/ld)^ 2/3), from 10.3.5, ASCE 41-17.
with fsv = fs = 253.4875
with Esv = Es = 200000.00
1 = Asl,ten/(b*d)*(fs1/fc) = 0.29147618
2 = Asl,com/(b*d)*(fs2/fc) = 0.29147618
v = Asl,mid/(b*d)*(fsv/fc) = 0.6364888
and confined core properties:
b = 140.00
d = 327.00
d' = 13.00
fcc (5A.2, TBDY) = 19.13667
cc (5A.5, TBDY) = 0.00475778
c = confinement factor = 1.27578
1 = Asl,ten/(b*d)*(fs1/fc) = 0.45459588
2 = Asl,com/(b*d)*(fs2/fc) = 0.45459588
v = Asl,mid/(b*d)*(fsv/fc) = 0.99268896
Case/Assumption: Unconfined full section - Steel rupture
'satisfies Eq. (4.3)
--->
v < vs,y2 - LHS eq.(4.5) is not satisfied

```

```

--->
v < vs,c - RHS eq.(4.5) is satisfied
--->
su (4.8) = 0.40159417
Mu = MRc (4.15) = 1.9001E+008
u = su (4.1) = 1.7086748E-005
-----

Calculation of ratio lb/ld
-----

Lap Length: lb/ld = 0.22053887
lb = 300.00
ld = 1360.304
Calculation of lb,min according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.
= 1
db = 18.00
Mean strength value of all re-bars: fy = 555.55
fc' = 15.00, but fc'^0.5 <= 8.3 MPa (22.5.3.1, ACI 318-14)
t = 1.00
s = 0.80
e = 1.00
cb = 24.02082
Ktr = 0.82673491
Atr = Min(Atrx,Atry) = 157.0796
where Atrx, Atry are the sum of the area of all stirrup legs along X and Y loxal axis
s = 380.00
n = 20.00
-----
-----
-----

Calculation of Shear Strength Vr = Min(Vr1,Vr2) = 227350.021
-----

Calculation of Shear Strength at edge 1, Vr1 = 227350.021
Vr1 = VCol ((10.3), ASCE 41-17) = knl*VCol0
VCol0 = 227350.021
knl = 1 (zero step-static loading)
-----

NOTE: In expression (10-3) 'Vs' is replaced by 'Vs+ f*Vf'
where Vf is the contribution of FRPs (11.3), ACI 440).
-----

= 1 (normal-weight concrete)
fc' = 15.00, but fc'^0.5 <= 8.3 MPa (22.5.3.1, ACI 318-14)
M/Vd = 2.00
Mu = 0.00988804
Vu = 1.5456333E-009
d = 0.8*h = 320.00
Nu = 4737.328
Ag = 80000.00
From (11.5.4.8), ACI 318-14: Vs = Vs1 + Vs2 = 0.00
where:
Vs1 = 0.00 is calculated for section web, with:
d = 160.00
Av = 157079.633
fy = 444.44
s = 380.00
Vs1 is multiplied by Col1 = 0.00
s/d = 2.375
Vs2 = 0.00 is calculated for section flange, with:
d = 320.00
Av = 157079.633
fy = 444.44
s = 380.00
Vs2 is multiplied by Col2 = 0.00
s/d = 1.1875
Vf ((11-3)-(11.4), ACI 440) = 188111.148
f = 0.95, for fully-wrapped sections

```

$wf/sf = 1$  (FRP strips adjacent to one another).

In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot a)\sin a$  which is more a generalised expression, where  $a$  is the angle of the crack direction (see KANEPE).

This later relation, considered as a function  $Vf(\theta, a)$ , is implemented for every different fiber orientation  $a_i$ , as well as for 2 crack directions,  $\theta = 45^\circ$  and  $\theta = -45^\circ$  to take into consideration the cyclic seismic loading.

orientation 1:  $\theta = b1 + 90^\circ = 90.00$

$Vf = \text{Min}(|Vf(45, \theta)|, |Vf(-45, a1)|)$ , with:

total thickness per orientation,  $tf1 = NL \cdot t / \text{NoDir} = 1.016$

$dfv = d$  (figure 11.2, ACI 440) = 357.00

$ffe$  ((11-5), ACI 440) = 259.312

$Ef = 64828.00$

$fe = 0.004$ , from (11.6a), ACI 440

with  $fu = 0.01$

From (11-11), ACI 440:  $Vs + Vf \leq 164661.611$

$bw = 200.00$

Calculation of Shear Strength at edge 2,  $Vr2 = 227350.021$

$Vr2 = VCol$  ((10.3), ASCE 41-17) =  $knl \cdot VCol0$

$VCol0 = 227350.021$

$knl = 1$  (zero step-static loading)

NOTE: In expression (10-3) ' $Vs$ ' is replaced by ' $Vs + f \cdot Vf$ ' where  $Vf$  is the contribution of FRPs (11.3), ACI 440).

$= 1$  (normal-weight concrete)

$fc' = 15.00$ , but  $fc'^{0.5} \leq 8.3$  MPa (22.5.3.1, ACI 318-14)

$M/Vd = 2.00$

$Mu = 0.00525978$

$Vu = 1.5456333E-009$

$d = 0.8 \cdot h = 320.00$

$Nu = 4737.328$

$Ag = 80000.00$

From (11.5.4.8), ACI 318-14:  $Vs = Vs1 + Vs2 = 0.00$

where:

$Vs1 = 0.00$  is calculated for section web, with:

$d = 160.00$

$Av = 157079.633$

$fy = 444.44$

$s = 380.00$

$Vs1$  is multiplied by  $Col1 = 0.00$

$s/d = 2.375$

$Vs2 = 0.00$  is calculated for section flange, with:

$d = 320.00$

$Av = 157079.633$

$fy = 444.44$

$s = 380.00$

$Vs2$  is multiplied by  $Col2 = 0.00$

$s/d = 1.1875$

$Vf$  ((11-3)-(11.4), ACI 440) = 188111.148

$f = 0.95$ , for fully-wrapped sections

$wf/sf = 1$  (FRP strips adjacent to one another).

In (11.3)  $\sin + \cos$  is replaced with  $(\cot + \cot a)\sin a$  which is more a generalised expression, where  $a$  is the angle of the crack direction (see KANEPE).

This later relation, considered as a function  $Vf(\theta, a)$ , is implemented for every different fiber orientation  $a_i$ , as well as for 2 crack directions,  $\theta = 45^\circ$  and  $\theta = -45^\circ$  to take into consideration the cyclic seismic loading.

orientation 1:  $\theta = b1 + 90^\circ = 90.00$

$Vf = \text{Min}(|Vf(45, \theta)|, |Vf(-45, a1)|)$ , with:

total thickness per orientation,  $tf1 = NL \cdot t / \text{NoDir} = 1.016$

$dfv = d$  (figure 11.2, ACI 440) = 357.00

$ffe$  ((11-5), ACI 440) = 259.312

$Ef = 64828.00$

$fe = 0.004$ , from (11.6a), ACI 440

with  $fu = 0.01$

From (11-11), ACI 440:  $Vs + Vf \leq 164661.611$

$bw = 200.00$



End Of Calculation of Shear Capacity ratio for element: column TC1 of floor 1  
At local axis: 2

Start Of Calculation of Chord Rotation Capacity for element: column TC1 of floor 1  
At local axis: 3  
Integration Section: (b)  
Section Type: rctcs

#### Constant Properties

Knowledge Factor,  $\gamma = 0.90$   
Chord Rotation is generally considered as Deformation-Controlled Action according to Table C7-1, ASCE 41-17.  
Mean strengths are used for Deformation-Controlled Actions according to 7.5.1.3, ASCE 41-17  
Consequently:  
Existing material of Primary Member: Concrete Strength,  $f_c = f_{cm} = 15.00$   
Existing material of Primary Member: Steel Strength,  $f_s = f_{sm} = 444.44$   
Concrete Elasticity,  $E_c = 18203.022$   
Steel Elasticity,  $E_s = 200000.00$   
Max Height,  $H_{max} = 400.00$   
Min Height,  $H_{min} = 200.00$   
Max Width,  $W_{max} = 400.00$   
Min Width,  $W_{min} = 200.00$   
Eccentricity,  $Ecc = 100.00$   
Cover Thickness,  $c = 25.00$   
Element Length,  $L = 3000.00$   
Primary Member  
Ribbed Bars  
Ductile Steel  
Without Detailing for Earthquake Resistance (including stirrups not closed at 135°)  
Longitudinal Bars With Ends Lapped Starting at the End Sections  
Lap Length  $l_b = 300.00$   
FRP Wrapping Data  
Type: Carbon  
Cured laminate properties (design values)  
Thickness,  $t = 1.016$   
Tensile Strength,  $f_{fu} = 1055.00$   
Tensile Modulus,  $E_f = 64828.00$   
Elongation,  $ef_u = 0.01$   
Number of directions,  $NoDir = 1$   
Fiber orientations,  $bi: 0.00^\circ$   
Number of layers,  $NL = 1$   
Radius of rounding corners,  $R = 40.00$

#### Stepwise Properties

Bending Moment,  $M = 1473.353$   
Shear Force,  $V_2 = 3961.043$   
Shear Force,  $V_3 = -0.77690092$   
Axial Force,  $F = -4742.638$   
Longitudinal Reinforcement Area Distribution (in 2 divisions)  
-Tension:  $As_t = 0.00$   
-Compression:  $As_c = 5152.212$   
Longitudinal Reinforcement Area Distribution (in 3 divisions)  
-Tension:  $As_{t,ten} = 1231.504$   
-Compression:  $As_{c,com} = 1231.504$   
-Middle:  $As_{mid} = 2689.203$   
Mean Diameter of Tension Reinforcement,  $Db_L = 17.60$

Existing component: From table 7-7, ASCE 41\_17: Final chord rotation Capacity  $\phi_{u,R} = \phi_u = 0.0396757$

$$u = y + p = 0.04408411$$

- Calculation of  $y$  -

$$y = (M_y * L_s / 3) / E_{eff} = 0.00208411 \text{ ((4.29), Biskinis Phd)}$$

$$M_y = 1.3657E+008$$

$$L_s = M/V \text{ (with } L_s > 0.1 * L \text{ and } L_s < 2 * L) = 300.00$$

$$\text{From table 10.5, ASCE 41\_17: } E_{eff} = \text{factor} * E_c * I_g = 6.5531E+012$$

$$\text{factor} = 0.30$$

$$A_g = 120000.00$$

$$f_c' = 15.00$$

$$N = 4742.638$$

$$E_c * I_g = 2.1844E+013$$

Calculation of Yielding Moment  $M_y$

Calculation of  $y$  and  $M_y$  according to Annex 7 -

$$y = \text{Min}(y_{ten}, y_{com})$$

$$y_{ten} = 5.8874430E-006$$

$$\text{with ((10.1), ASCE 41-17) } f_y = \text{Min}(f_y, 1.25 * f_y * (I_b / I_d)^{2/3}) = 235.317$$

$$d = 357.00$$

$$y = 0.44020587$$

$$A = 0.0724421$$

$$B = 0.04070795$$

$$\text{with } p_t = 0.0075814$$

$$p_c = 0.01724796$$

$$p_v = 0.03766391$$

$$N = 4742.638$$

$$b = 200.00$$

$$" = 0.12044818$$

$$y_{comp} = 1.0162879E-005$$

$$\text{with } f_c' (12.3, (ACI 440)) = 16.12972$$

$$f_c = 15.00$$

$$f_l = 0.93147527$$

$$b = b_{max} = 400.00$$

$$h = h_{max} = 400.00$$

$$A_g = 120000.00$$

$$g = p_t + p_c + p_v = 0.07215983$$

$$r_c = 40.00$$

$$A_e / A_c = 0.38686758$$

$$\text{Effective FRP thickness, } t_f = N L * t * \text{Cos}(b_1) = 1.016$$

$$\text{effective strain from (12.5) and (12.12), } \epsilon_{fe} = 0.004$$

$$f_u = 0.01$$

$$E_f = 64828.00$$

$$E_c = 18203.022$$

$$y = 0.43961339$$

$$A = 0.0719516$$

$$B = 0.04042568$$

$$\text{with } E_s = 200000.00$$

Calculation of ratio  $I_b / I_d$

$$\text{Lap Length: } I_d / I_{d,min} = 0.27567359$$

$$I_b = 300.00$$

$$I_d = 1088.244$$

$$\text{Calculation of } I \text{ according to (25.4.3.2), ACI 318-14, using mean values for all the section re-bars.}$$

$$= 1$$

$$d_b = 18.00$$

$$\text{Mean strength value of all re-bars: } f_y = 444.44$$

$$f_c' = 15.00, \text{ but } f_c'^{0.5} \leq 8.3 \text{ MPa (22.5.3.1, ACI 318-14)}$$

$$t = 1.00$$

$s = 0.80$   
 $e = 1.00$   
 $cb = 24.02082$   
 $K_{tr} = 0.82673491$   
 $A_{tr} = \min(A_{tr_x}, A_{tr_y}) = 157.0796$   
 where  $A_{tr_x}$ ,  $A_{tr_y}$  are the sum of the area of all stirrup legs along X and Y local axis  
 $s = 380.00$   
 $n = 20.00$

- Calculation of  $p$  -

From table 10-8:  $p = 0.042$

with:

- Columns controlled by inadequate development or splicing along the clear height because  $l_b/l_d < 1$

shear control ratio  $V_{yE}/V_{ColOE} = 0.55718248$

$d = 357.00$

$s = 0.00$

$t = A_v/(b_w*s) + 2*t_f/b_w*(f_{fe}/f_s) = A_v*L_{stir}/(A_g*s) + 2*t_f/b_w*(f_{fe}/f_s) = 0.0075814$

$A_v = 78.53982$ , is the area of every stirrup

$L_{stir} = 960.00$ , is the total Length of all stirrups parallel to loading (shear) direction

The term  $2*t_f/b_w*(f_{fe}/f_s)$  is implemented to account for FRP contribution

where  $f = 2*t_f/b_w$  is FRP ratio (EC8 - 3, A.4.4.3(6)) and  $f_{fe}/f_s$  normalises  $f$  to steel strength

All these variables have already been given in Shear control ratio calculation.

$NUD = 4742.638$

$A_g = 120000.00$

$f_{cE} = 15.00$

$f_{ytE} = f_{ylE} = 444.44$

$p_l = \text{Area\_Tot\_Long\_Rein}/(b*d) = 0.07215983$

$b = 200.00$

$d = 357.00$

$f_{cE} = 15.00$

End Of Calculation of Chord Rotation Capacity for element: column TC1 of floor 1

At local axis: 3

Integration Section: (b)