بنام خدا

سیستم های نوین کنترل لرزه ای در ساختمان

ارائه دهنده:

غلامرضا قدرتی امیری

عضو کمیته تخصصی مبحث ششم مقررات ملی ساختمان

استاد دانشکده مهندسی عمران دانشگاه علم و صنعت ایران

زمستان ۱۳۹۳

اهمیت موضوع

۱) مهترین مبحث مقررات ملی - مبحث بارگذاری
۲) مهمترین بار وارد بر ساختمان "زلزله"
۳) بهینه سازی در طراحی
۴) اهمیت حفظ منابع و محیط زیست
۵)توجه به مفاهیم جدید در مهندسی زلزله (حوزه نزدیک)
۶) تسهیل ورود مفاهیم جدید طراحی (احتمالات)
۷) توجه نسبی به کاربرد تکنولوژی جدید به موازات به روز شدن آیین نامه ها
۸) توجه بیشتر به خسارات اجزاء غیرسازه ای و تاسیسات
۹) توجه کمی بیشتر به موارد تجویزی آیین نامه زلزله

فهرست مطالب:

فلسفه استفاده از سیستم های

کنترل لرزه ای

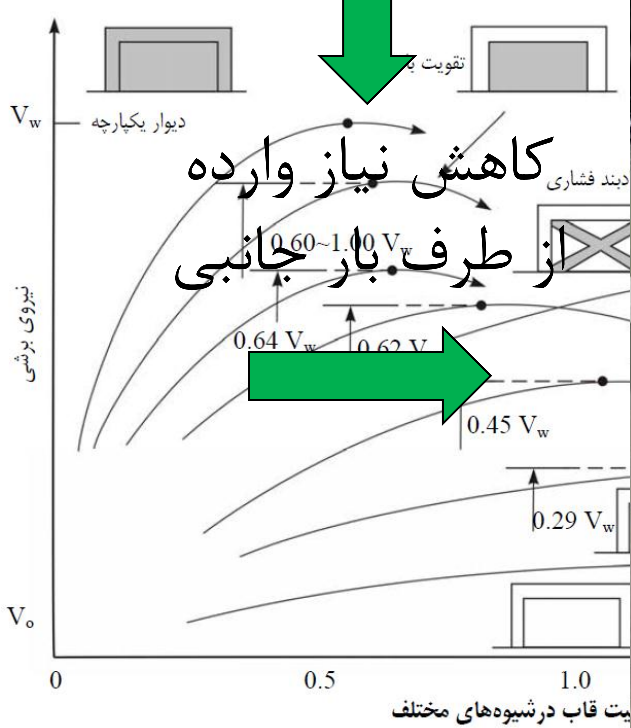
چرا سیستم های نوین؟

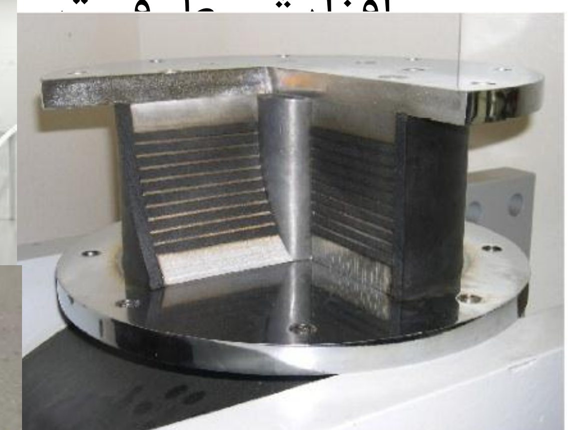
هدف اصلی در مهندسی عمران:

ظرفیت سازه < **نیاز وارده**

افزایش ظرفیت

کاهش نیاز وارده
از طرف بار جانبی





انواع سیستم های کنترل لرزه ای

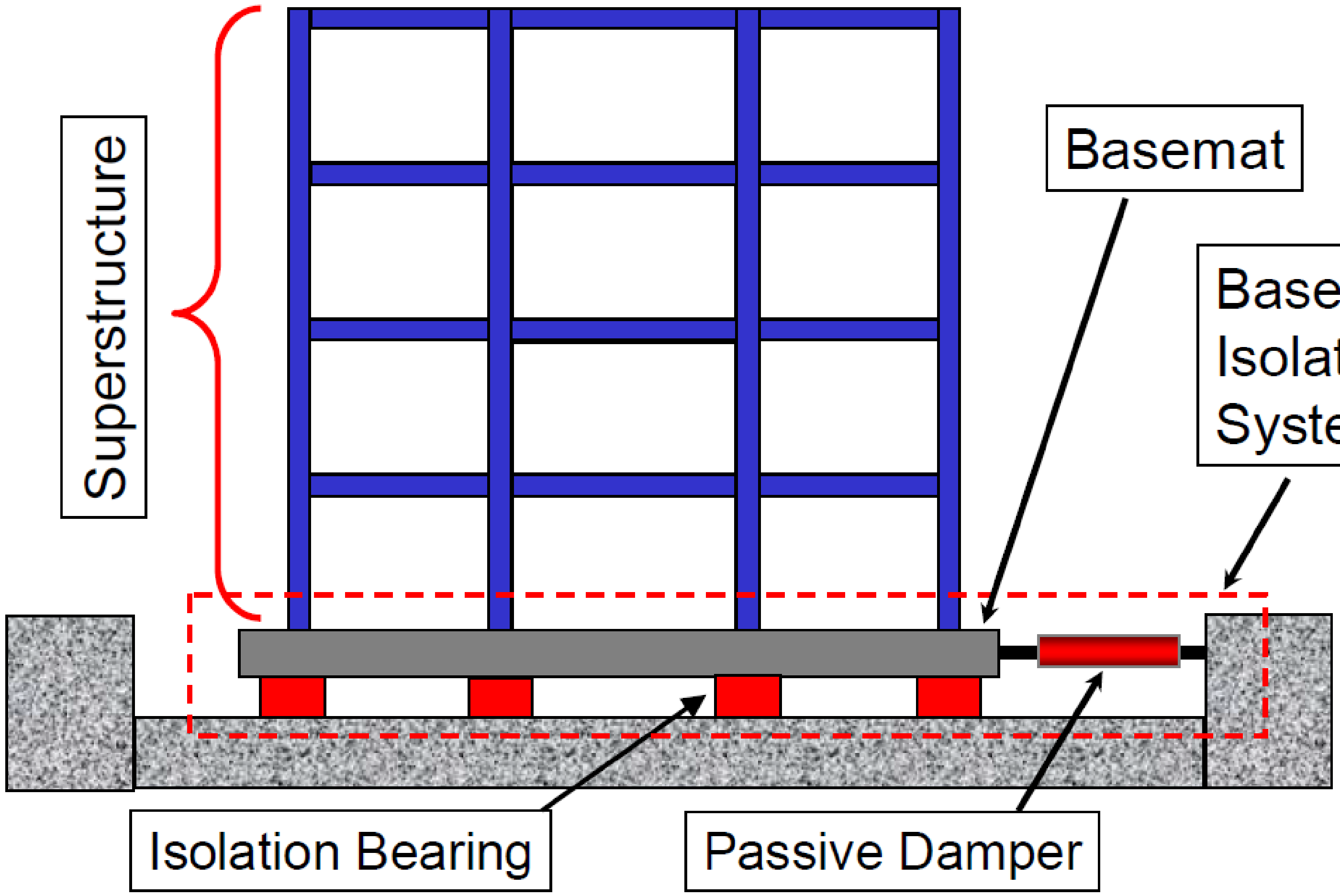
- **سیستم های غیر فعال** ← **سختی و میرایی ثابت**
- **سیستم نیمه فعال** ← ترکیب سیستم های فعال و غیرفعال
- **سیستم های فعال** ← **سختی و میرایی متغیر**

انواع سیستم های غیر فعال کنترل لرزه ای

- **سیستم های غیر فعال متداول در ساختمان:**
  - **جداسازی لرزه ای:** جدا کردن ساختمان از خسارات وارده از طرف زلزله
  - **میراگرها:** جذب و اتلاف انرژی وارده بر سازه

فلسفه استفاده از سیستم های کنترل لرزه ای

Configuration of Building Structure with Base Isolation System



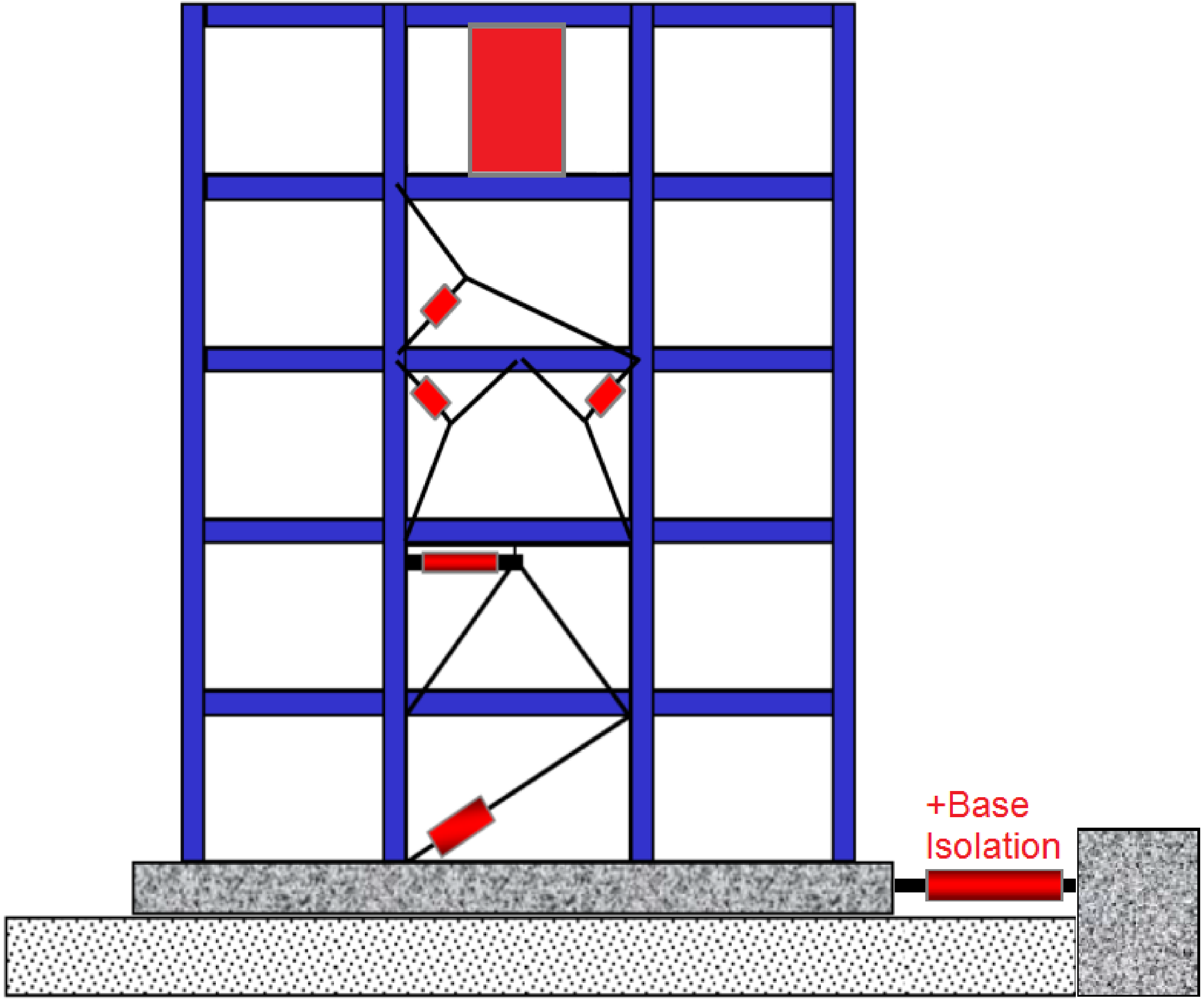
Early Seismic Protective System

Persia, Pasargadae, 530BC
Tomb of King Cyrus the Great

Stone blocks above foundation built without mortar allowing for sliding in earthquakes.

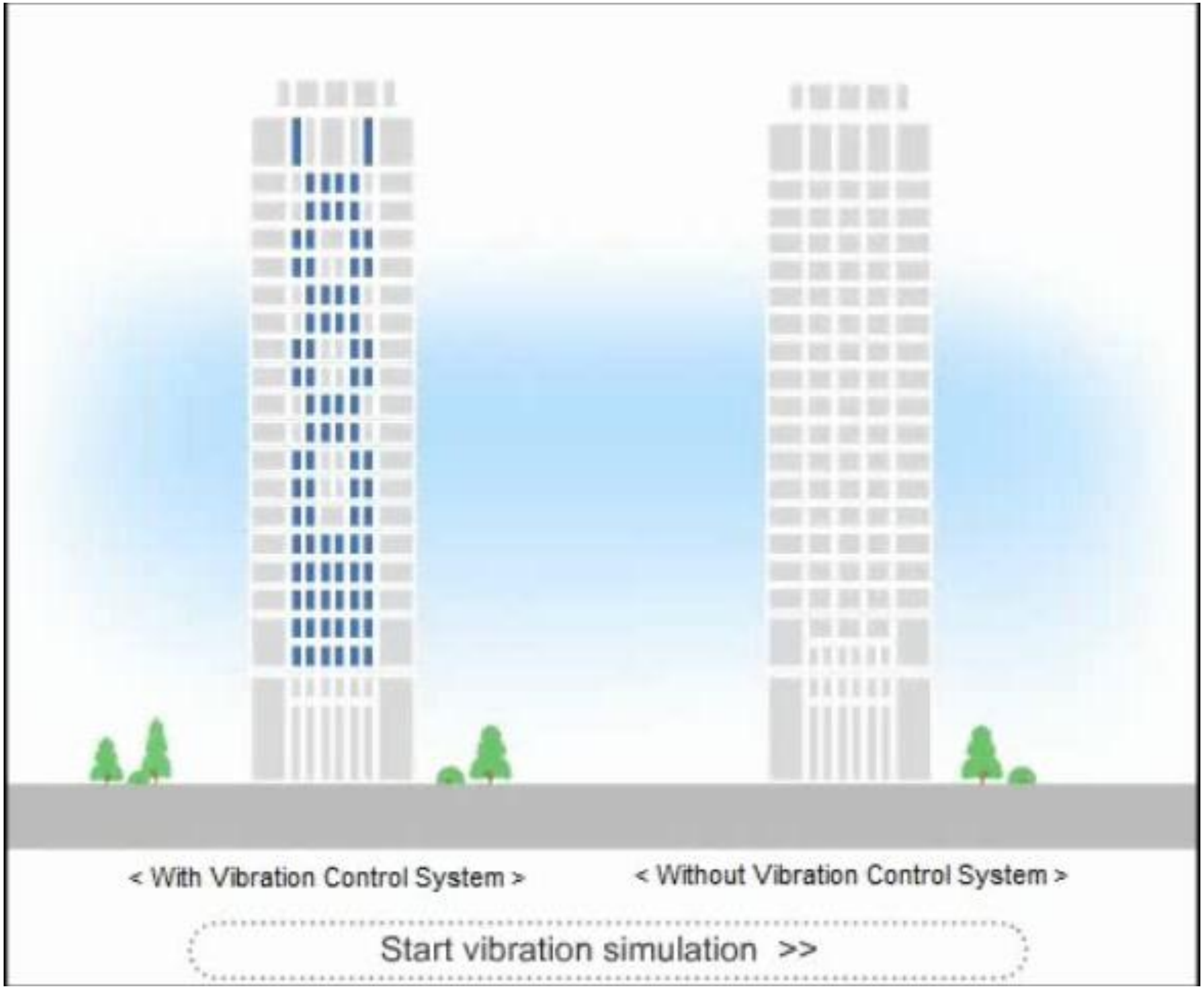
Behavior of Building Structure with Base Isolation System

Possible Damper Placement within Structure



نمونه هایی از کاربرد سیستم های کنترل لرزه ای در جهان

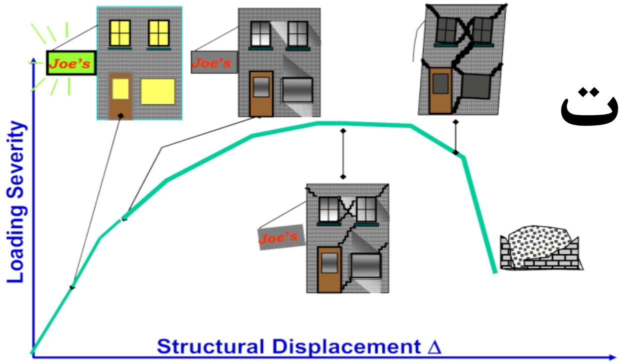
Behavior of Building Structure with Damper



هدف اصلی از به کارگیری سیستم های کنترل لرزه ای

- **علاوه بر حفظ ایمنی سازه، محدود کردن خسارات اعضاء سازه ای و اجزاء غیرسازه ای با افزایش سطح عملکرد بر اساس:**

  - کاهش نیروی جانبی وارد بر طبقات
  - کاهش شتاب وارد بر طبقات
  - کاهش جابجایی نسبی بین طبقات



Fundamental Concepts

- **Basic performance objective of "conventional" seismic design: Life Safety**
- **Life safety performance objective not sufficient for Important structures**
- **To increase seismic performance level at reasonable cost: Seismic Isolation & Supplemental Damping**

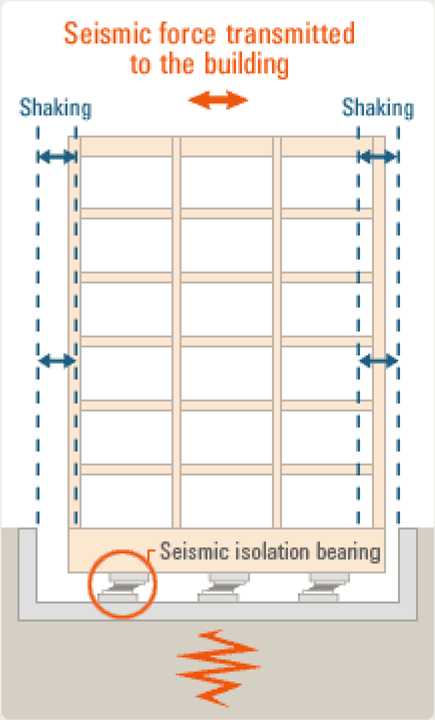
فلسفه طراحی عملکردی ساختمانها در برابر زلزله در ویرایش چهارم استاندارد ۲۸۰۰ سال ۹۳ (تجویزی)

سطح زلزله	ساختمان	عملکرد مورد انتظار	نحوه طراحی
زلزله طرح **(Major)** (زلزله شدید تا درجه **IX** مرکالی یا بالای ۶ ریشتر **T_R=475**)	اهمیت متوسط (مسکونی – اداری)	بدون آسیب عمده سازه‌ای و غیر سازه ای و تلفات جانی حداقل **(Life Safety-Collapse Prevention)**	به اندازه کافی مقاومت و شکل‌پذیری فراهم کنیم تا مانع از انهدام سازه‌ای شود تا جان انسانها نجات یابد.
	اهمیت زیاد (مدارس)	آسیب عمده نبینند بطوری که در زمان کوتاهی قابل مرمت باشند. **(Immediate Occupancy)** **damage control**	(استفاده از **R** و اجازه ایجاد مفاصل پلاستیک یعنی خسارت)
	اهمیت خیلی زیاد (بیمارستان ها)	تغییر مقاومت و سختی در اجزای سازه ای و غیر سازه ای نداشته باشند بطوری که بهره برداری از آنها امکانپذیر باشد. **(Operational)** **damage control**	یعنی برای ساختمان های با اهمیت زیاد و خیلی زیاد (مدارس و بیمارستان ها) عملکرد لازم تامین نمی شود.
زلزله سطح بهره برداری **(Minor)** (زلزله خفیف تا درجه **VII** مرکالی یا پایین ۵ ریشتر **T_R=10**)	-بلندتر از ۵۰ متر یا ۱۵ طبقه -با اهمیت زیاد (مدارس) و خیلی زیاد (بیمارستان ها)	بدون آسیب و با قابلیت بهره برداری **(Operational)**	به اندازه کافی سختی فراهم کنیم تا جلوی خسارات معماری گرفته شود. طرح الاستیک

مقایسه انواع سیستم های غیر فعال کنترل لرزه ای در ساختمان

Seismic isolation structure

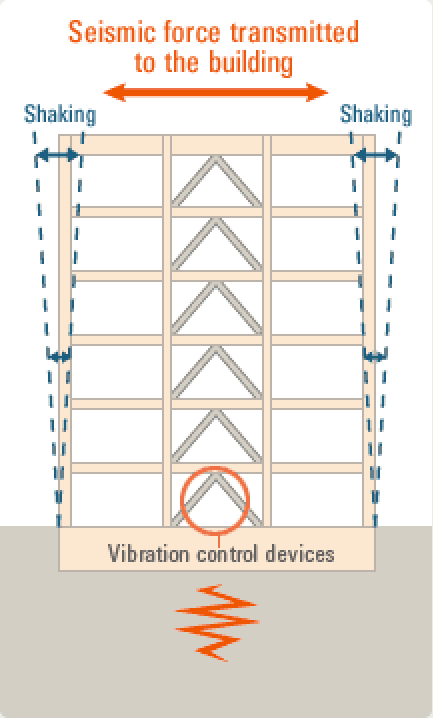
Earthquake energy is absorbed by seismic isolation bearing.



The Structure which is mounted on seismic isolation bearing installed between the building and foundation, softly responding to seismic force and reducing the earthquake input to the building.

Seismic vibration control structure

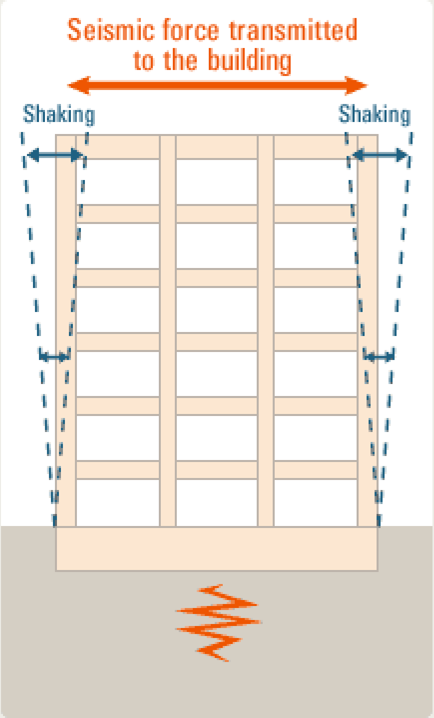
Earthquake energy is absorbed by vibration control devices.



The structure which is installed with vibration control devices (damper etc.) in the building to absorb earthquake energy for reducing the damage on building.

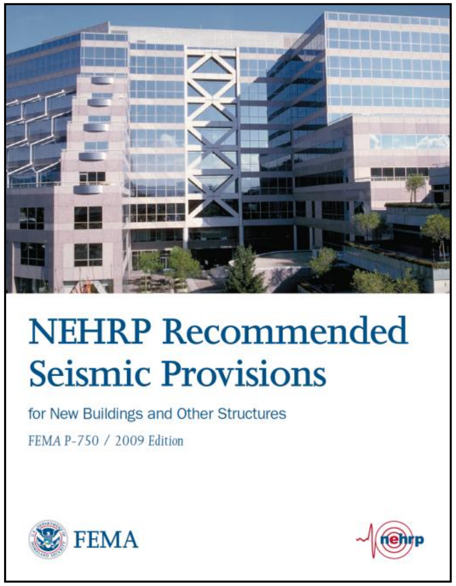
Seismic resistant structure

Earthquake energy is absorbed by columns or beams damage.



The structure that resists earthquake by strength and tenacity of main structural members such as columns, beams, bracing and shear wall.

سطوح عملکرد مورد انتظار انواع سیستم های غیر فعال کنترل لرزه ای



FEMA P-750 / NEHRP 2009

Table C17.2-1 Performance Expected for Minor, Moderate, and Major Earthquakes[a]

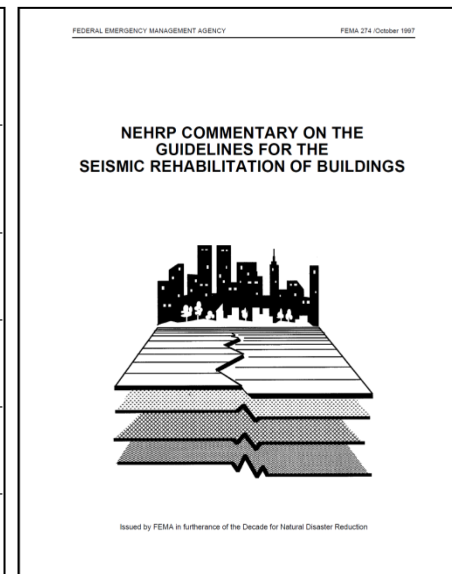
Performance Measure	Earthquake Ground Motion Level		
	Minor	Moderate	Major
Life safety: loss of life or serious injury is not expected	F, I	F, I	F, I
Structural damage: significant structural damage is not expected	F, I	F, I	I
Nonstructural damage: significant nonstructural or contents damage is not expected	F, I	I	I

[a] F indicates fixed base; I indicates isolated.

FEMA 274

Table C9-1 Applicability of Isolation and Energy Dissipation Systems

Performance Level	Performance Range	Isolation	Energy Dissipation
Operational	Damage Control	Very Likely	Limited
Immediate Occupancy		Likely	Likely
Life Safety	Limited Safety	Limited	Likely
Collapse Prevention		Not Practical	Limited

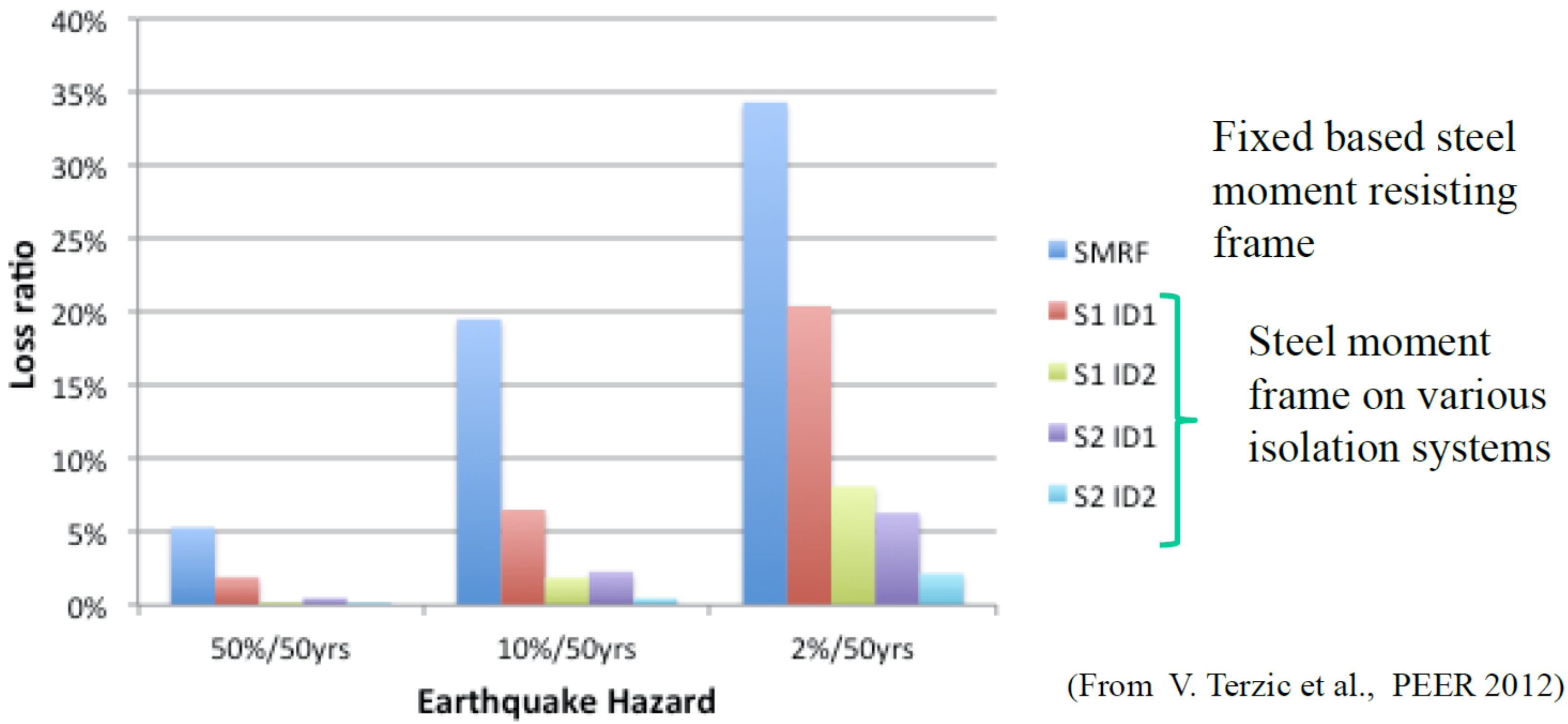


Suitable Buildings for Seismic Isolation

Type of Building	Reasons for Isolating
Essential Facilities	Functionality High Importance Factor, I
Health Care Facilities	Functionality High Importance Factor, I
Old Buildings	Preservation Low R
Museums	Valuable Contents
Manufacturing Facilities	Continued Function High Value Contents

Example of Loss Estimation Studies

- **Comparison of expected repair cost for fixed based and seismically isolated structure with 4 different systems**
- **Loss Ratio = Repair/Replacement cost**



(From V. Terzic et al., PEER 2012)

نکات فنی سیستم های کنترل لرزه ای

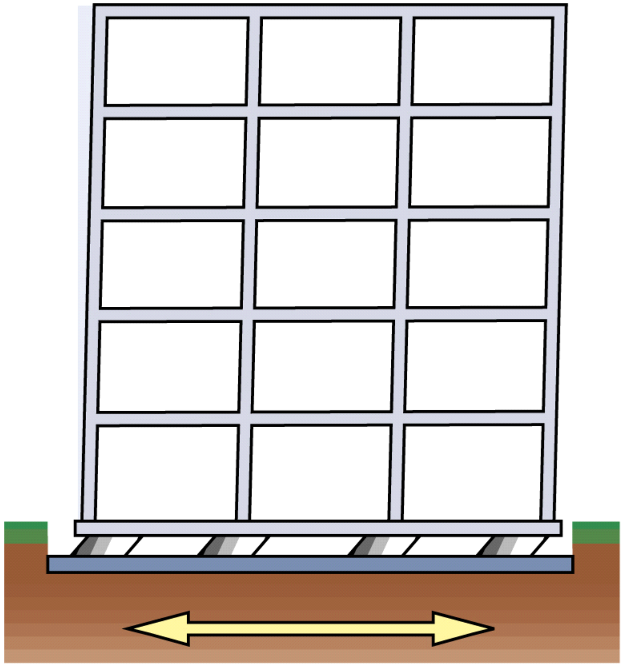
Components of Seismic Isolation Systems:

- **Isolator:**
  - **Lateral stiffness much less than superstructure**
  - **Increase effective period of vibration**
  - **Dissipate seismic energy**
- **Supplemental damping mechanism:**
  - **Dissipate residual seismic input energy**
  - **Limits displacements of isolator**
  - **Reduces force transmitted to superstructure**

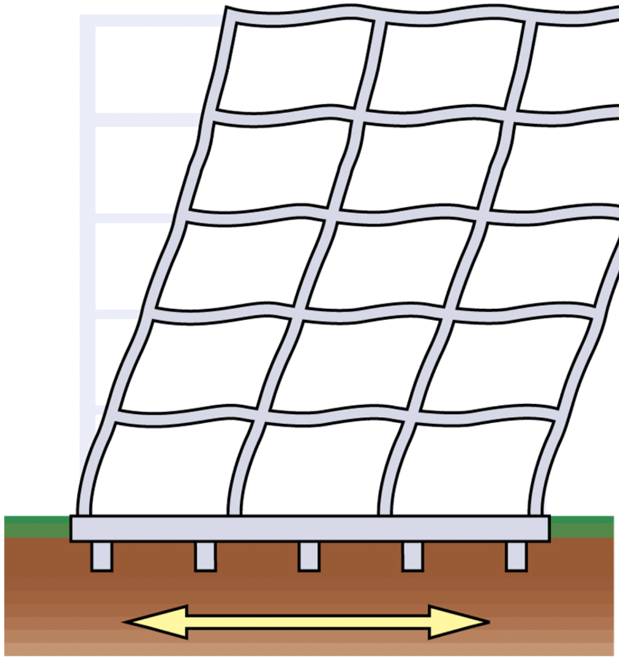
Seismic Isolation Systems

- **Installation of "isolators" beneath supporting points of the structure:**
    - **Buildings: isolators located between superstructure and foundation**
    - **Bridges: isolators located between deck and piers**
- **Isolators have much lower lateral stiffness than superstructure**
- **Isolators limit transfer of seismic energy to superstructure**
- **If no seismic energy transmitted to superstructure: no damage**

Behavior of Building Structure with Base Isolation System



Base-Isolated Structure



Conventional Structure

Behavior of Building Structure with Base Isolation System

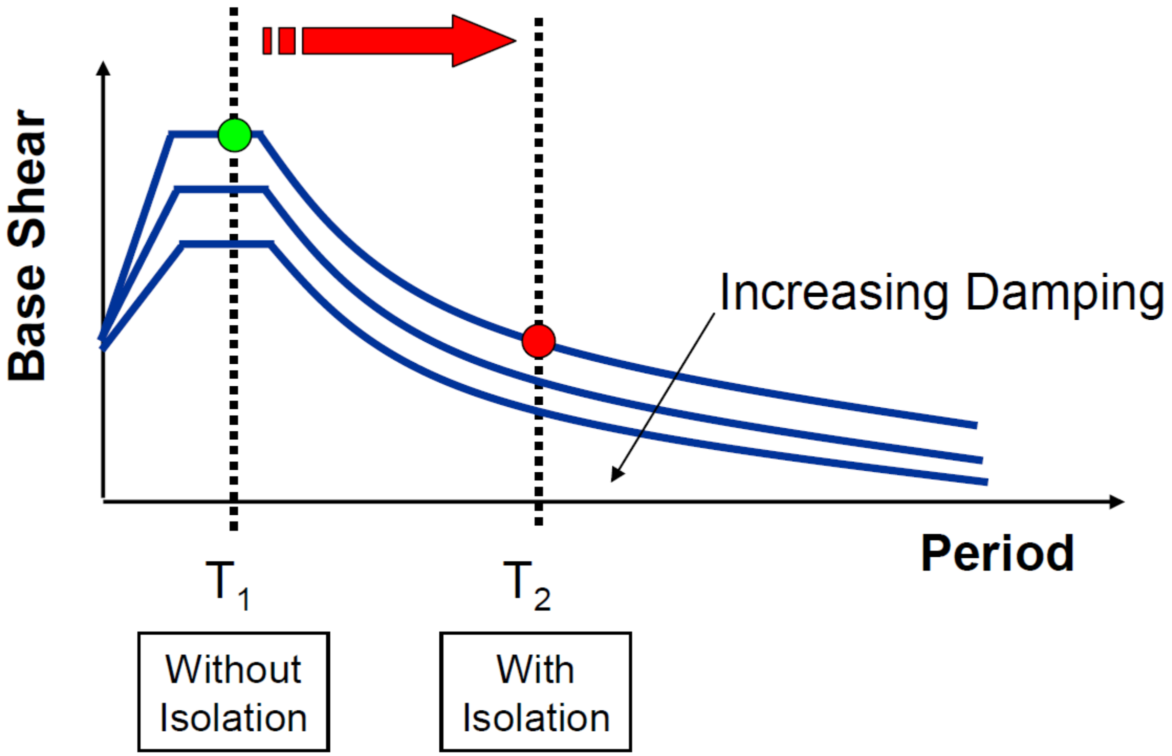
Base-Isolated Room

Conventional Room

Effect of Seismic Isolation

(Acceleration Response Spectrum Perspective)

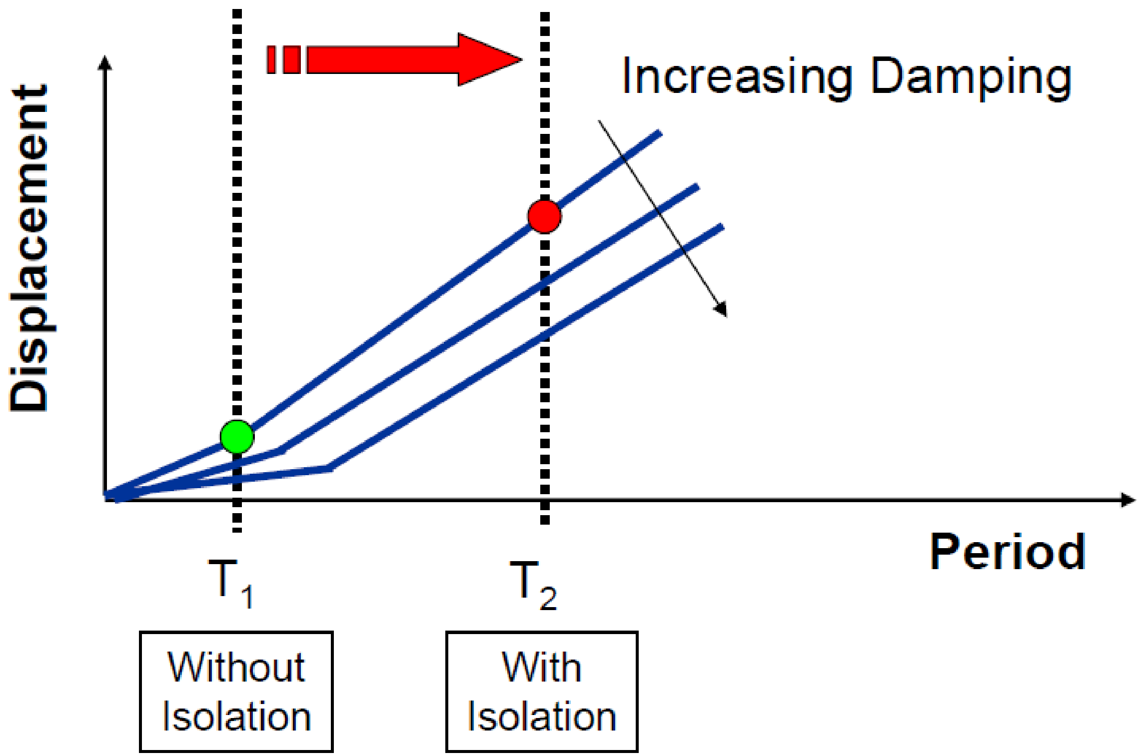
- **Increase period of vibration of structure to reduce base shear:**



Effect of Seismic Isolation

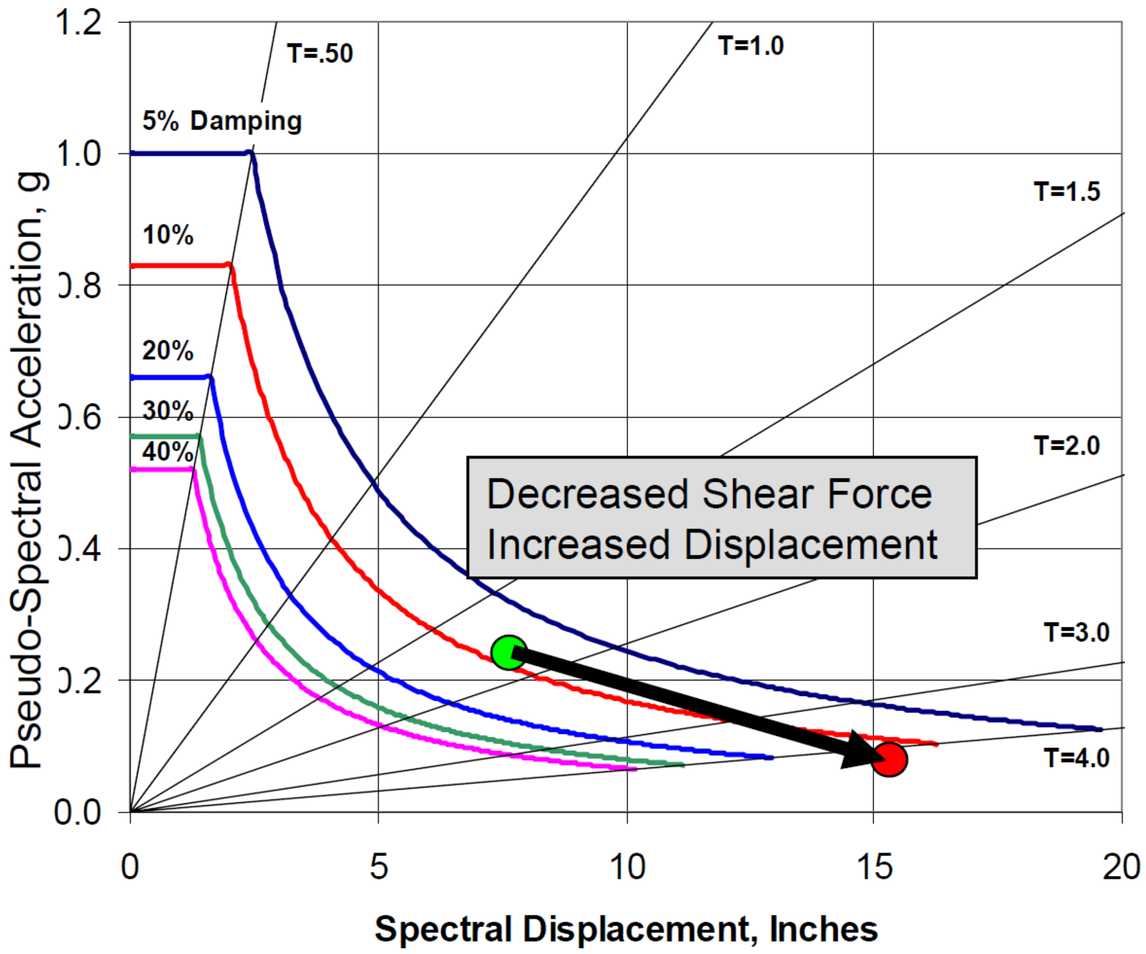
(Acceleration Response Spectrum Perspective)

- Increase of period **increases displacement demand** but now **concentrated at base**:

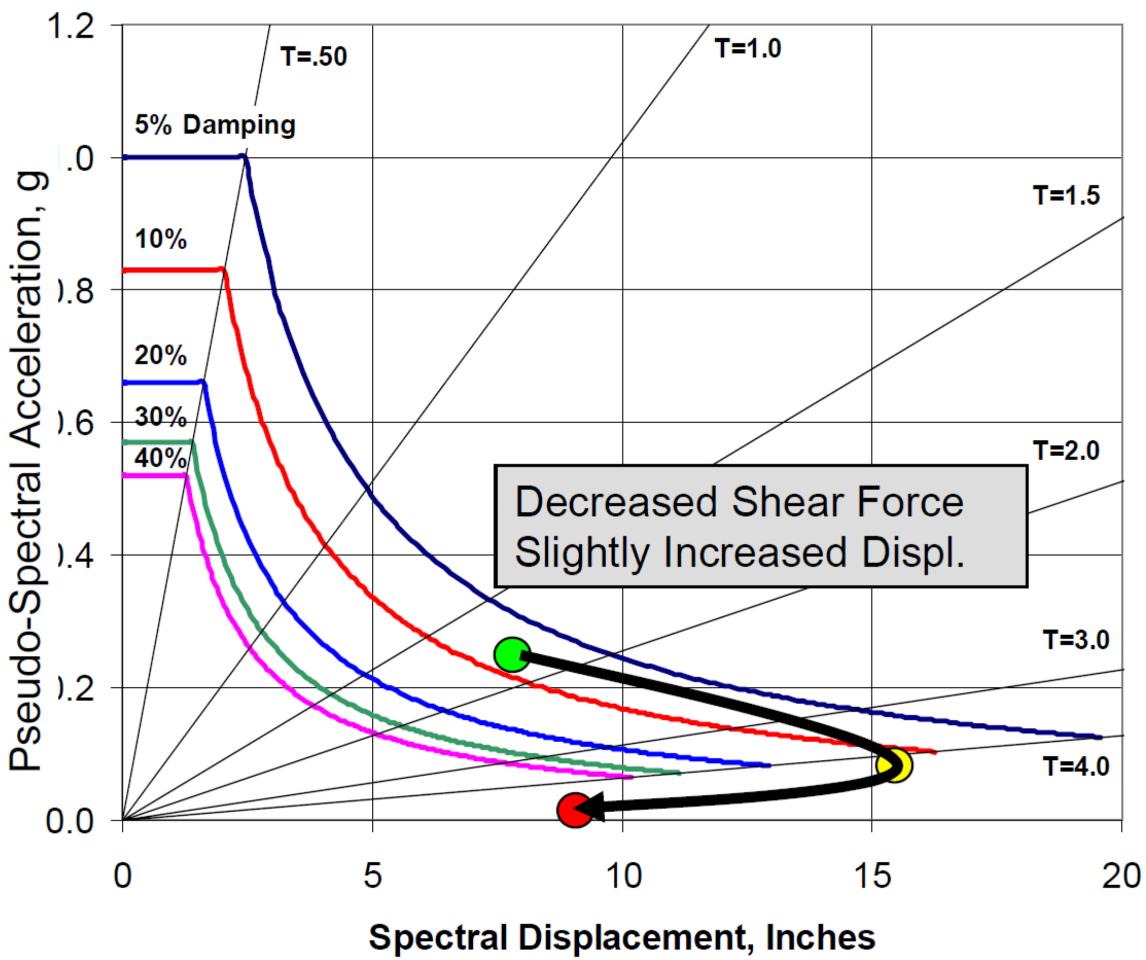


Effect of Seismic Isolation

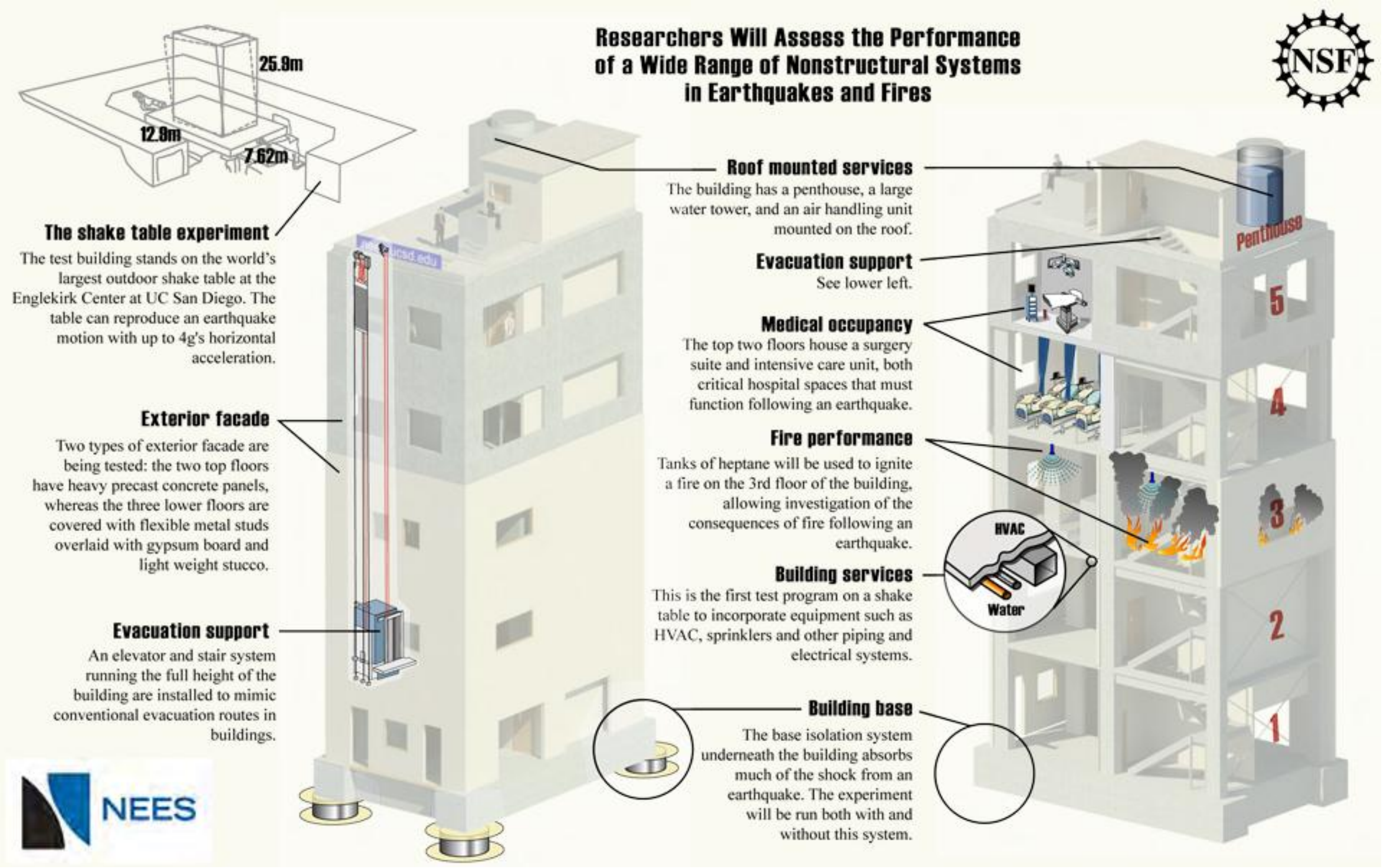
(Acceleration-Displacement Response Spectrum Perspective)



Effect of Seismic Isolation with Supplemental Dampers
(Acceleration-Displacement Response Spectrum Perspective)



Full Size Shaking Table Results



- **The Pisco, Peru, Earthquake of August 15, 2007**
- Mw = 8.0, hypocenter depth is 39 km

Characteristics of Well-Designed Seismic Isolation Systems

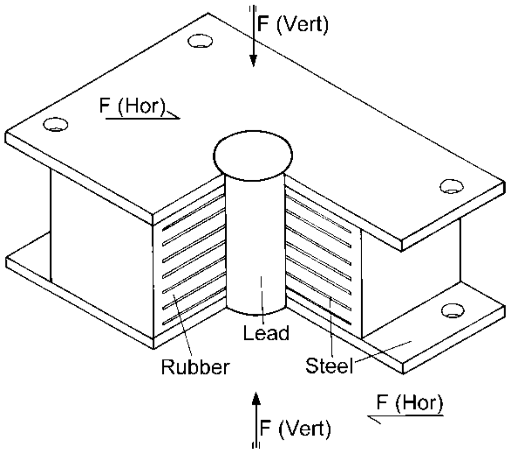
- **Flexibility to increase period of vibration and thus reduce force response**
- **Energy dissipation to control the isolation system displacement**
- **Rigidity under low load levels such as wind and minor earthquakes**
- **Provide sufficient force to Restore isolation system to original location**

Classification of Seismic Isolation Bearings

- **Elastomeric Bearings:**
  - **Low Damping Natural or Synthetic Rubber Bearing**
  - **High Damping Natural Rubber Bearing**
  - **Lead Rubber Bearing**
- **Sliding Bearings:**
  - **Flat Sliding**
  - **Spherical Sliding Bearing**

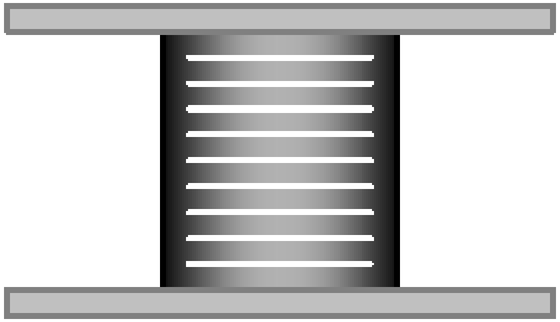
Geometry of Elastomeric Bearings

- **Rubber Layers: Provide lateral flexibility, restoring force & damping**
- **Steel Shims: Provide vertical stiffness to support building weight while limiting lateral bulging of rubber**
- **Lead plug: Provides source of energy dissipation**



Low Damping Natural or Synthetic Rubber Bearings

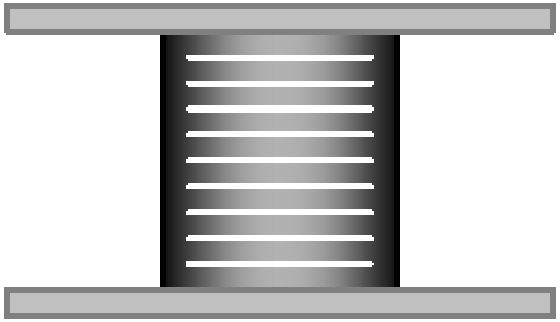
- **Linear behavior in shear for shear strains up to and exceeding 100%**
- **Damping ratio = 2 to 3%**



- **Advantages:**
  - **Simple to manufacture**
  - **Easy to model**
  - **Low cost**
- **Disadvantage:**
  - **High displacements so need supplemental damping system**
  - **Low damping**
  - **No resistance to service loads**
  - **P-Δ moments top and bottom**

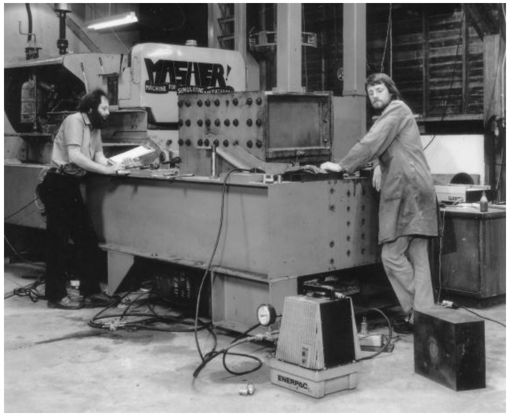
High Damping Natural Rubber Bearings

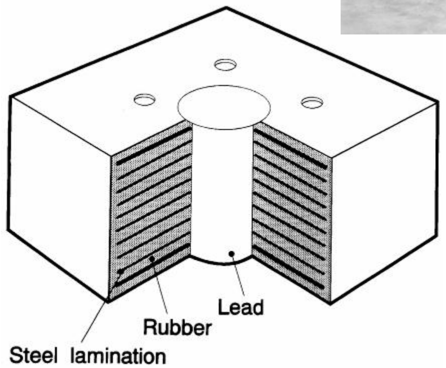
- **Maximum shear strain = 200 to 350%**
- **Damping increased by adding extrafine carbon black, oils or resins, and other proprietary fillers to rubber**
- **Damping ratio = 10 to 20% at shear strains of 100%**
- **Advantages:**
  - **Moderate in-structure accelerations**
  - **Resistance to service loads**
  - **Moderate to high damping**
- **Disadvantage:**
  - **Strain dependent stiffness and damping**
  - **Complex analysis**
  - **Limited choice of stiffness and damping**
  - **Change in properties with scragging**
  - **P-Δ moments top and bottom**



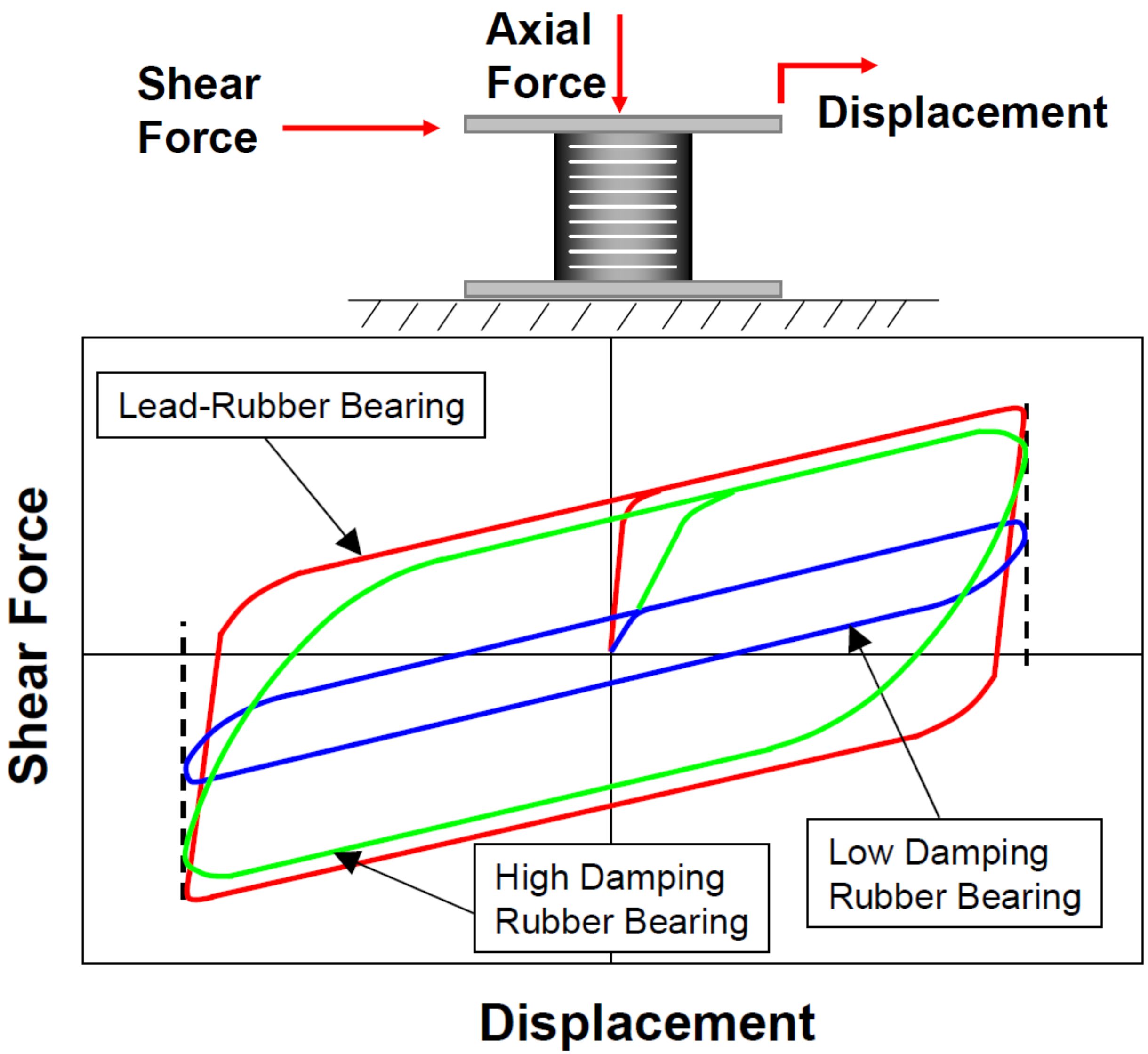
Lead Rubber Bearings

- **Invented in 1975 in New Zealand and used extensively in New Zealand, Japan, and the United States**
- **Maximum shear strain = 125 to 200%**
- **Damping ratio = 20 to 30% at shear strains of 100%**
- **Advantages:**
  - **Moderate in-structure accelerations**
  - **Wide choice of stiffness / damping**
- **Disadvantage:**
  - **Cyclic change in properties**
  - **P-Δ moments top and bottom**





Rubber Bearing Hysteresis Loops



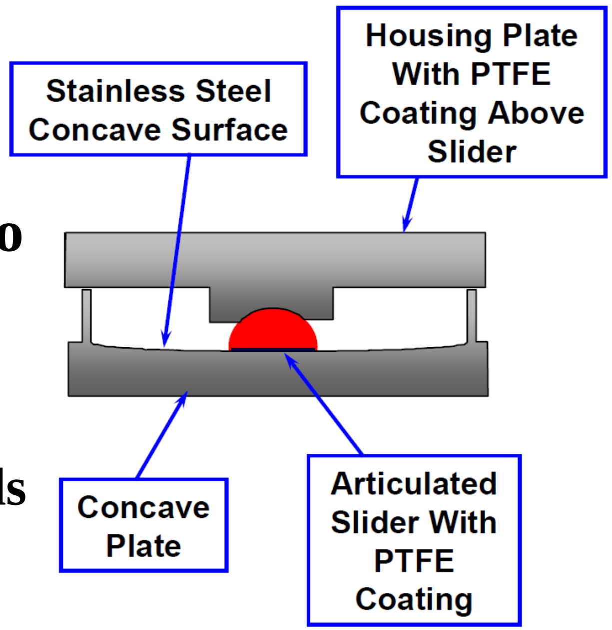
Cyclic Testing of Elastomeric Bearing

Testing of Full-Scale Xindian Hospital Elastomeric Bearing

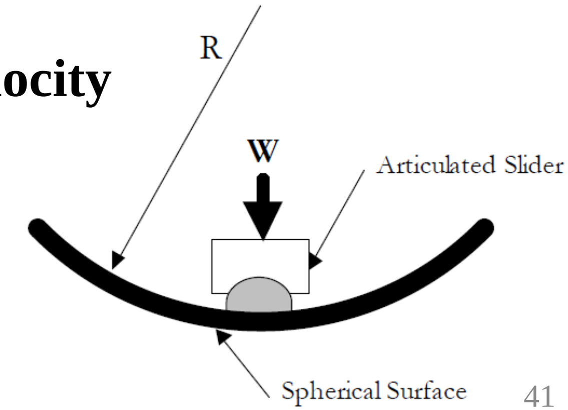
- **Compressive load = 17800 kN**
- **400% Shear Strain (1.0 m lateral displacement)**
- **Video shown at 16X actual speed of 25.4 mm/sec**

Spherical Sliding Bearing:

Friction Pendulum System (FPS)

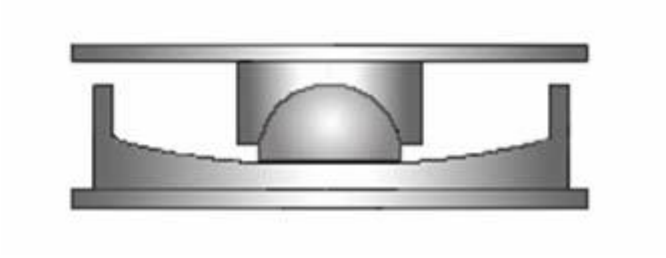


- Invented in 1988 in University at Buffalo
- **Advantages:**
  - Low profile
  - Resistance to very high compression loads
  - Moderate to high damping
  - Reduced torsion response
- **Disadvantage:**
  - High in-structure accelerations
  - Properties a function of pressure and velocity
  - Sticking
  - No tension resistance

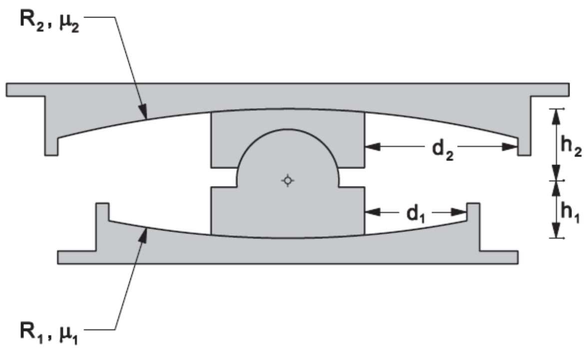


Types of FPS Bearings

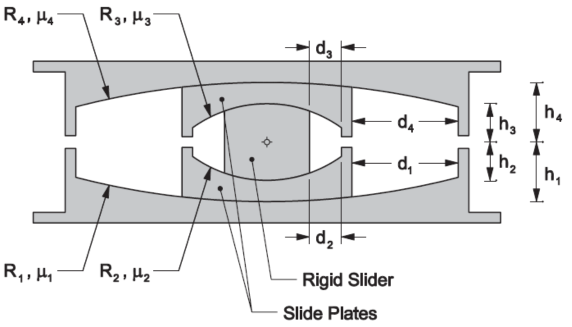
- Single Friction Pendulum Bearing



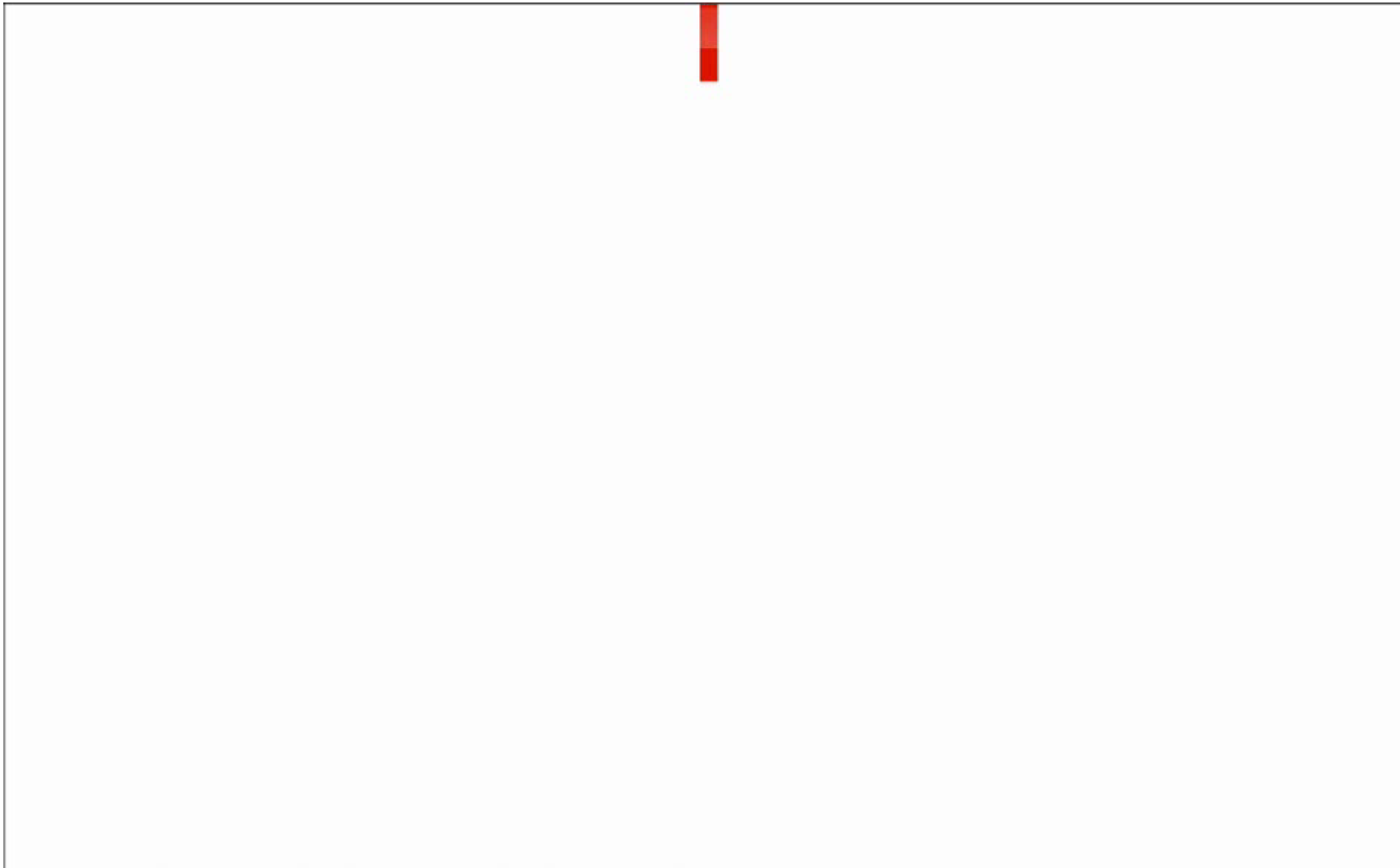
- Double Friction Pendulum Bearing



- Triple Friction Pendulum Bearing

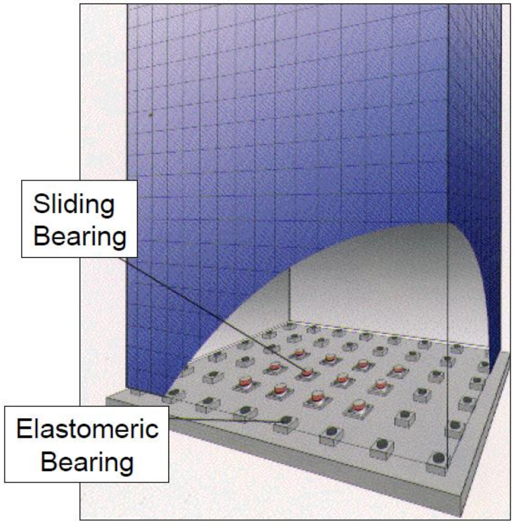


Triple versus Single Pendulum Bearing

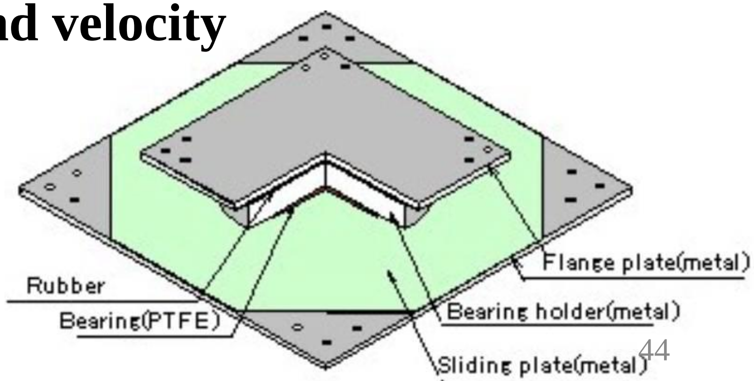


Flat Sliding Bearings

- Usually combine with elastomeric bearing to eliminate tension force, increasing damping & period of isolation system

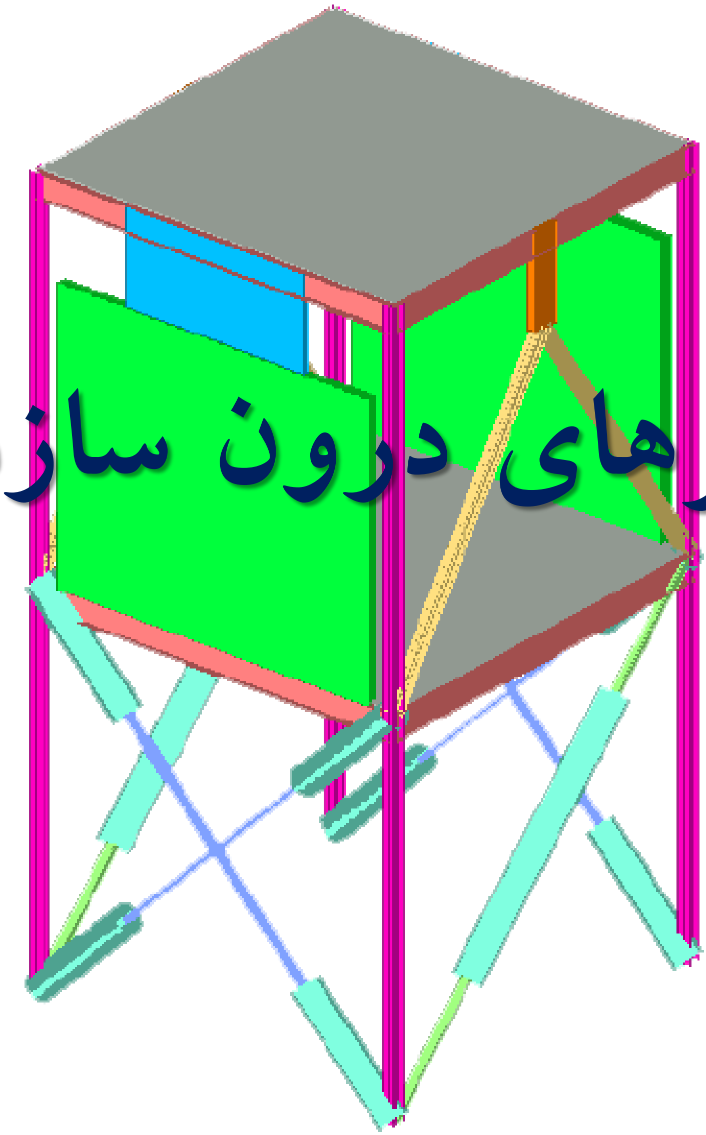


- **Advantages:**
  - Low profile
  - Resistance to very high compression loads
  - High damping
- **Disadvantage:**
  - High in-structure accelerations
  - Properties a function of pressure and velocity
  - Sticking
  - No restoring force



High Speed Test of Triple Pendulum Bearing

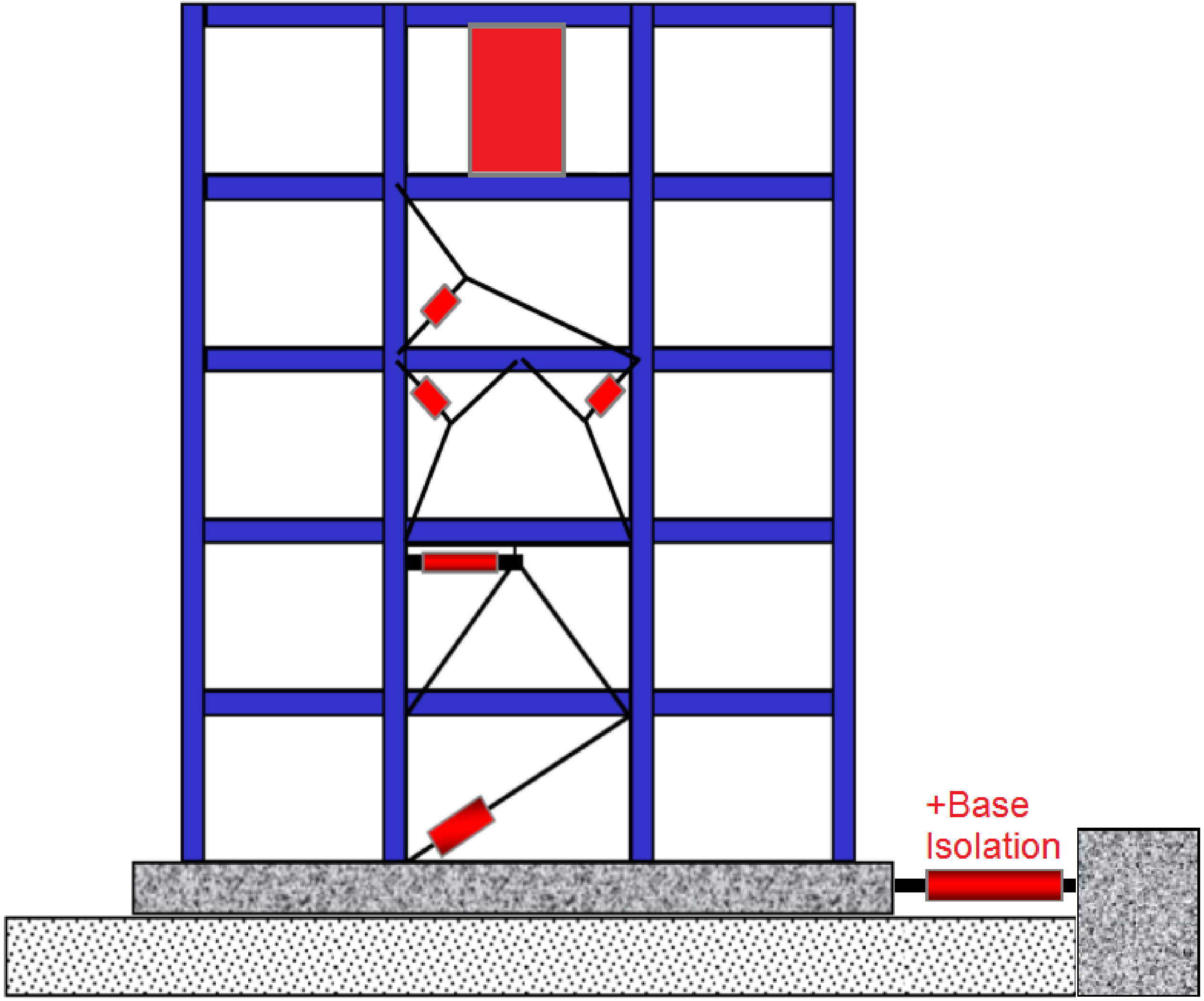
میراگرهای درون سازه ای



Supplemental Damping Systems

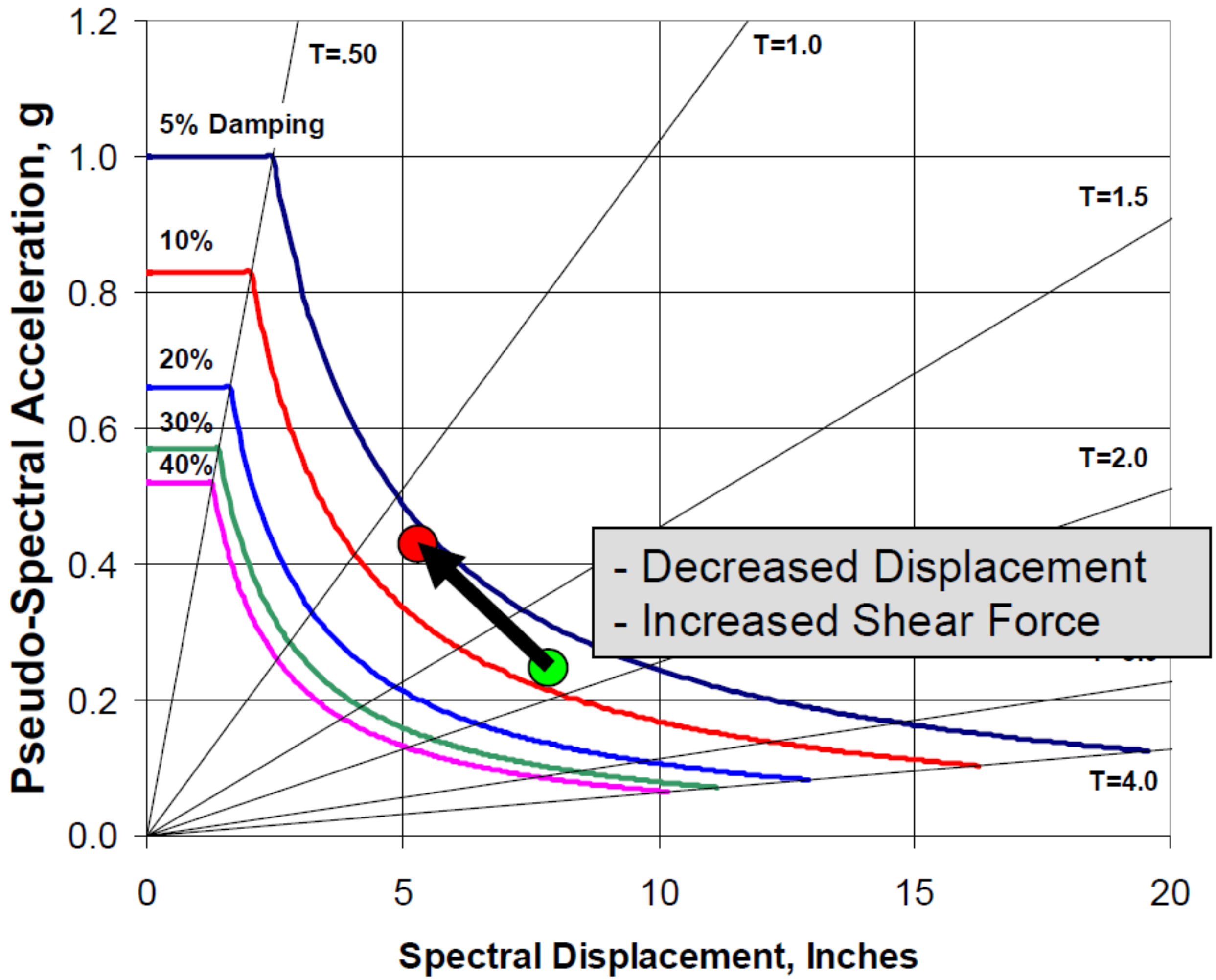
- Special devices – "mechanical dampers"
- Mechanical energy dissipation through heat by movements of the structural elements
- Protect main structural elements
- If all seismic energy dissipated mechanically: no damage

Possible Damper Placement within Structure



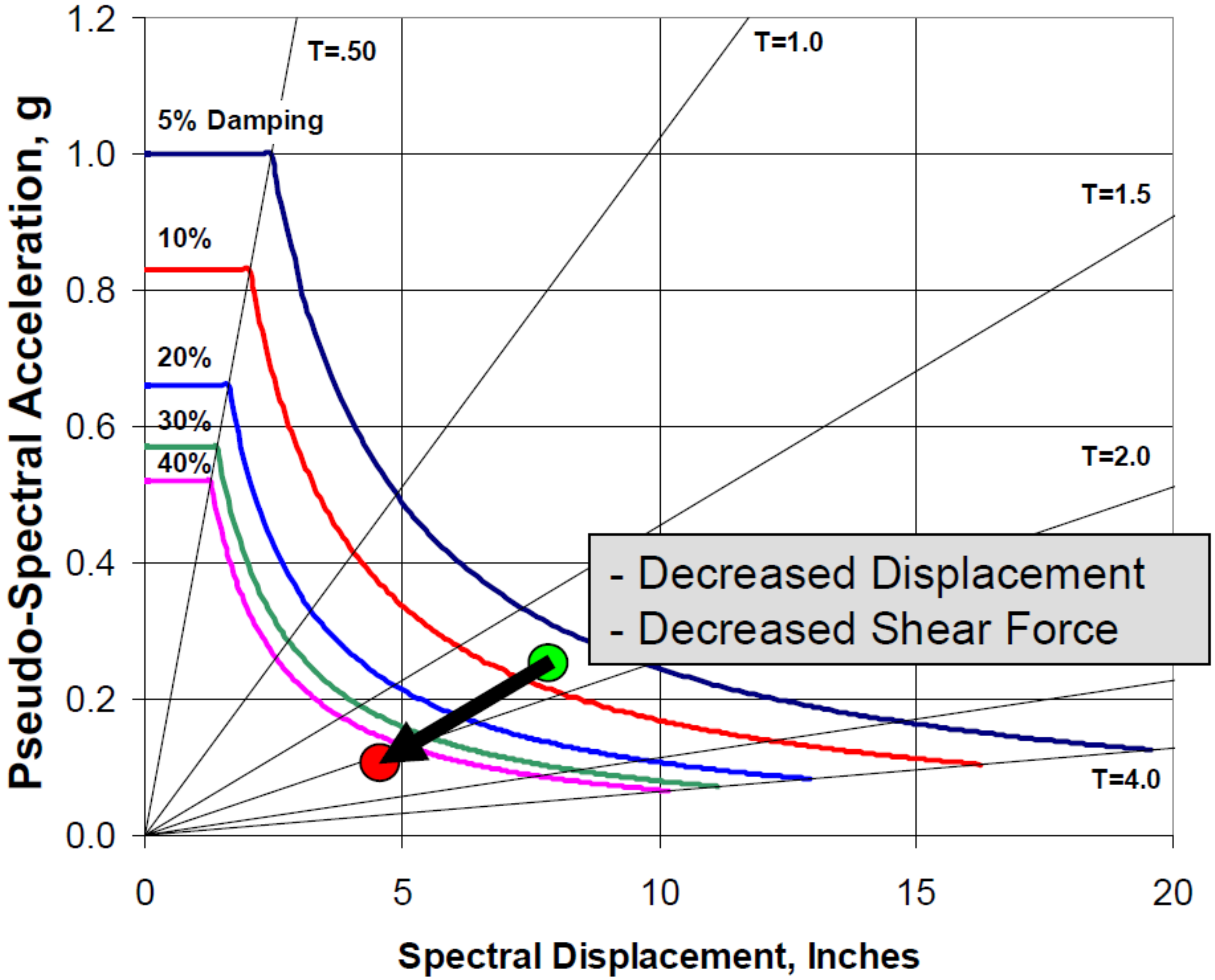
Effect of Added Stiffness (Added Bracing)

(Acceleration-Displacement Response Spectrum Perspective)



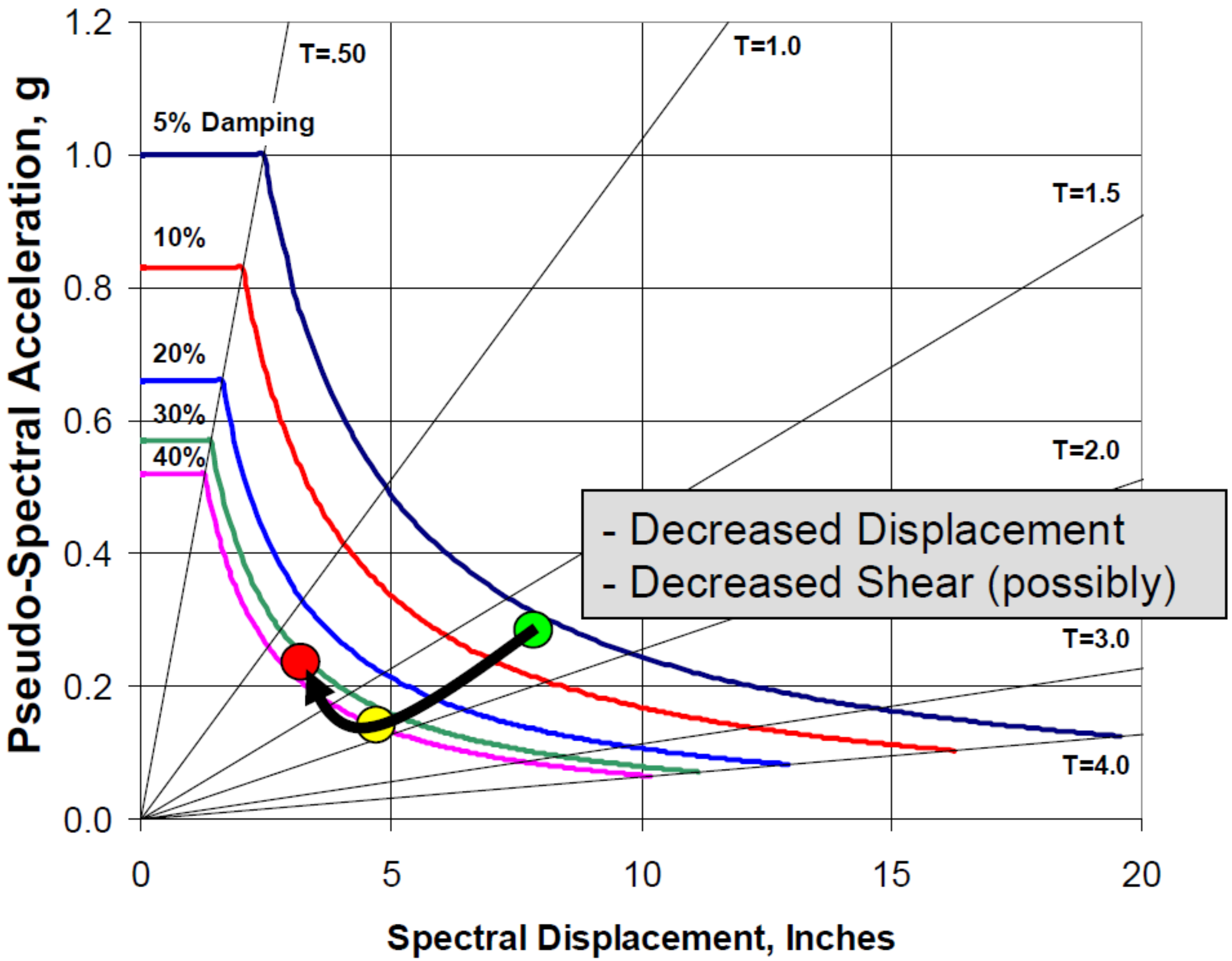
Effect of Added Damping (Viscous Damper)

(Acceleration-Displacement Response Spectrum Perspective)



Effect of Added Damping and Stiffness (ADAS System)

(Acceleration-Displacement Response Spectrum Perspective)



Energy Concepts in Earthquake Engineering

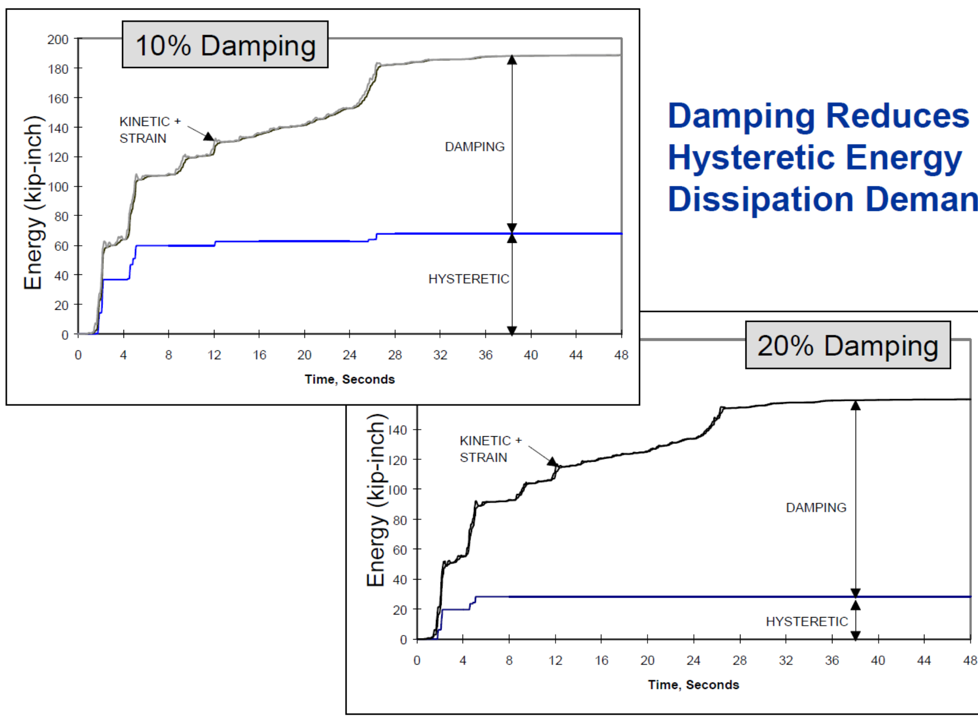
Hysteretic Energy

Energy Balance:

$$E_I = E_S + E_K + (E_{DI} + E_{DA}) + E_H$$

Inherent Damping

Added Damping



Damping Reduces Hysteretic Energy Dissipation Demand

Reduction in Seismic Damage

u_{max} = maximum displacement

u_{ult} = monotonic ultimate displacement

ρ = calibration factor

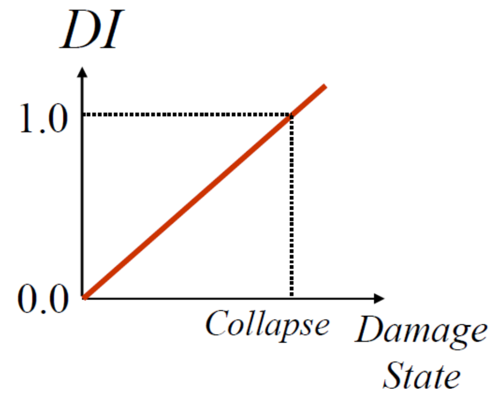
E_H = hysteretic energy dissipated

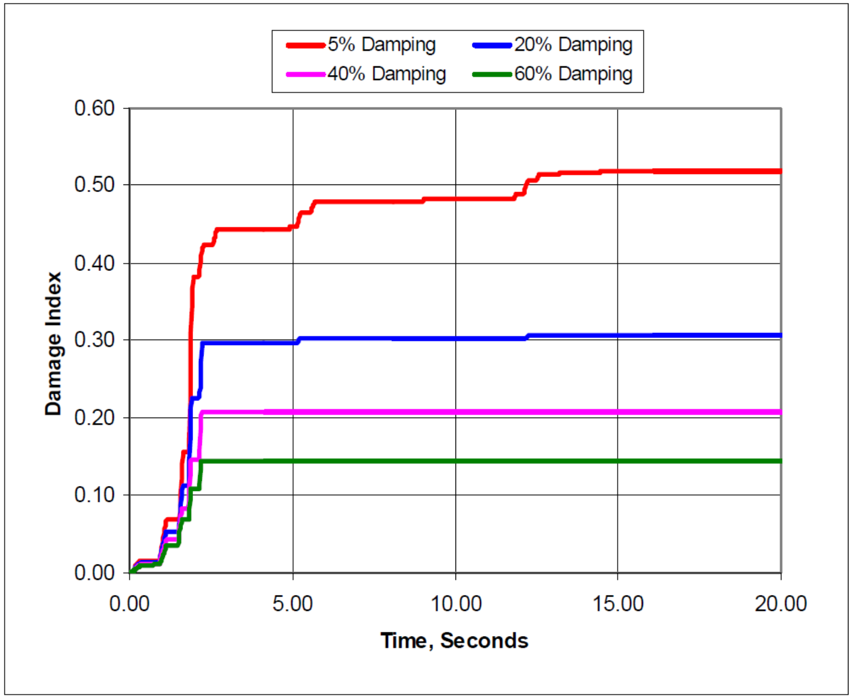
F_y = monotonic yield force

Damage Index:

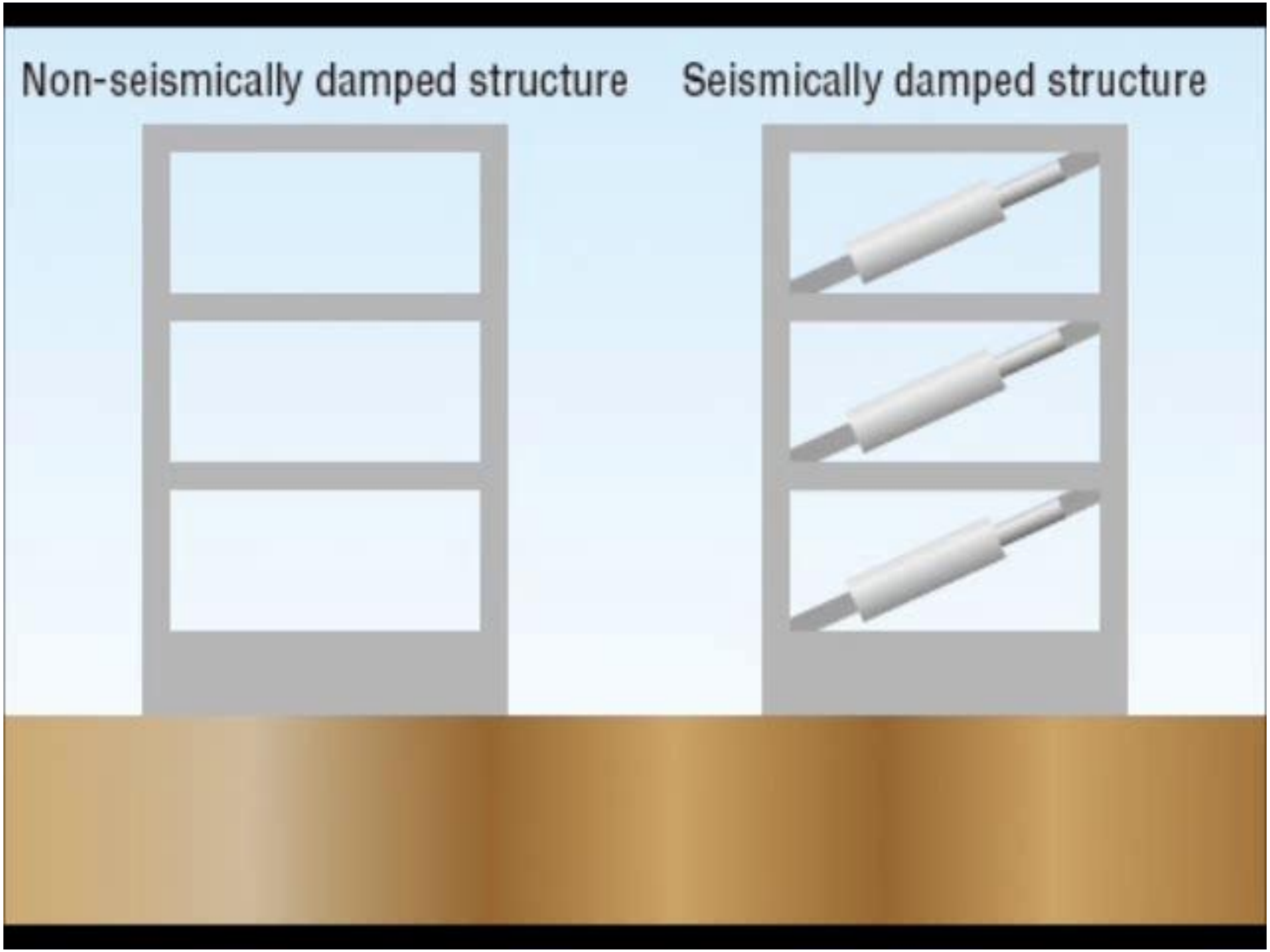
$$DI(t) = \frac{u_{max}}{u_{ult}} + \rho \frac{E_H(t)}{F_y u_{ult}}$$

Source: Park and Ang (1985)



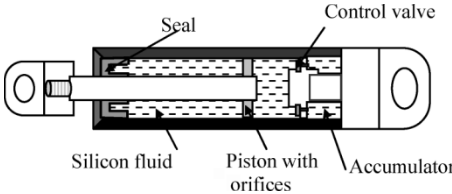


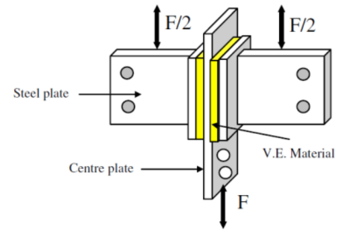
Behavior of Building Structure with Damper



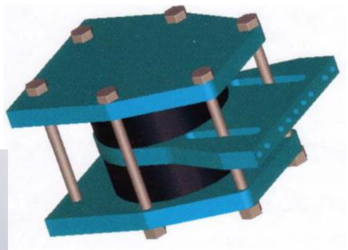
Classification of Passive Energy Dissipation Systems

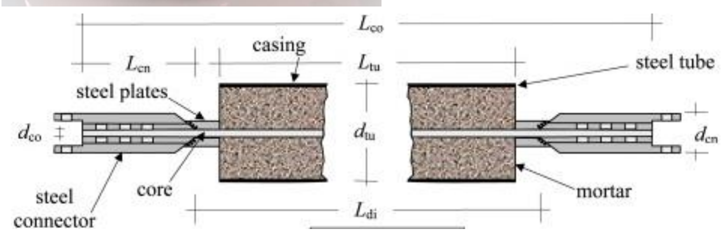
- **Velocity Dependent Systems:**
  - **Viscous fluid damper**
  - **Viscoelastic solid damper**





- **Displacement Dependent Systems:**
  - **Metallic yielding damper**
  - **Friction damper**
  - ***Buckling restrained brace***

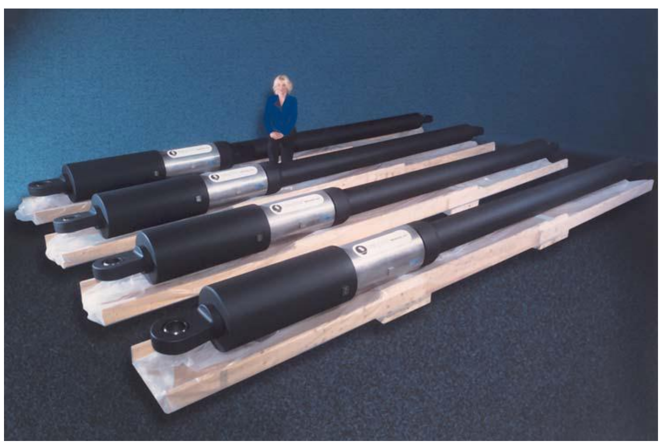


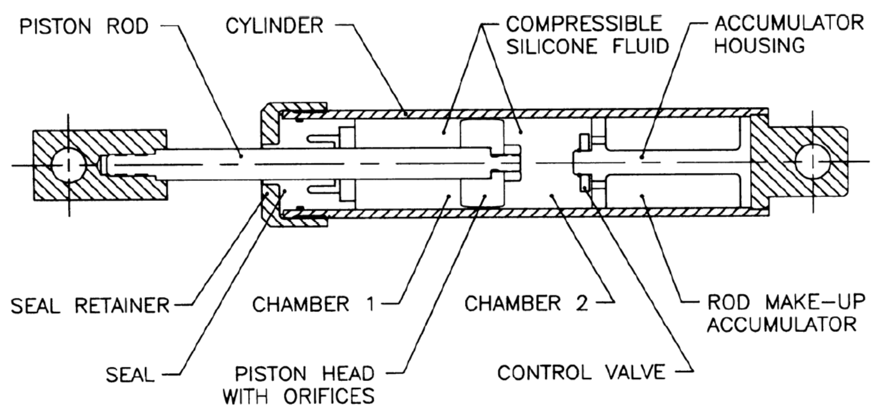


- **Other:**
  - **Re-centering devices (shape-memory alloys, etc.)**
  - **Vibration absorbers (tuned mass dampers)**

میراگر ویسکوز مایع

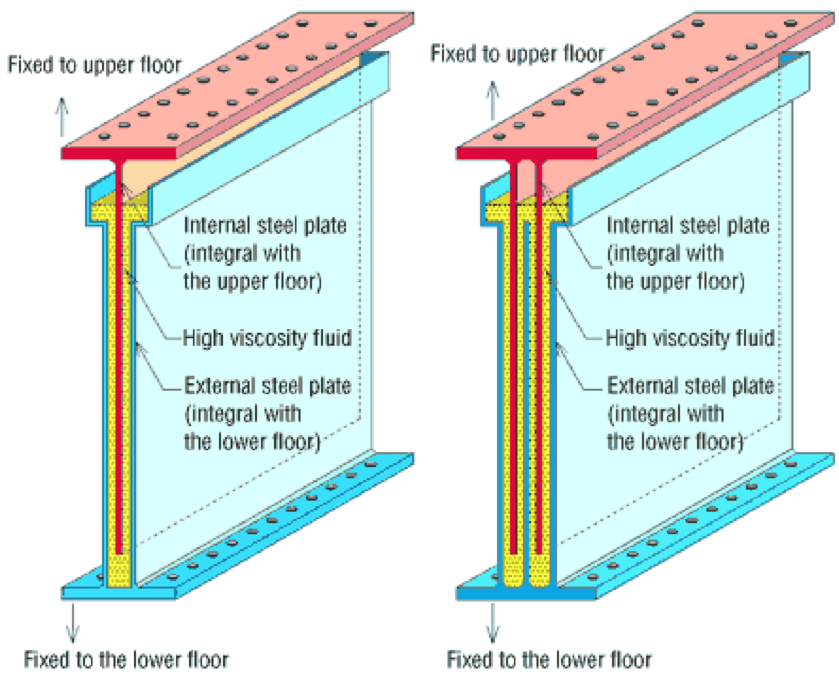
- متداولترین نوع میراگر لرزه ای منصوب در سازه
- حرکت پیستون در داخل سیلندری از مایع لزج





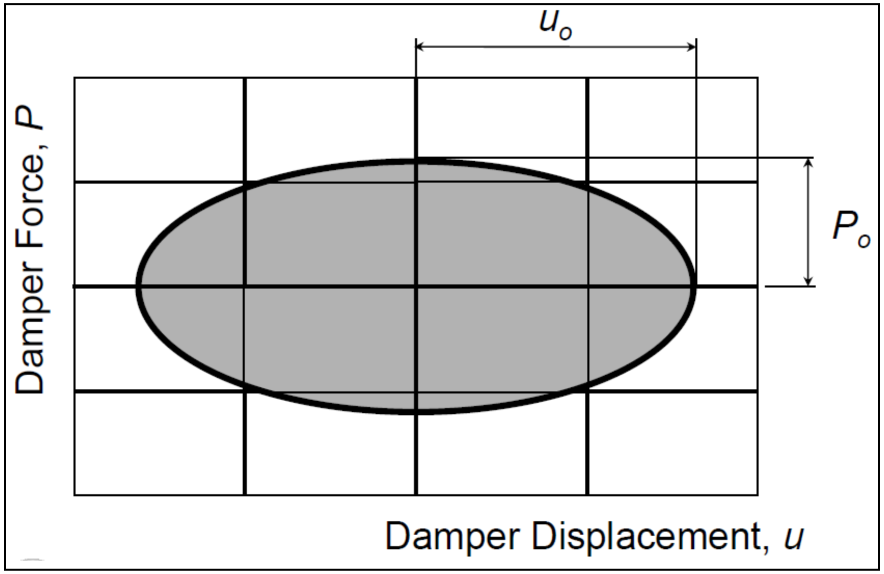
میراگر ویسکوز مایع

- قابل نصب به صورت میراگر ویسکوز دیواری به منظور عدم تداخل با بازشوهای معماری
- حرکت یک یا چند صفحه فولادی در داخل مایعی لزج



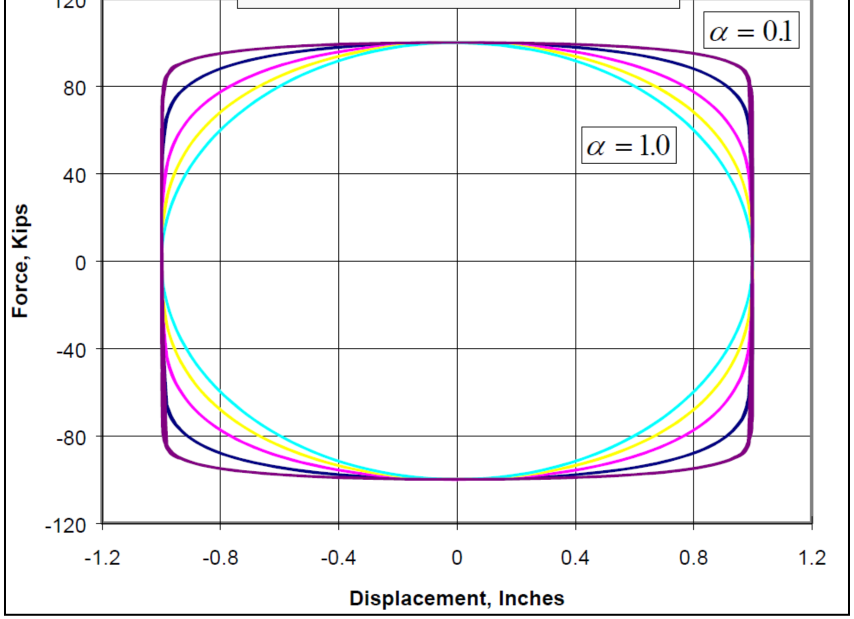
میراگر ویسکوز مایع

- مشخصات فنی میراگرهای ویسکوز خطی و غیرخطی:



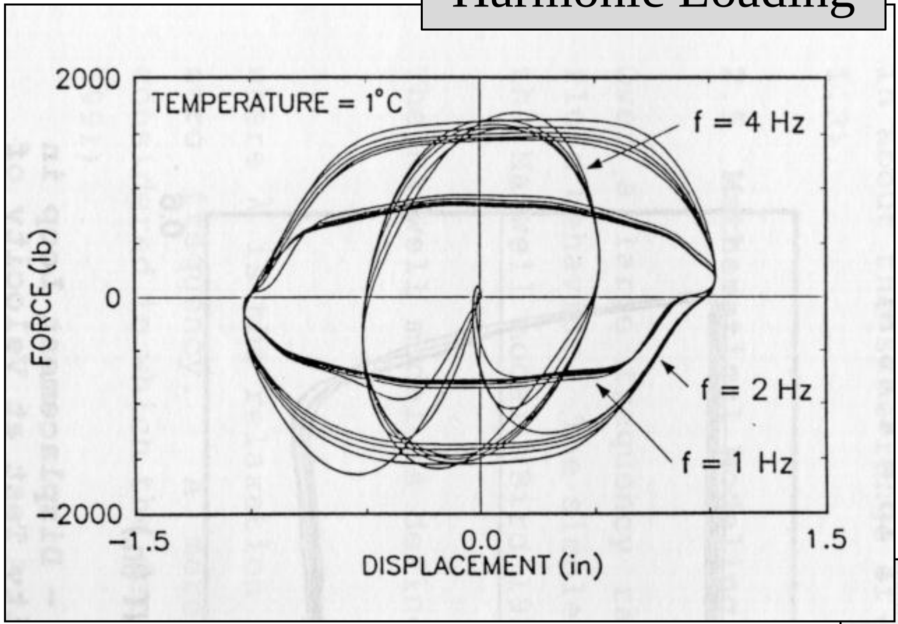
$$E_d = \pi P_o u_o$$

$$P(t) = C|\dot{u}|^{\alpha}\,\mathrm{sgn}(\dot{u})$$

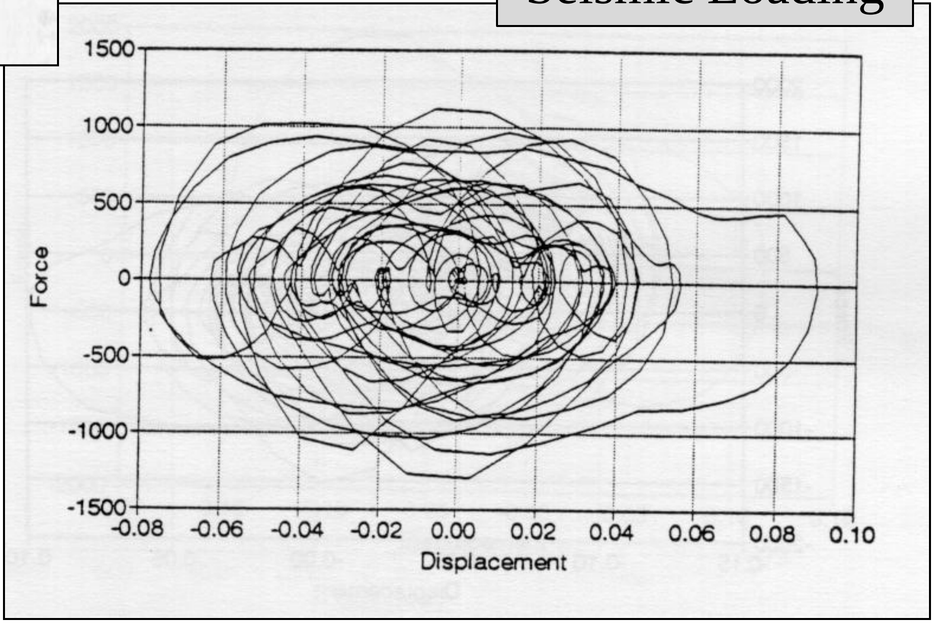


میراگر ویسکوز مایع

Harmonic Loading



Seismic Loading



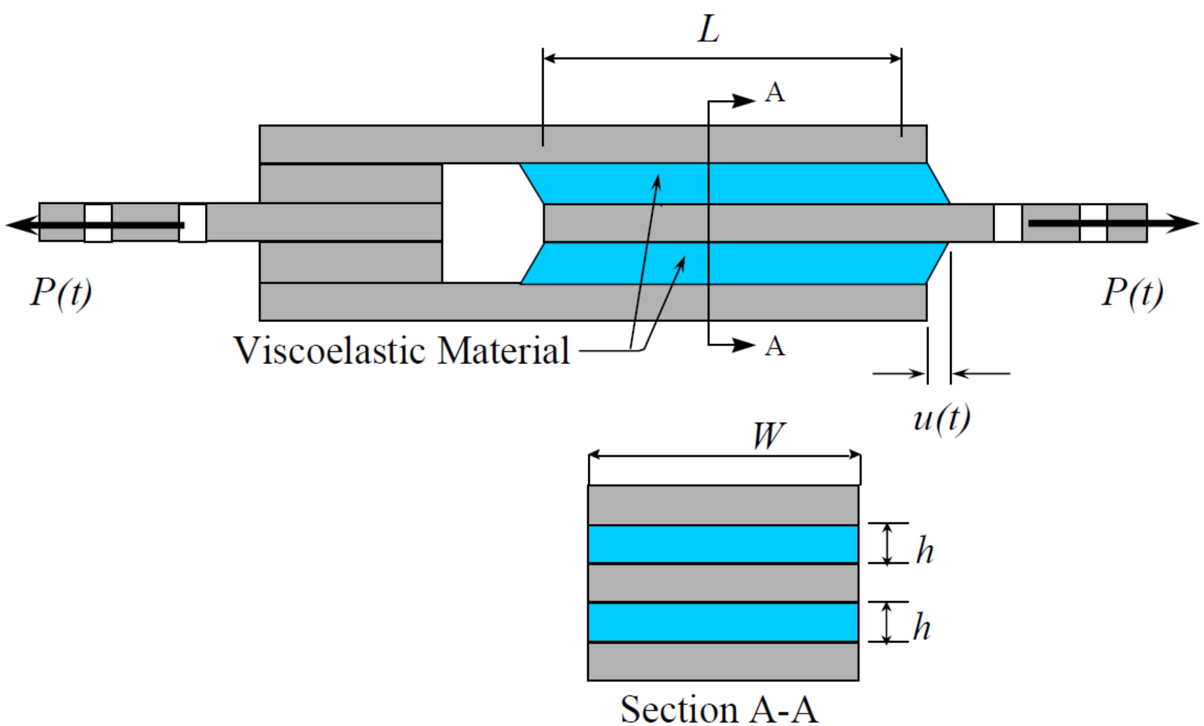
میراگر ویسکوز مایع

- **مزایا:**
  - قابلیت اطمینان بالا،
  - ظرفیت بالای نیرو و جابجایی،
  - در جابجایی ها کوچک نیز فعال می شود،
  - وابستگی کمی به دما و فرکانس وارده دارند،
  - امکان مدلسازی سازه برای میراگرهای خطی،
  - عرضه توسط تعداد زیادی از تولید کنندگان.

- **معایب:**
  - قیمت نسبتاً زیاد در برخی از مواقع،
  - نشت مایعات از سیلندر در طول زمان و در نتیجه نیاز به نگهداری،
  - در اکثر مواقع نیاز تحلیل تاریخچه زمانی غیرخطی می باشد،
  - عدم وجود حد بالا برای نیروی تولید شده زمانیکه توان سرعت برابر واحد است.

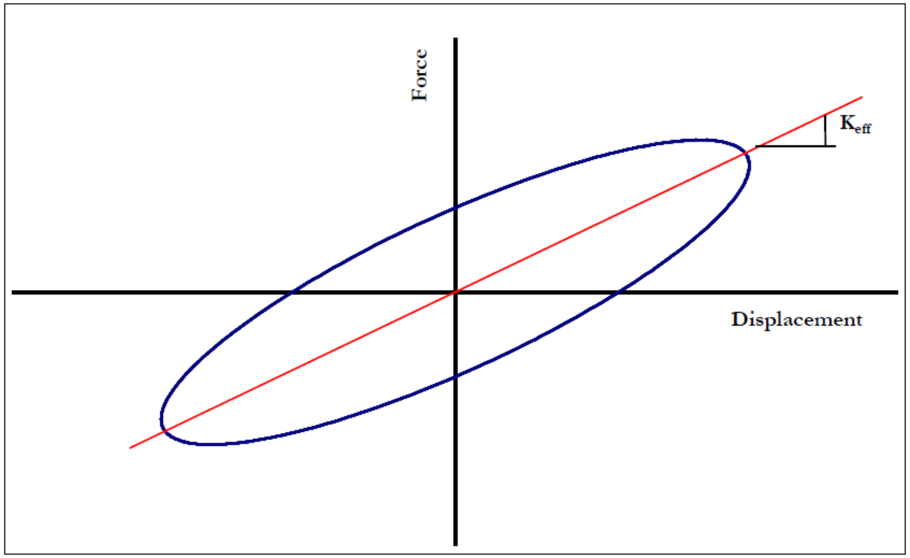
میراگر ویسکوالاستیک جامد

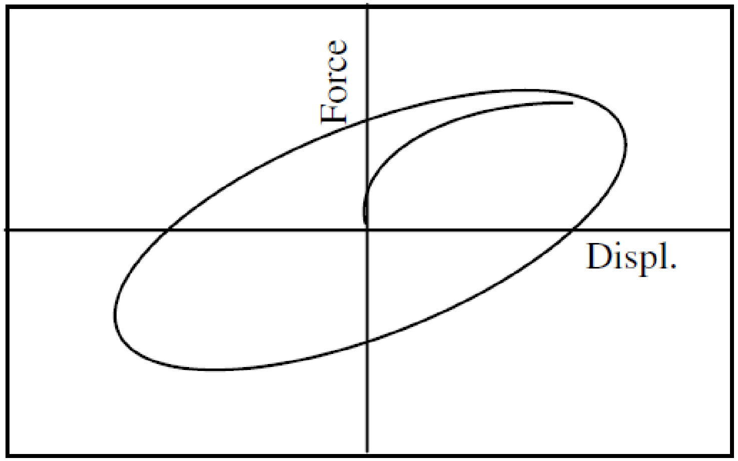
- در دهه ۶۰ میلادی تولید و جهت کنترل ارتعاشات ناشی از زلزله و باد در ساختمان ها و حرکت ترافیک بر روی پل ها بطور گسترده استفاده می شوند.



میراگر ویسکوالاستیک جامد

- مشخصات فنی:

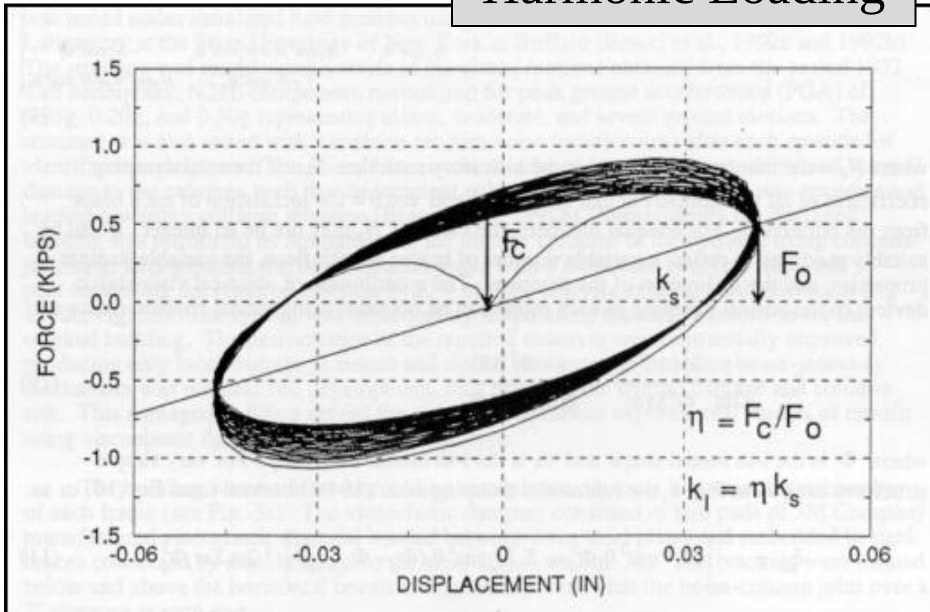




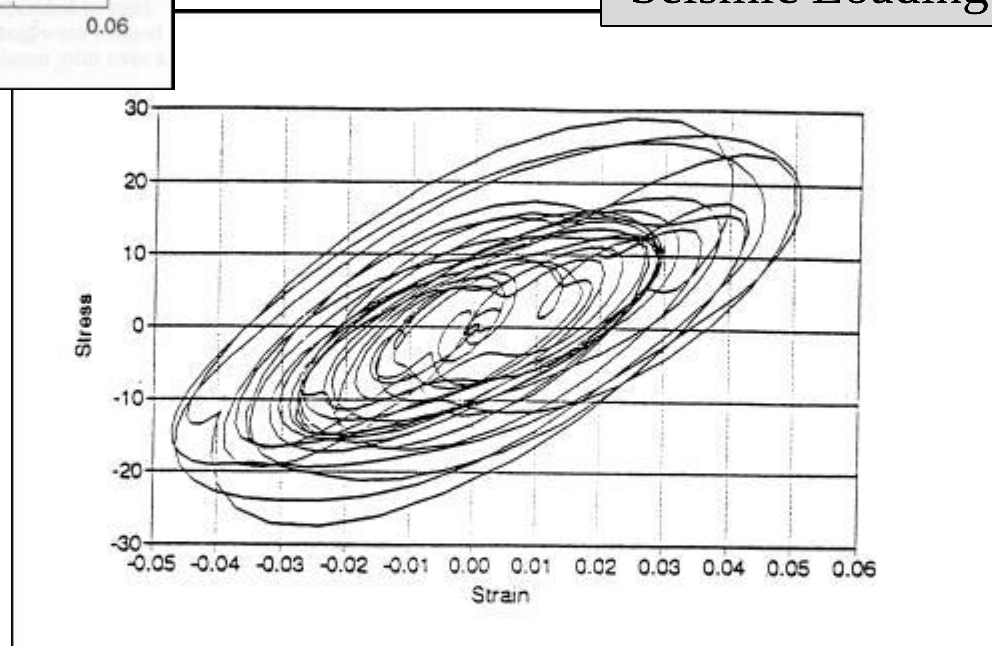
$$P(t) = K_{eff}u(t) + C_D\dot{u}(t)$$

میراگر ویسکوالاستیک جامد

Harmonic Loading

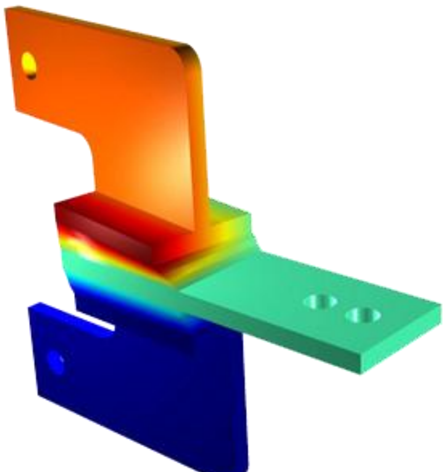


Seismic Loading



میراگر ویسکوالاستیک جامد

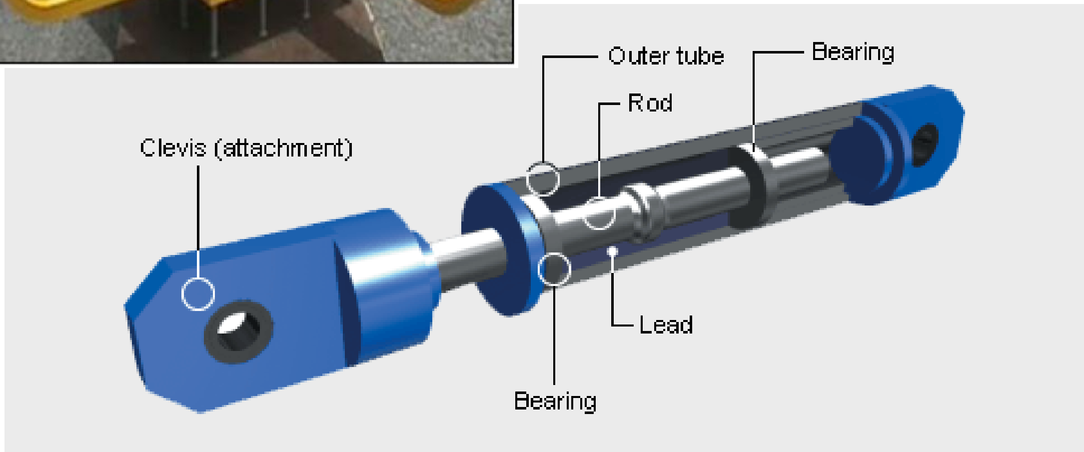
- **مزایا:**
  - قابلیت اطمینان بالا،
  - قیمت نسبتاً پایین،
  - تولید نیروی بازگرداننده کافی،
  - در جابجایی ها کوچک نیز فعال می شود.



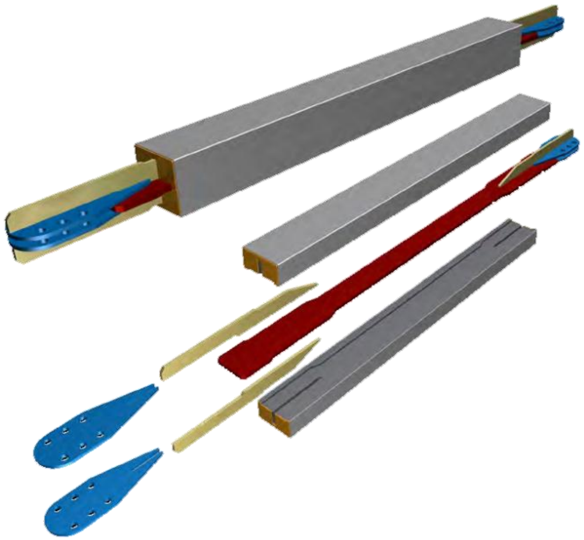
- **معایب:**
  - ظرفیت کم نیرو و جابجایی،
  - وابستگی نسبتاً زیاد مشخصات به فرکانس بار وارده و حرارت،
  - حد نهایی برای نیروی میراگر وجود ندارد،
  - نیازمند انجام تحلیل های غیرخطی.

میراگرهای تسلیمی

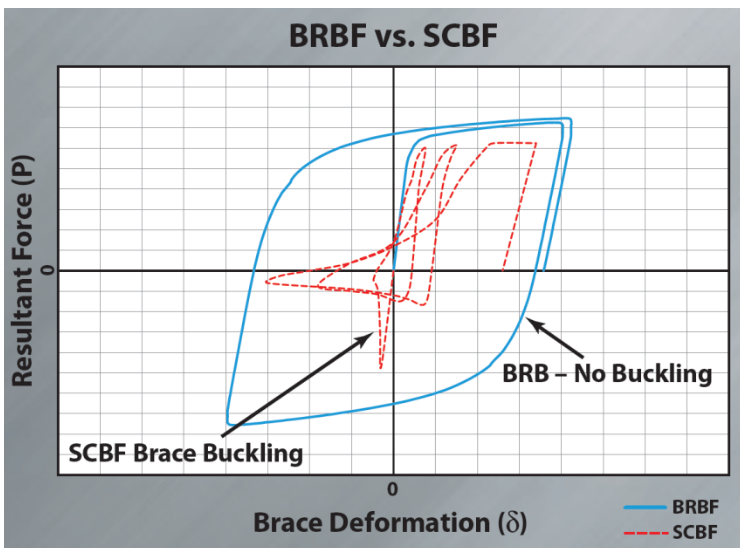
- اتلاف انرژی از طریق تسلیم و رفتار غیر خطی در قطعات (معمولاً سرب و یا فولد) بکار رفته در میراگر انجام می شود،



مهاربندهای کمانش ناپذیر

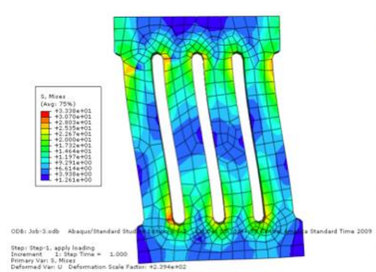
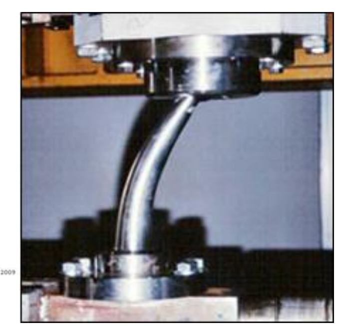


- مبانی اصلی عملکرد این میراگر، جلوگیری از وقوع کمانش هسته فولادی به منظور امکان وقوع پدیده تسلیم فشاری در آن و در نتیجه امکان جذب انرژی در این عضو از سازه می باشد.
- حلقه های هیسترزیس سیستم از نوع پایدار بوده و طی چرخه های بارگذاری، و باربرداری متعدد افت در مقاومت و سختی سیستم مشاهده نمی شود.



میراگرهای تسلیمی و مهاربندهای کمانش ناپذیر

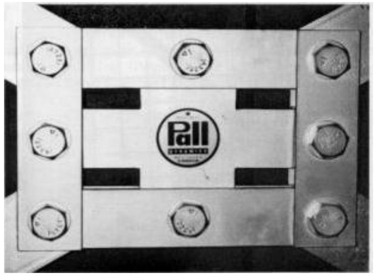
- **مزایا:**
  - ساخت با مصالح در دسترس و در نتیجه ساخت راحت،
  - قیمت نسبتاً پایین،
  - افزایش همزمان سختی و میرایی،
  - چرخه هیسترزیس پایدار،
  - دارای قابلیت اطمینان طولانی مدت.

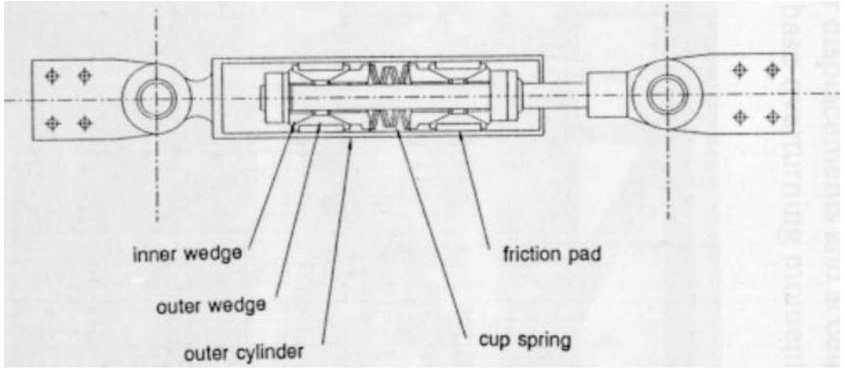



- **معایب:**
  - بعد از زلزله های شدید نیاز به بازنگری و تعویض قطعات وجود دارد،
  - اضافه کردن سختی به سیستم که در بعضی مواقع سبب افزایش برش پایه می شود،
  - امکان وجود تغییرمکان های ماندگار در میراگر.

میراگرهای اصطکاکی

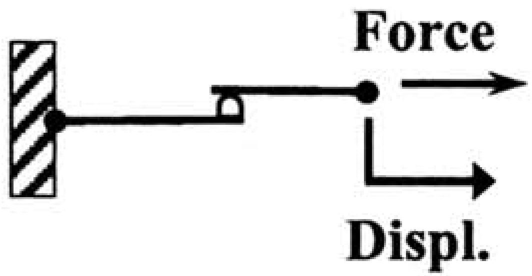
- اتلاف انرژی از طریق غلبه بر اصطکاک موجود در سطح تماس اجزاء میراگر انجام می شود،
- این میراگرها تحت بارهای ضمن خدمت فعال نمی شوند،
- این میراگرها به موازات مهاربندها نصب می شوند،
- انواع مختلفی از این نوع میراگرها ابداع شده است.

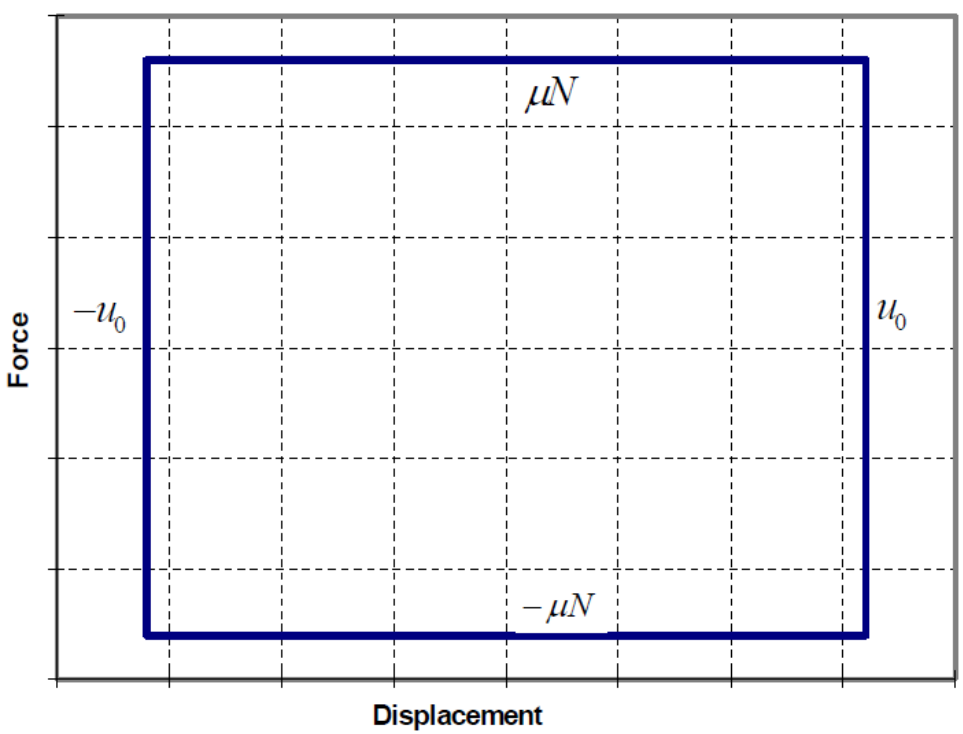




میراگرهای اصطکاکی

- مشخصات فنی:



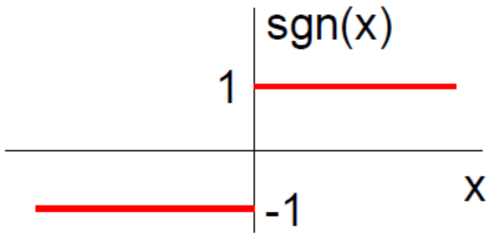


Normal Force

$$F_D = N\mu \frac{\dot{u}(t)}{\left|\dot{u}(t)\right|}$$

Coefficient of Friction

$$F_D = N\mu \, sgn\left[\dot{u}(t)\right]$$



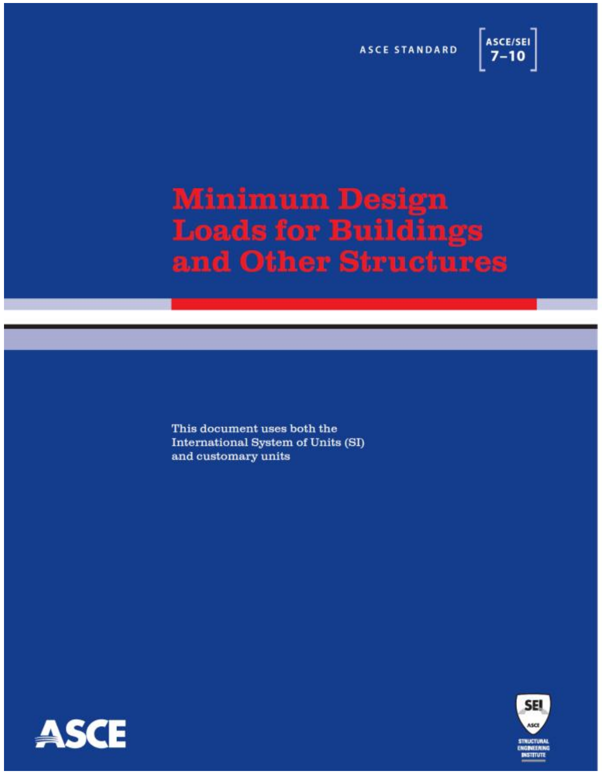
میراگرهای اصطکاکی

- **مزایا:**
  - ساخت راحت،
  - قیمت نسبتاً پایین،
  - اتلاف انرژی زیاد طی هر چرخه،
  - عدم وابستگی به حرارت.

- **معایب:**
  - نیاز به نگهداری در طول زمان،
  - اضافه کردن سختی اولیه بسیار زیاد به سیستم،
  - امکان ایجاد تغییرمکان های ماندگار،
  - فعال شدن تنها در یک سطح خطر،
  - امکان نیاز به بازنگری و تعویض قطعات پس از زلزله های شدید.

آیین نامه ها، استانداردها و ضوابط مرتبط

ASCE 7-10



Chapter 17
SEISMIC DESIGN REQUIREMENTS FOR SEISMICALLY ISOLATED STRUCTURES

17.1 GENERAL

Every seismically isolated structure and every portion thereof shall be designed and constructed in accordance with the requirements of this section and the applicable requirements of this standard.

17.1.1 Variations in Material Properties

The analysis of seismically isolated structures, including the substructure, isolators, and superstructure, shall consider variations in seismic isolator material properties over the projected life of the structure including changes due to aging, contamination, environmental exposure, loading rate, scragging, and temperature.

EFFECTIVE STIFFNESS: The value of the lateral force in the isolation system, or an element thereof, divided by the corresponding lateral displacement.

ISOLATION INTERFACE: The boundary between the upper portion of the structure, which is isolated, and the lower portion of the structure, which moves rigidly with the ground.

ISOLATION SYSTEM: The collection of structural elements that includes all individual isolator units, all structural elements that transfer force between elements of the isolation system, and all connections to other structural elements. The isolation system also includes the wind-restraint system, energy-dissipation devices, and/or the displacement restraint system if such systems and

Chapter 18
SEISMIC DESIGN REQUIREMENTS FOR STRUCTURES WITH DAMPING SYSTEMS

18.1 GENERAL

18.1.1 Scope

Every structure with a damping system and every portion thereof shall be designed and constructed in accordance with the requirements of this standard as modified by this section. Where damping devices are used across the isolation interface of a seismically isolated structure, displacements, velocities, and accelerations shall be determined in accordance with Chapter 17.

18.1.2 Definitions

The following definitions apply to the provisions of Chapter 18:

DAMPING DEVICE: A flexible structural

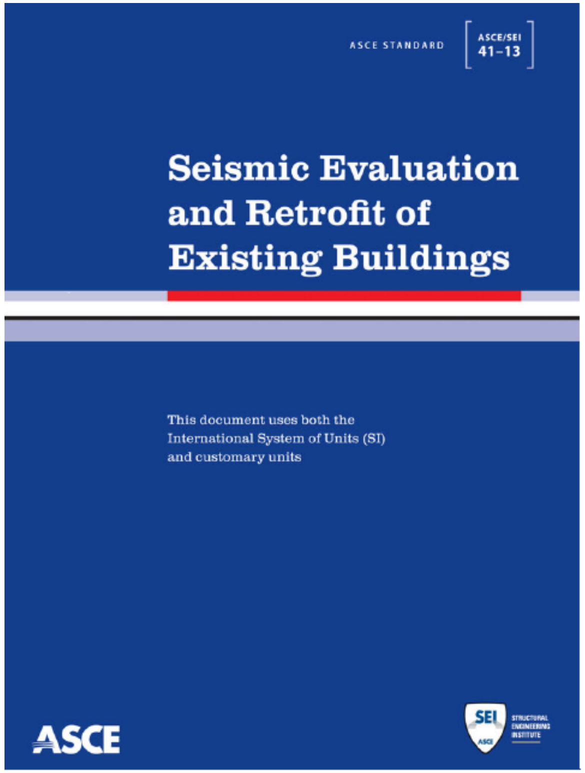
18.1.3 Notation

The following notations apply to the provisions of this chapter:

B_{1D} = numerical coefficient as set forth in Table 18.6-1 for effective damping equal to β_{ml} (m = 1) and period of structure equal to T_{1D}
B_{1E} = numerical coefficient as set forth in Table 18.6-1 for the effective damping equal to $\beta_I + \beta_{V1}$ and period equal to T_1
B_{1M} = numerical coefficient as set forth in Table 18.6-1 for effective damping equal to β_{mM} (m = 1) and period of structure equal to T_{1M}
B_{mD} = numerical coefficient as set forth in Table 18.6-1 for effective damping equal to β_{ml} and period of structure equal to T_m

- **Analyzing of Systems**
- **Designing of New Structures**
- **Testing of Isolator Units**

ASCE 41-13



CHAPTER 14
SEISMIC ISOLATION AND ENERGY DISSIPATION

14.1 SCOPE

This chapter sets forth requirements for the systematic evaluation and retrofit of buildings using seismic isolation and energy dissipation systems. Section 14.2 provides analysis and design criteria for seismic isolation systems. Section 14.3 provides analysis and design criteria for passive energy dissipation systems. Section 14.4 provides criteria for other control systems. Any of the Performance Objectives are permitted for seismic isolation and passive energy dissipation retrofits.

Whenever either the Reduced Performance Objective of Section 2.2.3.1 or the Partial Retrofit Objective of Section 2.2.3.2 is selected, the devices must be able to achieve performance responses larger than those used for the Reduced Performance Objectives.

Components and elements in buildings with seismic isolation and passive energy dissipation systems shall also comply with the requirements of Chapters 1 through 13 of this standard, unless they are modified by the requirements of this chapter. Independent design review is required for all retrofit schemes that use either seismic isolation or energy dissipation systems.

C14.1 SCOPE

The basic form and formulation of requirements for seismic isolation and passive energy dissipation systems have been established and coordinated with the performance objectives, target Building Performance Levels, and Seismic Hazard Level criteria of Chapter 2 and the linear and nonlinear procedures of Chapter 7.

Criteria for modeling the stiffness, strength, and deformation properties of conventional structural components of buildings with seismic isolation or passive energy dissipation systems are given in Chapters 9 through 12.

Limited guidance for other special seismic protective systems, including active control systems, hybrid active and passive systems, and tuned mass and liquid dampers, is provided in this chapter. Seismic isolation and passive energy dissipation systems are viable design strategies that have been used for seismic retrofit of a number of buildings. Other special seismic protective systems—including active control, hybrid combinations of active and passive energy devices, and tuned mass and liquid dampers—may also provide practical solutions in the near future. These systems are similar in that they enhance performance during an earthquake by modifying the building's response characteristics.

Seismic isolation and passive energy dissipation systems may not be appropriate design strategies for buildings that have only Limited Performance Objectives. In general, these systems are most applicable to the retrofit of buildings whose owners desire superior earthquake performance and can afford the special costs associated with the design, fabrication, and installation of seismic isolators and/or passive energy dissipation devices. These costs are typically offset by the reduced need for stiffening and strengthening measures that would otherwise be required to meet Performance Objectives.

Seismic isolation and passive energy dissipation systems include a wide variety of concepts and devices. In most cases, these systems and devices are implemented with some additional conventional strengthening of the structure; in all cases, they require evaluation of existing building components. As such, this chapter supplements the requirements of other chapters of this document with additional criteria and methods of analysis that are appropriate for buildings retrofitted with seismic isolators and/or passive energy dissipation devices.

Conceptually, isolation reduces response of the superstructure by decoupling the building from the ground. Typical isolation systems reduce forces transmitted to the superstructure by lengthening the period of the building and adding some amount of damping.

Added damping is an inherent property of most isolators, but it may also be provided by supplemental passive energy dissipation devices installed across the isolation interface. Under favorable conditions, the isolation system can reduce drift in the superstructure by a factor of at least two—and sometimes by as much as a factor of five—from that which would occur if the building were not isolated. Accelerations are also reduced in the structure, although the amount of reduction depends on the force-deflection characteristics of the isolators and may not be as significant as the reduction of drift. Reduction of drift in the superstructure protects structural components and elements, as well as nonstructural components sensitive to drift-induced damage. Reduction of acceleration protects nonstructural components that are sensitive to acceleration-induced damage.

Passive energy dissipation devices add damping (and sometimes stiffness) to the building. A wide variety of passive energy dissipation devices are available, including viscous fluid dampers, viscoelastic materials, and hysteretic devices. Ideally, passive energy dissipation devices dampen earthquake excitation of the structure that would otherwise cause higher levels of response and damage to components of the building. Under favorable conditions, passive energy dissipation devices can reduce drift of the structure by a factor of up to three (if no stiffness is added) and by larger factors if the devices also add stiffness to the structure. Passive energy dissipation devices also reduce force in the structure—provided the structure is responding nearly elastically—but are not expected to significantly reduce force in structures that are responding beyond yield, resulting in structural damage.

Seismic Evaluation and Retrofit of Existing Buildings 303

- **Modeling & Analyzing of Systems**
- **Retrofitting of Existing Buildings**
- **Testing of Isolator Units**

EN 15129-2009

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 15129

November 2009

ICS 91.120.25

English Version

Anti-seismic devices

Dispositifs anti-sismiques | Erdbebenvorrichtungen

This European Standard was approved by CEN on 19 September 2009.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN Management Centre or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the CEN Management Centre has the same status as the official versions.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

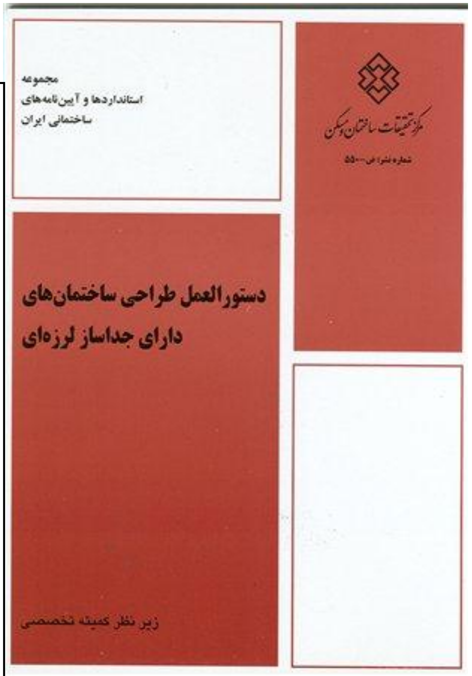
Management Centre: Avenue Marnix 17, B-1000 Brussels

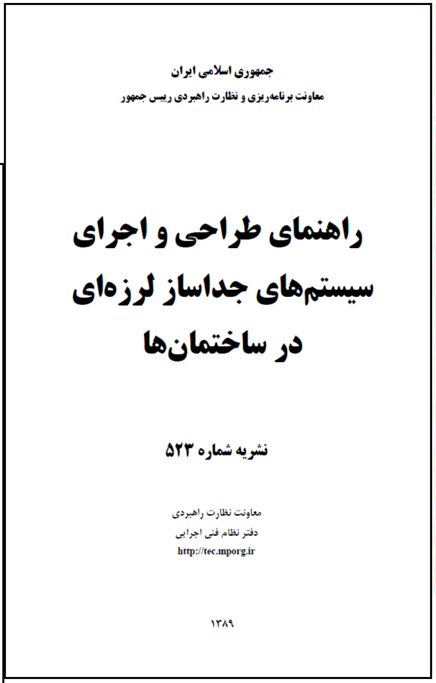
Ref. No. EN 15129:2009: E

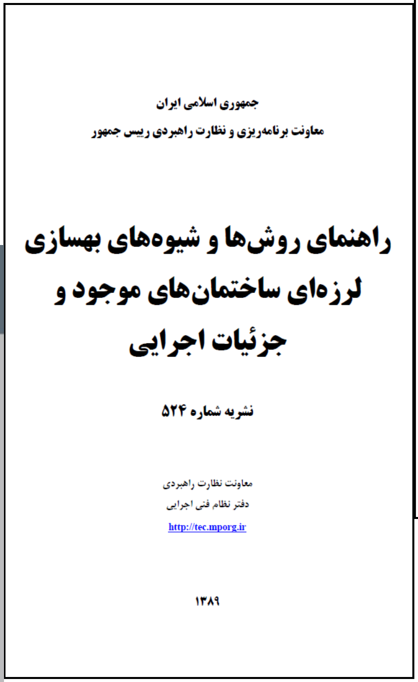
UNI EN 15129:2009

- **General Design Rules of Systems**
- **Testing Requirements of Systems**

آیین نامه ها، استانداردها و ضوابط مرتبط







Design Objectives of Base Isolation Provisions

- **Minor and Moderate Earthquakes:**
  - **No damage to structural elements**
  - **No damage to nonstructural components**
  - **No damage to building contents**

- **Major Earthquakes:**
  - **No failure of isolation system**
  - **No significant damage to structural elements**
  - **No extensive damage to nonstructural components**
  - **No major disruption to facility function**

General Design Approach for Base Isolation

- **EQ for Superstructure Design:**
  - **Design Base Earthquake**
  - **10%@50 yr = 475-yr return period**
  - **Loads reduced by up to a factor of 2 to allow for limited Inelastic response**
- **EQ for Isolation System Design:**
  - **Maximum Considered Earthquake**
  - **2%@50 yr = 2475-yr return period**
  - **No force reduction permitted for design of isolation system**

Required Tests of Isolation System

- **Prototype Tests:**
  - **Prototype tests shall be performed separately on two full-size specimens (or sets of specimens, as appropriate) of each predominant type and size of isolator unit of the isolation system**
  - **MCE Level**

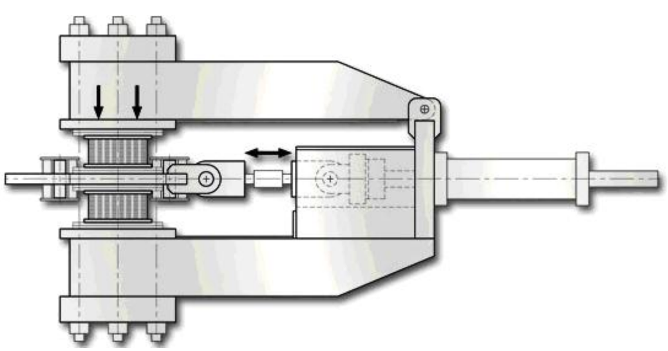
All isolators work as a single system

- **Production Testing:**
  - **Quality control**
  - **DBE Level**

Prototype Tests of Isolation System

- Check Wind Effects
  - 20 fully reversed cycles at force corresponding to wind design force
- Establish Displacement-Dependent Effective Stiffness and Damping
  - 3 fully reversed cycles at $0.25D_D$
  - 3 fully reversed cycles at $0.5D_D$
  - 3 fully reversed cycles at $1.0D_D$
  - 3 fully reversed cycles at $1.0D_M$
  - 3 fully reversed cycles at $1.0\ D_{TM}$
- Check Stability
  - Maximum and minimum vertical load at $1.0\ D_{TM}$
- Check Durability
  - $30S_{D1}B_D/S_{DS}$, but not less than 10, fully reversed cycles at $1.0\ D_{TD}$

For cyclic tests, bearings must carry specified vertical (dead and live) loads



Prototype Tests of Isolation System

Fire Prevention of Isolators

۵-۱۲- مقاومت در برابر آتش

این قطعات باید با رعایت ضوابطی مشابه آنچه برای تیرها و ستون ها تدوین شده در مقابل آتش محافظت شوند.

Rubber Bearing

Sliding Bearing

System Property Modification Factor

۵-۱۱- طراحی بر اساس شرایط محیطی

اجزای سامانه‌ی جداسازی باید برای عوامل محیطی مانند تغییرات ناشی از گذشت زمان، خزش، خستگی، دما، رطوبت یا مواد خارجی مخرب، احتمال خوردگی و زنگ‌زدگی، اتصال بین لایه‌های جداسازهای اصطکاکی و مانند این موارد طراحی شوند.

Upper- and Lower-Bound Design and Analysis

$$\lambda_{\min} = 1.0$$

$$\lambda_{\max} = \lambda_a . \lambda_t . \lambda_v . \lambda_c . \lambda_{tr} . \lambda_{scrag}$$

Table C14-1. Upper-Bound Multiplier Using AASHTO Lambda Factors

Variable	Unlubricated PTFE (μ)	Lubricated PTFE	Plain Elastomerics (K)	Lead Rubber (K2)
Aging (λ_a)	1.2	1.4	1.1	1.1
Velocity (λ_v)[a]	[b]	[b]	1	1
Contamination (λ_c)	1.1	1.1	1	1
Temperature (λ_t)	1.1	1.3	1.1	1.1
Scragging (λ_{scrag})[c]	1	1	1	1
Assumed lambda factor for first-cycle effect	1.10	1.10	1.10	1.10
Multiple of all lambda factors	1.60	2.20	1.33	1.33
Upper-bound with 0.67 SPAF	1.40	1.81	1.22	1.22
Lambda factor for specification tolerance	1.10	1.10	1.10	1.10
Upper-bound multiplier, including specification tolerance with 0.67 SPAF	1.54	1.99	1.34	1.34

Design Objectives of Passive Energy Dissipation System

- **Philosophy:**
  - **For DBE, confine inelastic behavior to dampers**
  - **Performance objective identical to conventional structural system**
- **Minimum Provisions:**
  - **At least two device per story in each principal direction,**
  - $$V_{min} = max\left\{ \frac{V}{B_{V+I}};\ 0.75V \right\}$$

Minimum base shear for design of structure without EDS

Minimum base shear for design of seismic force resisting system

Spectral reduction factor based on the sum of viscous and inherent damping

Required Tests of Damper

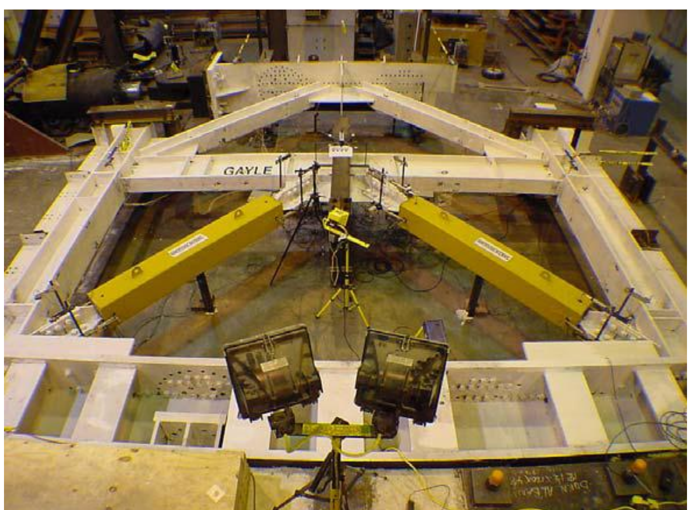
- **Prototype Tests:**
  - **The force-velocity displacement and damping properties used for the design of the damping system shall be based on the prototype tests.**
- **Production Testing:**
  - **Prior to installation in a building, damping devices shall be tested to ensure that their force-velocity-displacement characteristics fall within the limits set by the registered design professional responsible for the design of the structure.**

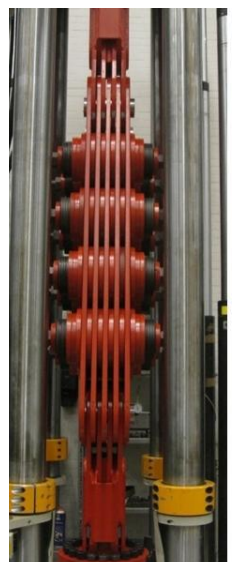
Prototype Tests of Dampers

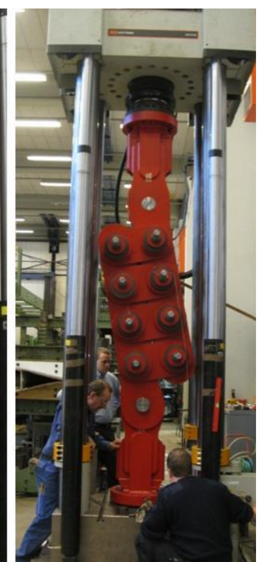
- **Prototype Tests on at least two full-size Dampers**

(unless prior testing has been documented)

- **200 fully reversed cycles corresponding to wind forces**
- **50 fully reversed cycles corresponding to DBE**
- **10 fully reversed cycles corresponding to MCE**







Prototype Tests of Dampers

نمونه هایی از کاربرد سیستم های

کنترل لرزه ای در جهان

نمونه هایی از کاربرد سیستم های کنترل لرزه ای در جهان

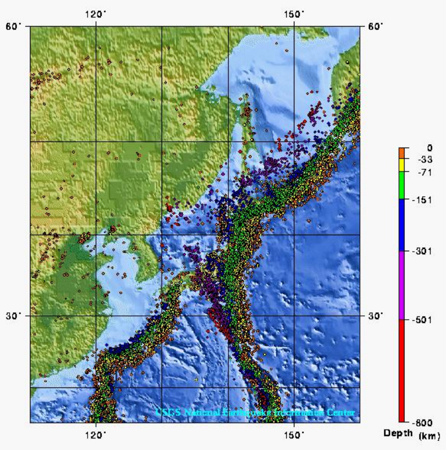
Brief History of Seismic Isolation Systems

- **1885: John Milne: built a base isolated house in Japan**

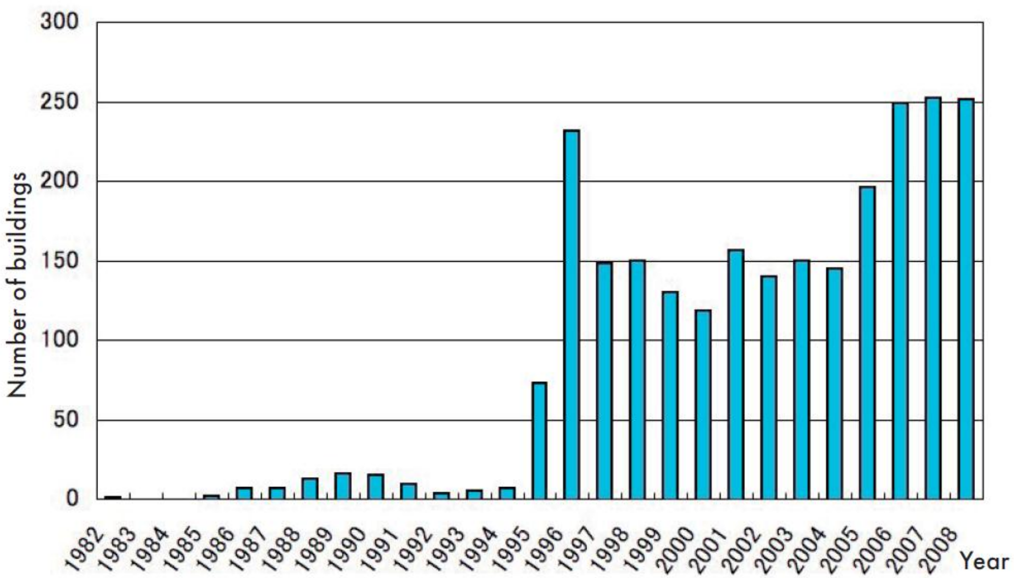
- **1909: J.A. Calantarients (MD) filed a patent in England for lubricated "free joints" on a layer of fine material**
- **1969: first rubber isolation of 3-story reinforced concrete elementary school building in Skopje, Yugoslavia**
- **1970 – present: wide spread worldwide applications (elastomeric bearings, high damping rubber bearings, lead-rubber bearings, metallic bearings, lead-extrusion bearings and friction pendulum bearings)**

Application of Seismic Isolation - Japan

- ~ 5000 isolated buildings in Japan
- Applications spurred by 1995 Kobe EQ
- Commercial and residential use
- Small homes to High rises



Trends in planned number of seismically isolated buildings by year from 1982 to 2008

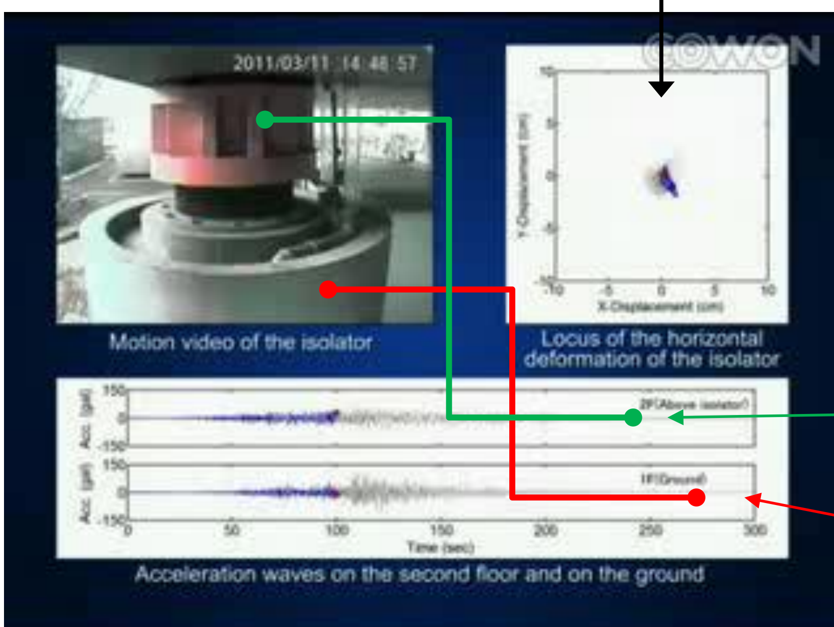


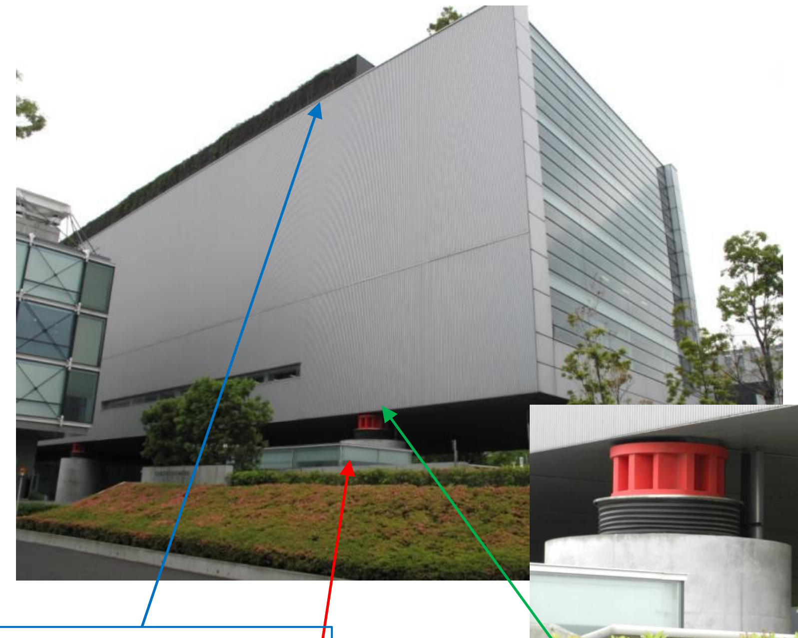
Source: Japan Society of Seismic Isolation

Main Building at the Shimizu Institute of Technology

- **The Wind Tunnel Testing Facility is constructed on a seismic isolation system.**
- **During Tohoku Earthquake:**

Maximum displacement of the isolation system = ~ 9 cm





Roof PA= 0.073g

above the isolation system PA= 0.07g

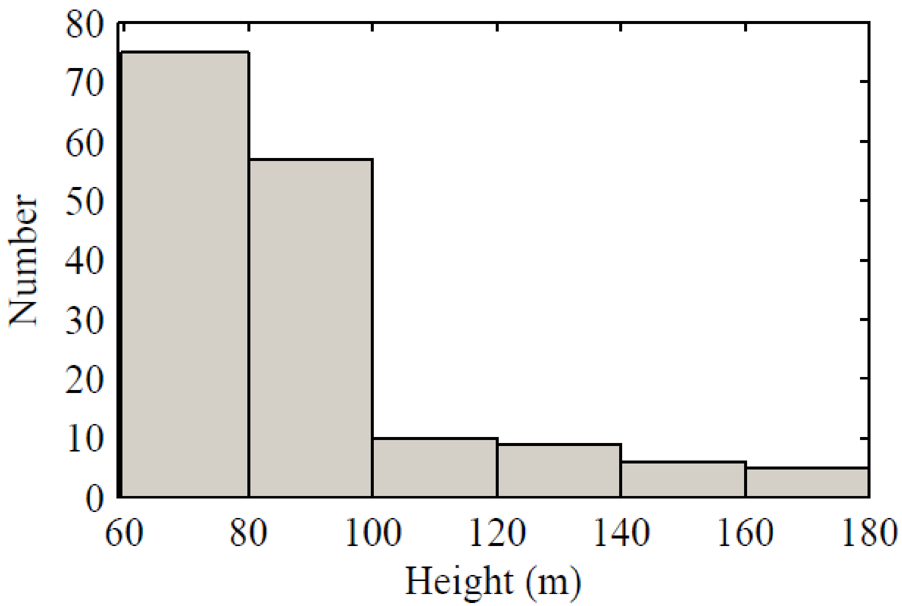
PGA = 0.135g

High-rise Isolated Buildings in Japan

- **Public demand and market for seismic protection**

Earthquake awareness based on historical seismicity

Reducing the cost of Repairing and Insurance



Heights of constructed isolated high-rises in Japan between 2000 and 2012

High-rise Isolated Buildings in Japan

- For the most part these buildings have concrete superstructures; less than 10% of constructed isolated high-rises are steel.
- Isolation systems are typically natural rubber bearings in combination with either high damping rubber bearings or lead plug rubber bearings.
- Flat sliding bearings or linear rolling bearings are sometimes used in the isolation systems along with rubber bearings to elongate the period of the isolation system.
- Additional damping is often provided with steel U dampers, viscous dampers or a combination of damping devices.

Yozemi Tower, Shinjuku, Tokyo

- **This Building incorporates 25 RBs and 24 PTFEs + 12 passive and 12 semi active oil dampers.**
- **During Tohoku Earthquake:**
- **The maximum isolation system displacement = 10 cm.**

27 Stories above Isolation level

Tokyo Institute of Technology Building J2

- **This Building incorporates 16 RBs + 14 yielding dampers and 2 oil dampers.**
- **During Tohoku Earthquake:**
- **The maximum isolation system displacement = 12.5 cm**

Top Story PA = 0.118g

Top of Isolators PA = 0.071g

PGA=0.07g

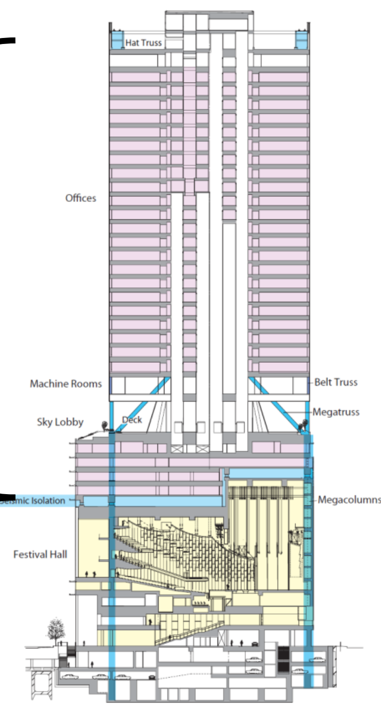
Total Height = 91 m
Plan Dim.=18×46 m

Nakanoshima Festival Tower

- LRBs and oil dampers are installed on the seismic isolation floor of this building,
- Two sets of square-shaped LRBs, at 1500 millimeters long (the largest in Japan), are joined together to support the mega columns.

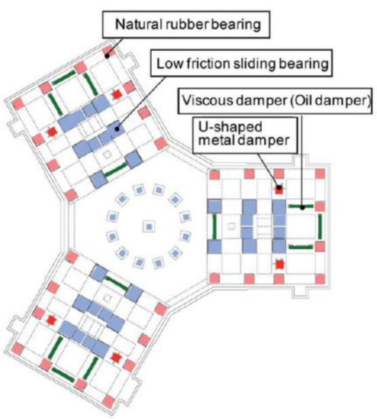
Height above BI = 155m

Height below BI = 45m



Island Tower Sky Club

- **NRB + low friction sliding bearing + oil damper are installed at the base of building.**

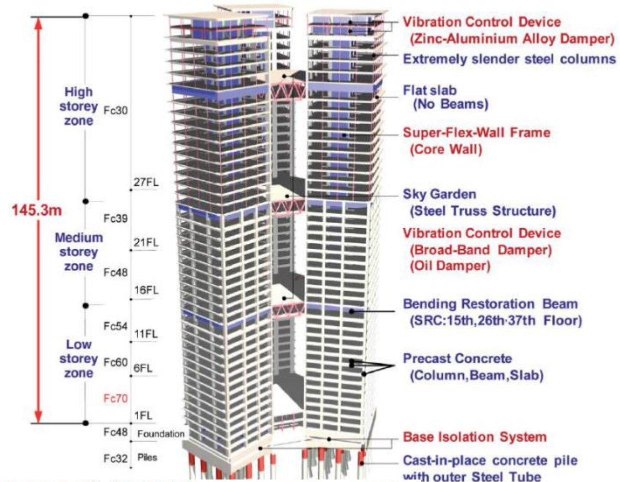


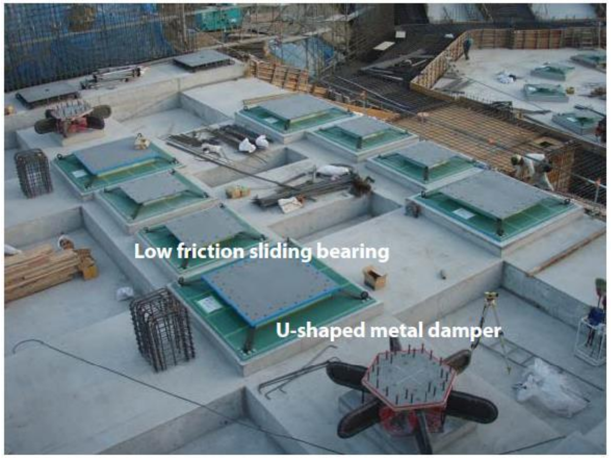
Explanatory notes for isolation material

Natural rubber bearing		
Name	Sign	Num.
NRB1300		18
NRB1400		12

Low friction sliding bearing		
Name	Sign	Num.
SSRR450		12
SSRR700		1
SSRS800		6
SSRS900		6
SSRS1400		12
SSRS1600		6

Isolation damper		
Name	Sign	Num.
Viscous damper		12
Metal damper		6
Displacement memory		3





Application of Seismic Isolation - USA

- ~300 isolated buildings
- Specialized applications, limited to essential buildings and historic retrofits in high seismic zones
- Designed for higher performance standards
- 5-10% increased construction cost impediment to ordinary structures

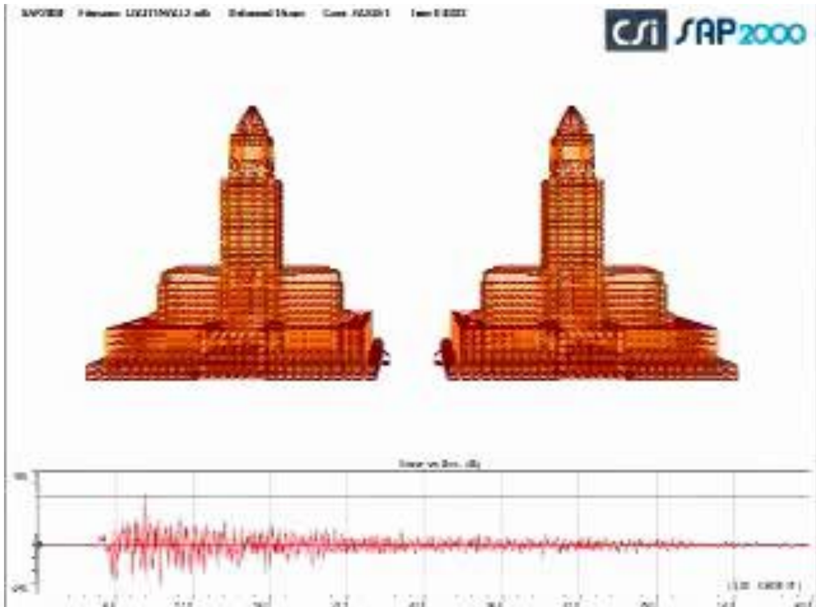
San Francisco City Hall
Lead-Rubber Bearings

Stanford hospital

Mills-Peninsula Health Services New Hospital

- **Total Area = 41,800 m^2**
- **The 176 bearings are installed between the foundation and the columns of the building and allow the decoupled structure to move ~750 mm in any direction during an earthquake.**

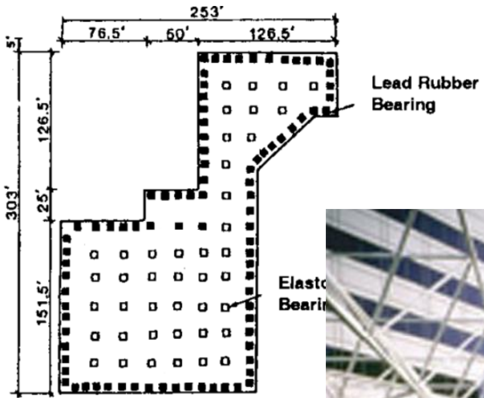
Retrofit Project Los Angeles City Hall

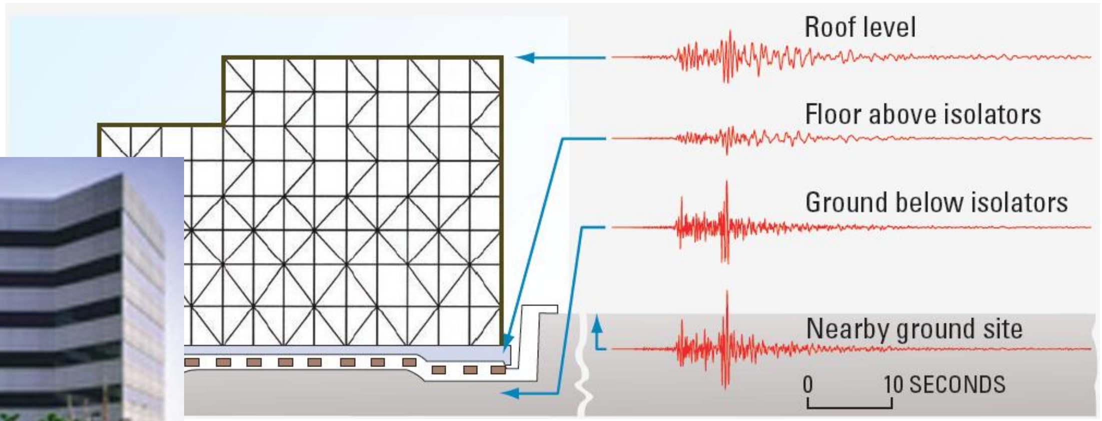


- **محل پروژه:** کالیفرونیا
- **مساحت پروژه** (m^2)**:** ۸۵۰۰۰
- **تعداد طبقات:** ۳۲
- **تاریخ ساخت:** ۱۹۲۶
- **تاریخ مقاوم سازی:** ۲۰۰۱
- **سیستم مورد استفاده:**
  میراگر **ویسکوز + جداگر لرزه ای**
- **هزینه مقاوم سازی:** ۲۴۰ میلیون دلار

Performance in 1994 Northridge EQ

- **USC University Hospital in Los Angeles is constructed in 1991.**
  - **8-story steel superstructure supported by 149 elastomeric isolators,**
  - **Reduced accelerations by 66% at the base and 40% at the roof.**





Application of Seismic Isolation – New Zealand

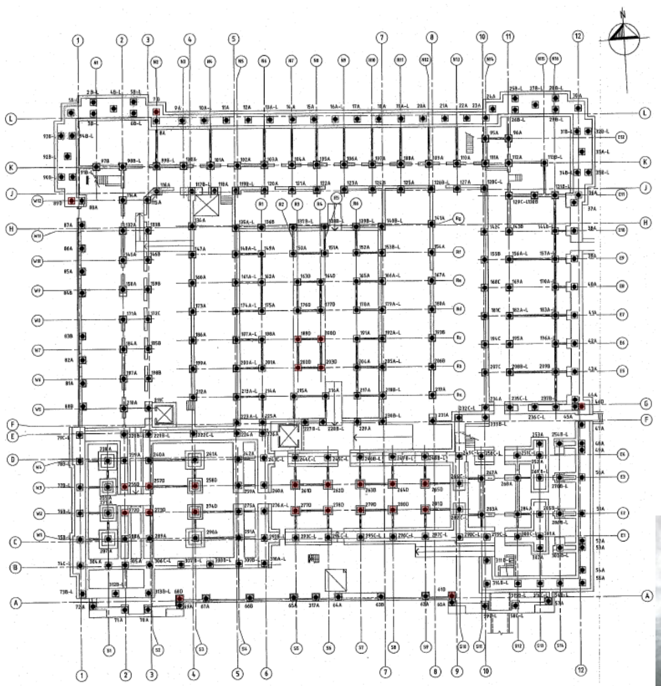
- **The seismically isolated buildings fall into two broad categories:**
- **fragile structures of historic significance**
- **new structures with contents which need to be protected.**

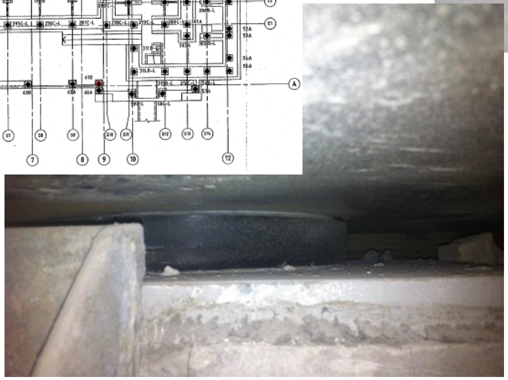
Christchurch Women's Hospital
LRB + Slider

Supreme Court of New Zealand
LRB + Slider

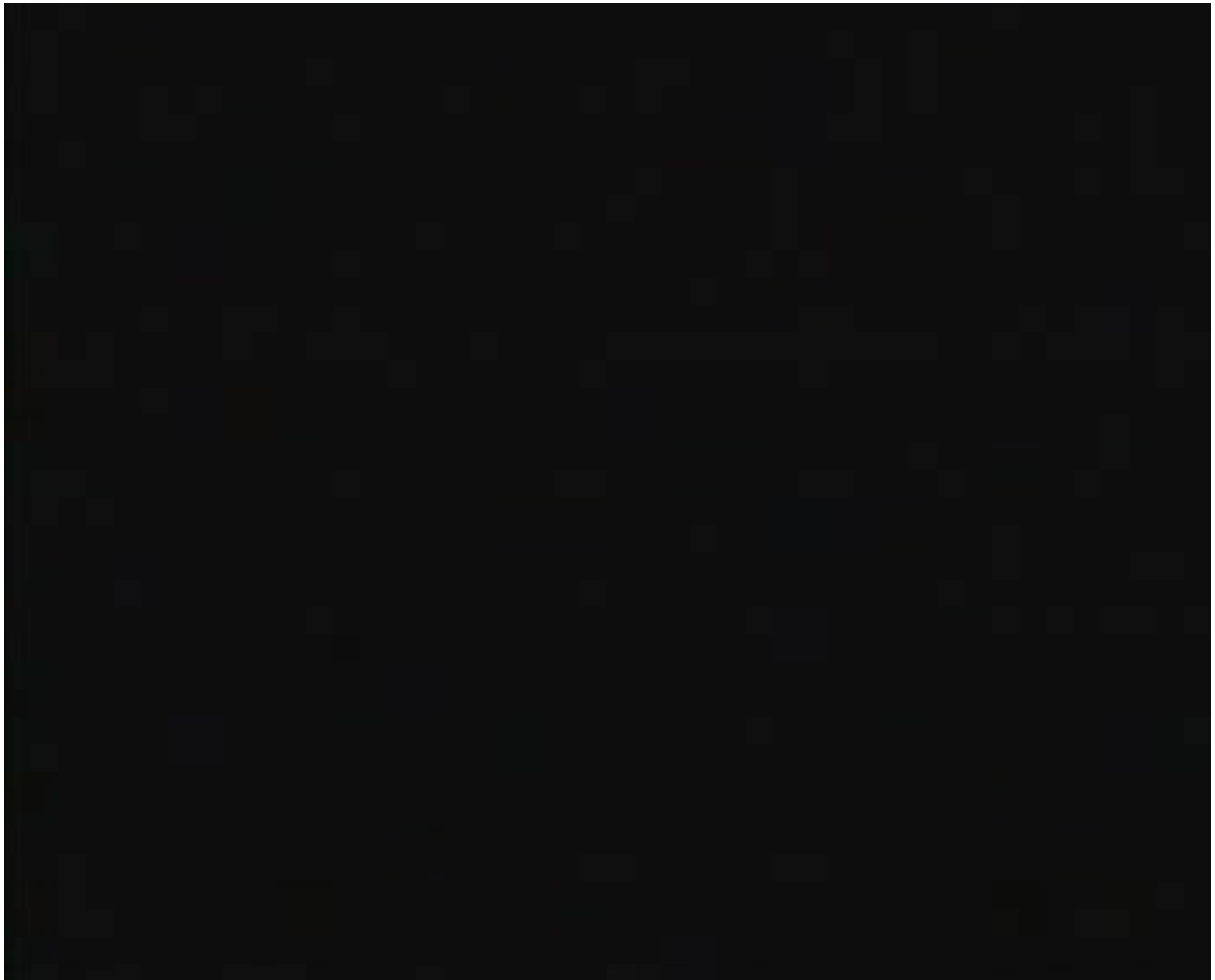
Retrofit of Parliament Buildings, Wellington

- **Historic buildings dating from 1883, of total area 40,000m^2**
- **Project Cost: $170 million**

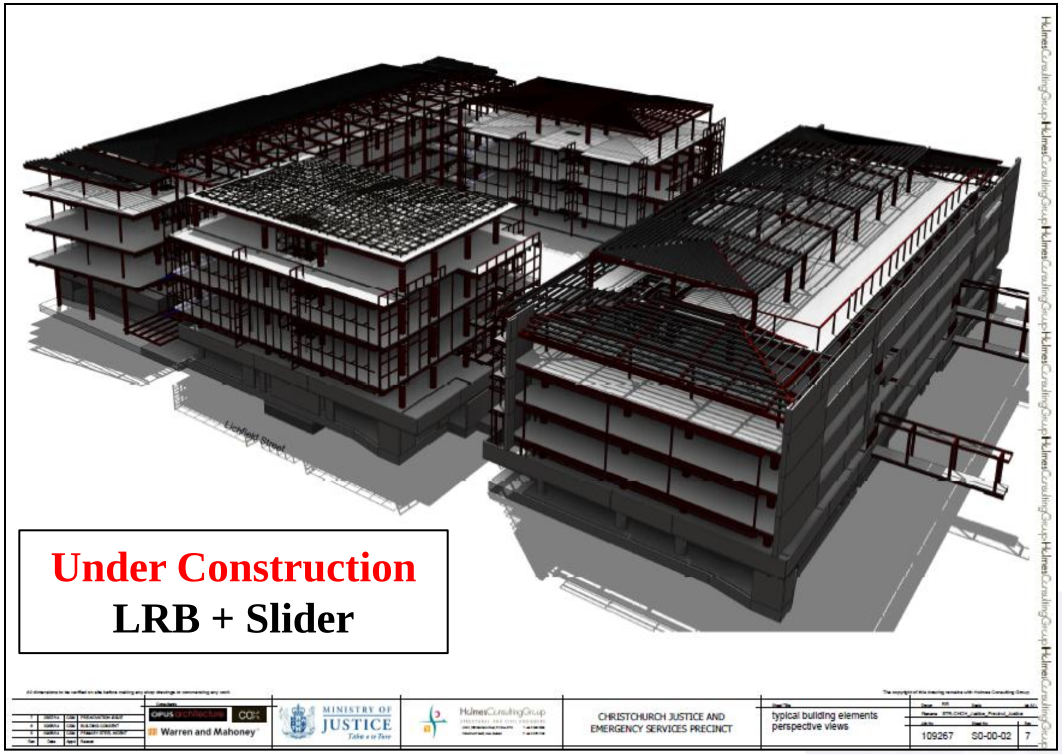


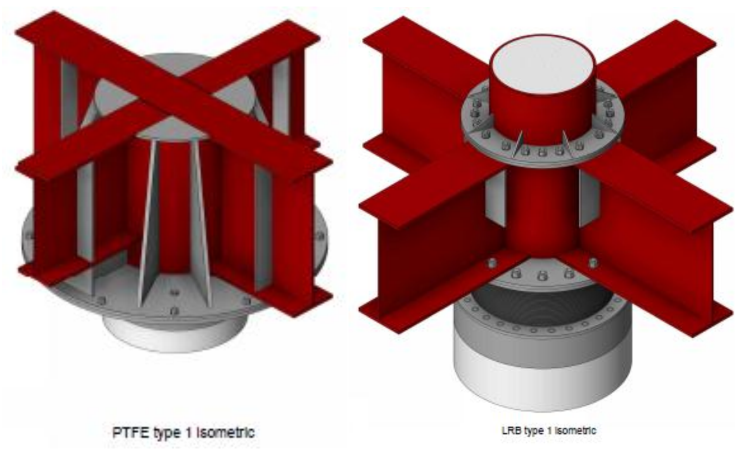


Retrofit of Parliament Buildings, Wellington



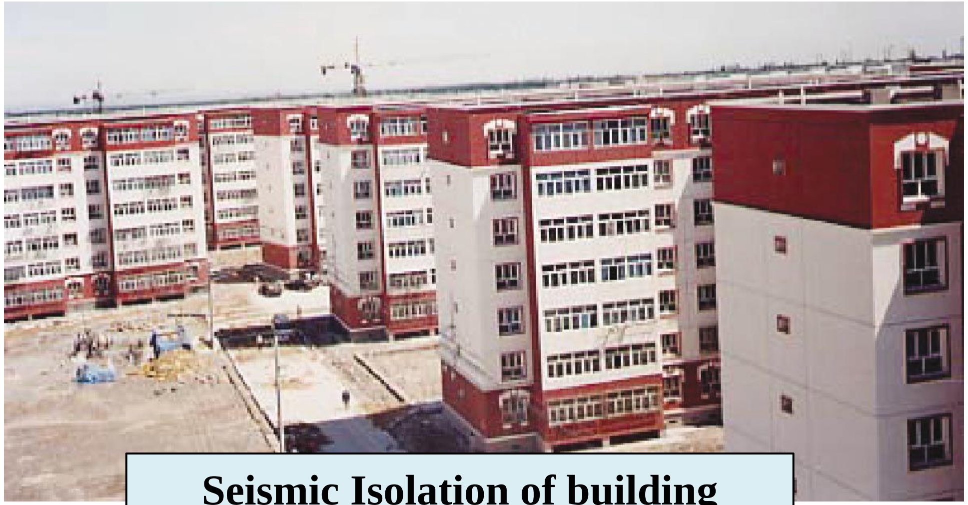
Christchurch Justice & Emergency Services Precinct



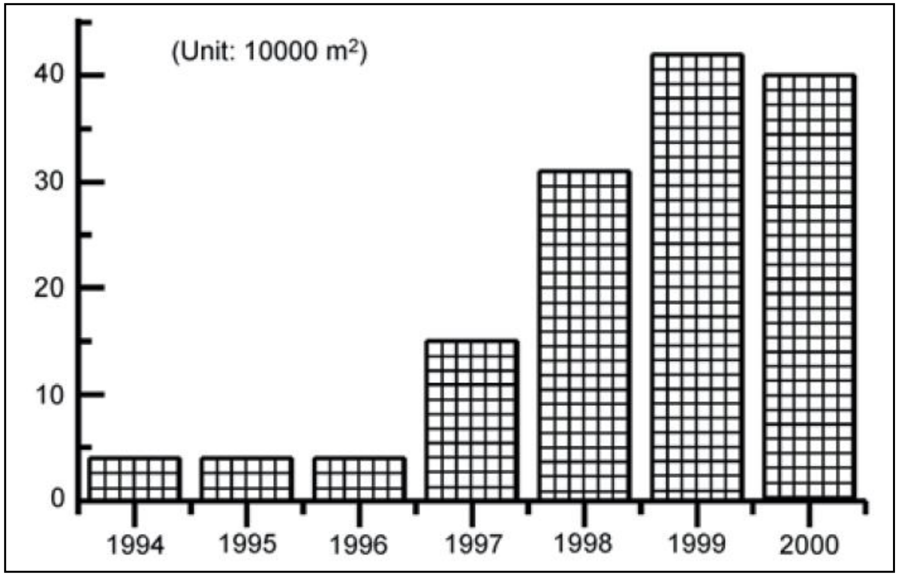


Application of Seismic Isolation – China

- ~ 600 isolated buildings
- Applications slowly started in 1993 and increase in 1997
- Potential for significant increase in use following 2008 Wenchuan Earthquake
- Highest isolated structure is 20 stories

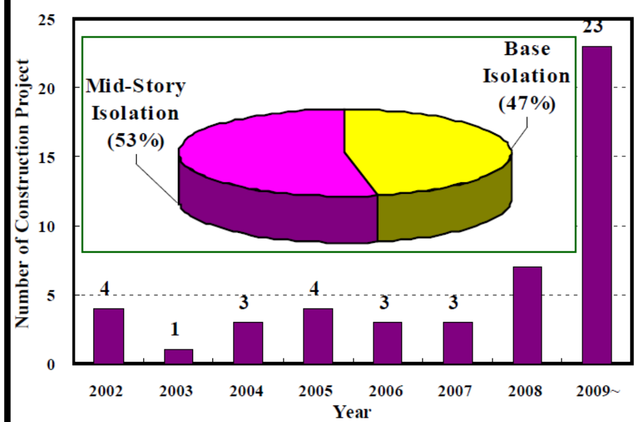


Seismic Isolation of building group in Beijing



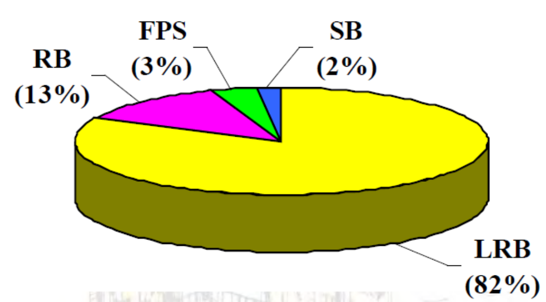
Application of Seismic Isolation – Taiwan

- ~ 50 isolated buildings
- Applications have been extensive after 1999 Chi-Chi earthquake



Number of Construction Project

- 48 construction projects



Commonly Used Seismic Isolator

1. Lead Rubber Bearing (LRB)
2. Friction Pendulum Syster
3. Rubber Bearing (RB)
4. Sliding Bearing (SB)

Story Number

Emergency Operations Center of Taipei City

- 7story RC (and Precast RC) structure
- Isolation system is installed at Ground
- Isolation System –36 LRB

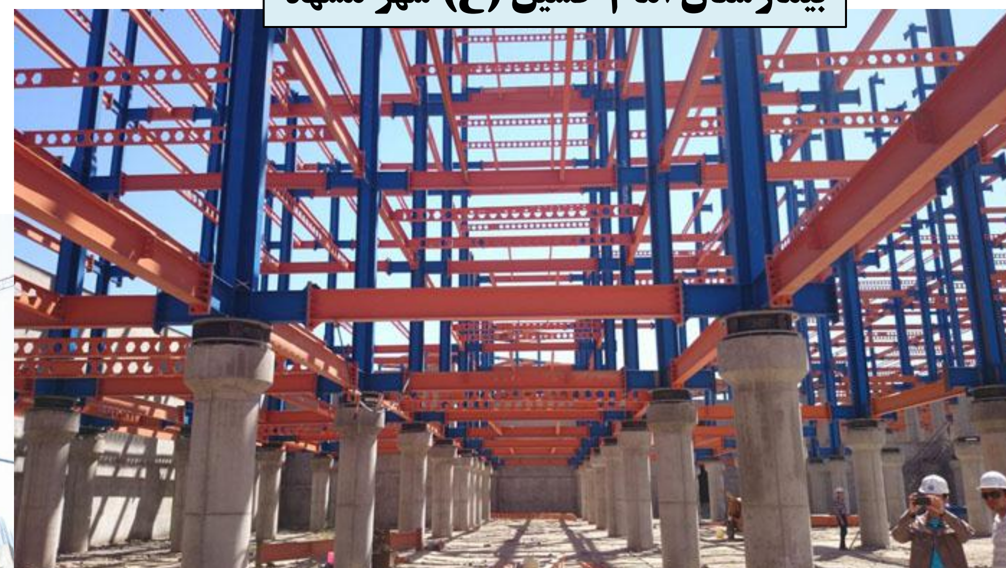
21 stories Apartment, Taipei

Structure	A	B
LRB install	16 sets	16sets
Total Height	58.6m	71.0m
FL area above ground	8206m2	5232m2
Length x Width (Column center to center)	27.2m x 21.77m	26.0m x 19.61m

کاربرد جداگر لرزه ای در ایران

- کمتر از ۱۰ ساختمان!؟

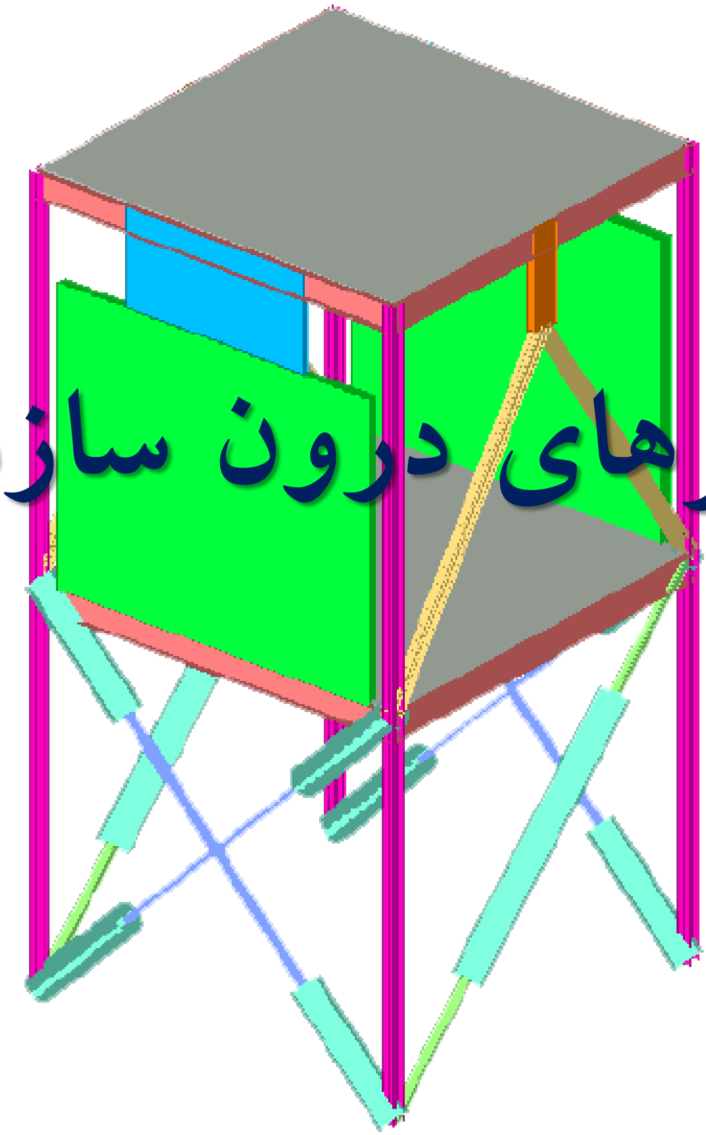
بیمارستان امام حسین (ع) شهر مشهد



مدیریت بحران شهر تربت حیدریه

ساختمان مسکونی در تهران

میراگرهای درون سازه ای

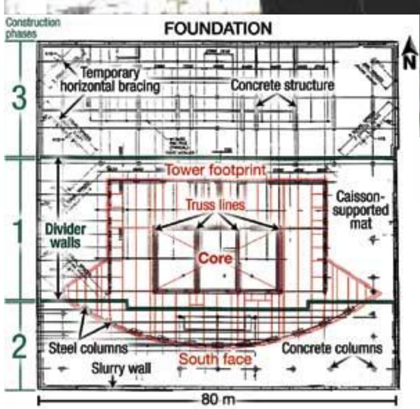


Brief History of Supplemental Damping Systems

- **Development more recent than base isolation systems**
- **1956: Pioneering work by G. Housner on energy in earthquake engineering**
- **1969-1972: Development of early metallic dampers in New Zealand and Japan**
- **1981: First application of hysteretic dampers on South Rangitikei viaduct in New Zealand**
- **1980-83: Development of friction dampers in Canada**
- **1987: First application of friction dampers at the Concordia University Library in Montreal, Canada**
- **1990-1995: Development of fluid type viscous dampers at the University at Buffalo**
- **1995: First application of fluid dampers in Pacific Bell North Area Operations Center in Sacramento, California**

Torre Mayor, Mexico

- **57 story, completed in 2003**
- **24 large viscous dampers, rated at 570 tones of output force**
- **74 smaller viscous dampers, rated at 280 tones of output force**

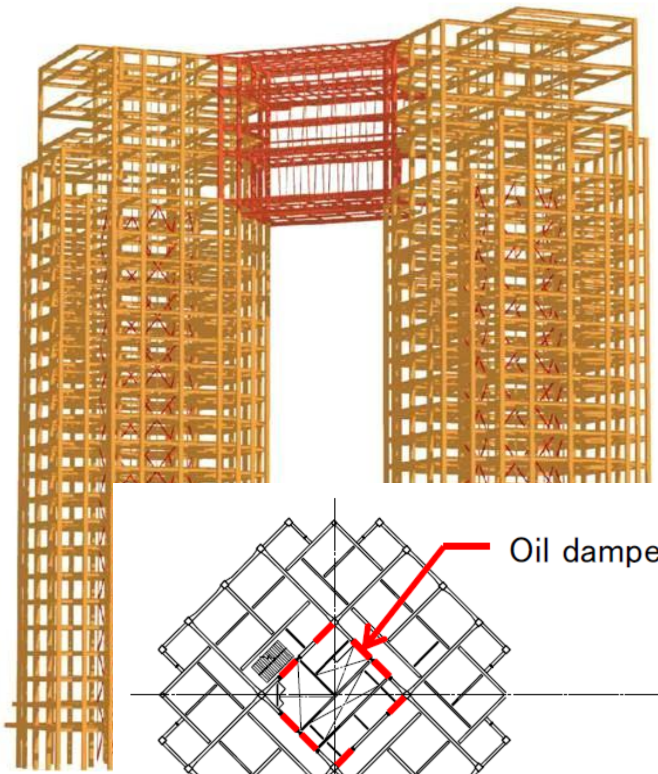


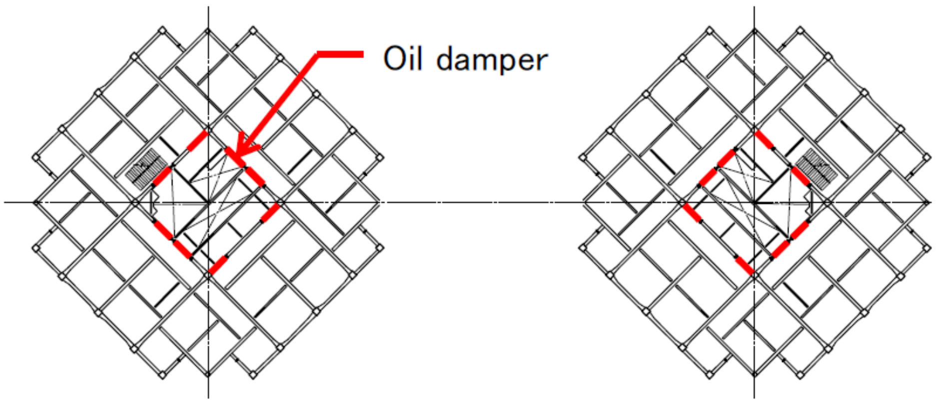
Tai-Shin Bank Headquarter, Taipei

- **New 28-story steel framed office building uses 72 viscous dampers in chevron braces for earthquake energy dissipation:**
  - **980 kN, ± 75 mm**
  - **1470 kN, ± 75 mm**
  - **1962 kN, ± 75 mm**

Tokyo Baycourt Club Hotel & Spa Resort, Japan

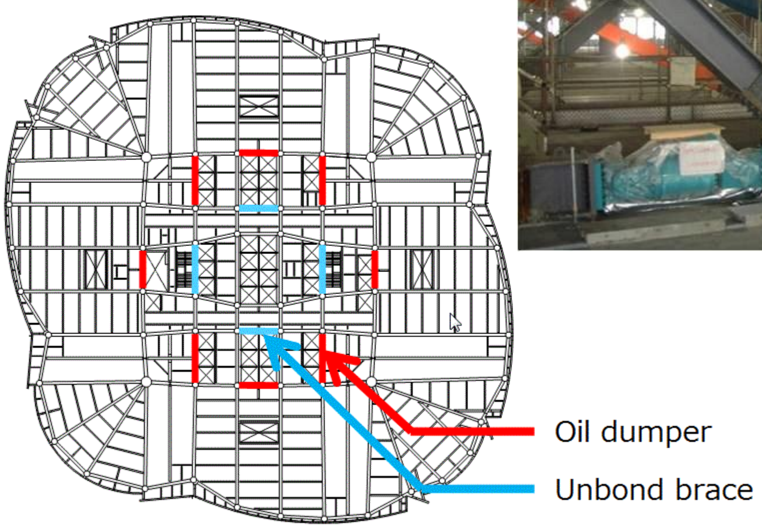
- **29-story building with total floor area 63,000 m^2 & 101.1 m height, using 336 oil (viscous) dampers in towers**

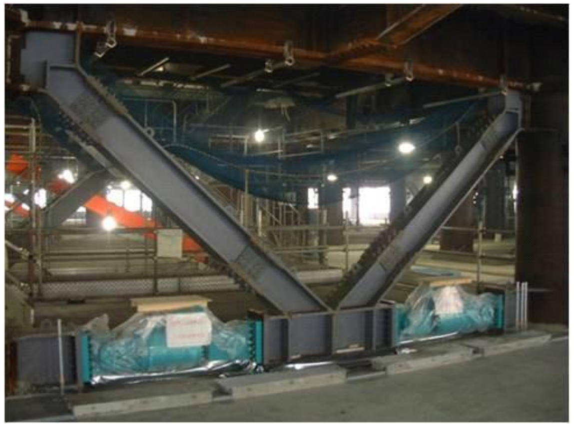


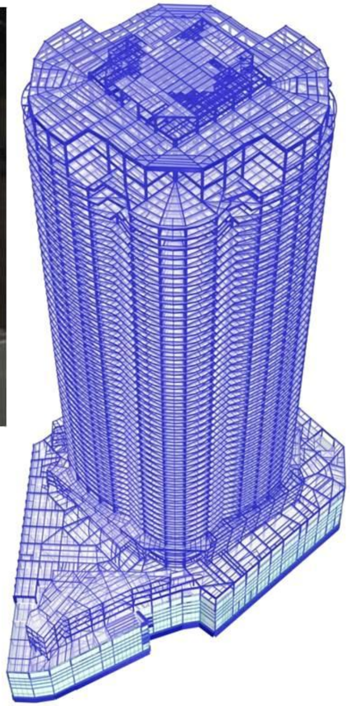


Roppongi Hills Mori Tower, Japan

- 54-story building with total floor area 380,100 m^2 & 238 m height
- Semi-active **Oil Damper** controls tremor by the flow of its oil + **Unbond Brace (BRB)**

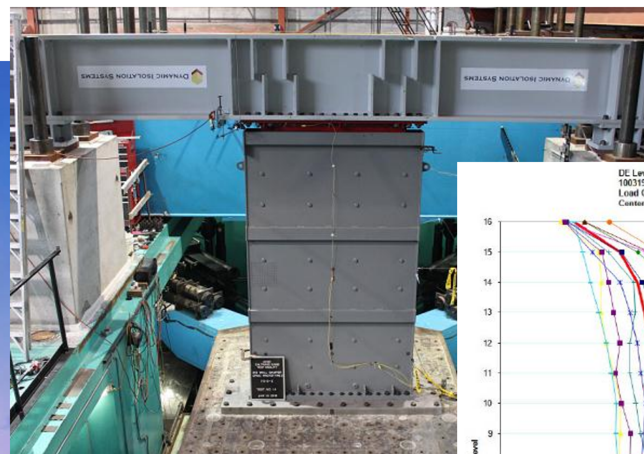


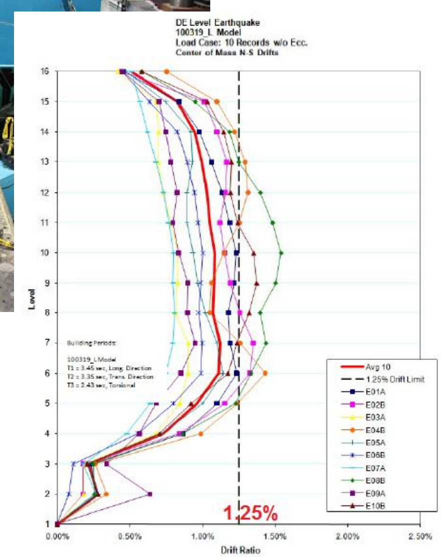




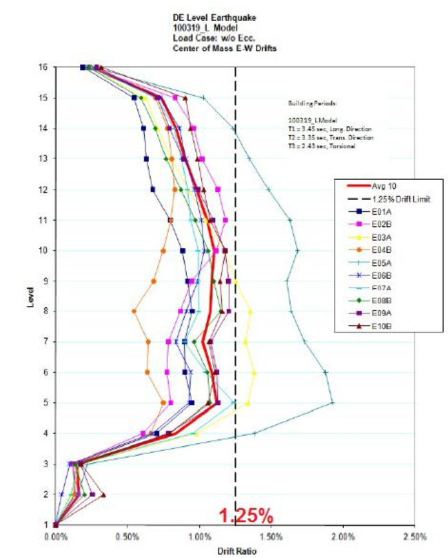
15 story hospital in San Francisco, California

- **15 Story + 2 basement high-rise hospital in San Francisco, 11 km from the San Andreas Fault**
- **Steel Moment Resisting Frame superstructure design for strength**
- **Supplemental Viscous Wall Dampers to control seismic drift**





North-South Drift Ratios



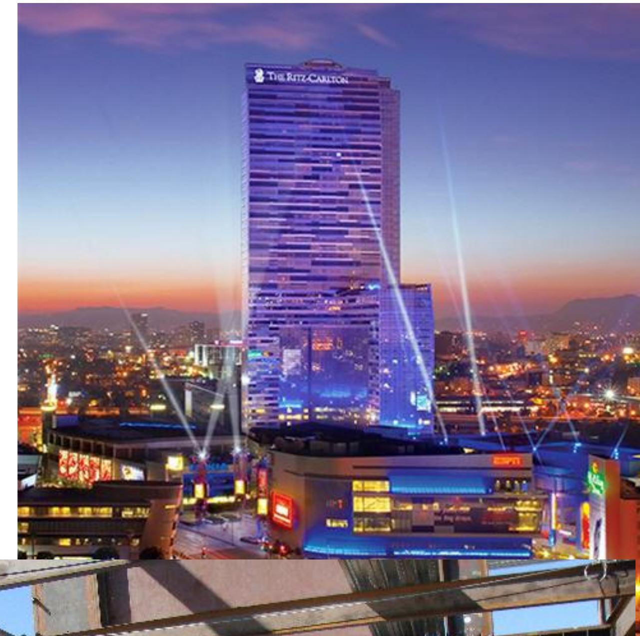
East-West Drift Ratios

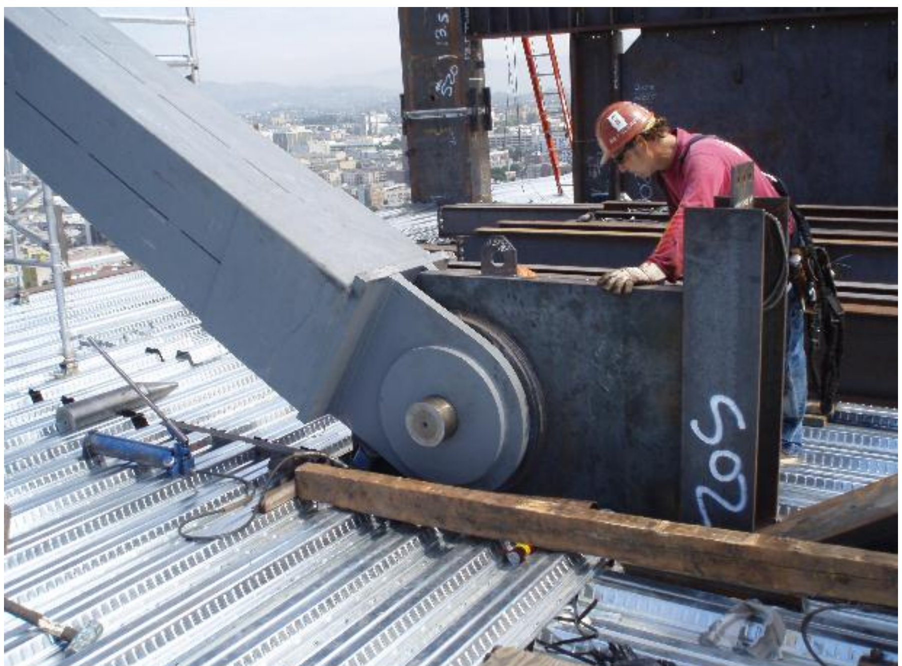
Plant and Environmental Sciences Replacement Facility

- The first application of BRBs in the US ~1998
- 3 stories with 11,600m^2 floor area
- 132 BRB with Diagonal or Chevron Brace Installation
- Cost of Dampers = 0.5% of Building Cost

LA Live, Los Angeles, CA

- ~ 520,000m^2 floor area
- Large BRB force capacity range 3000~9800 kN



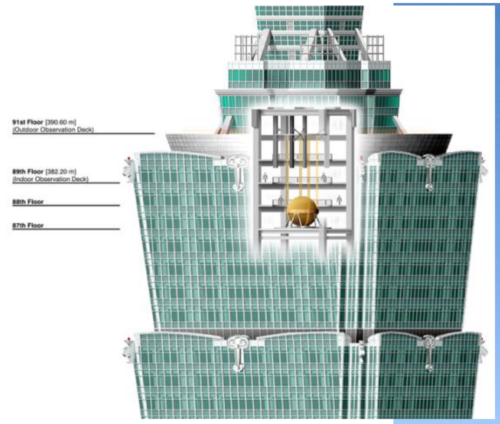


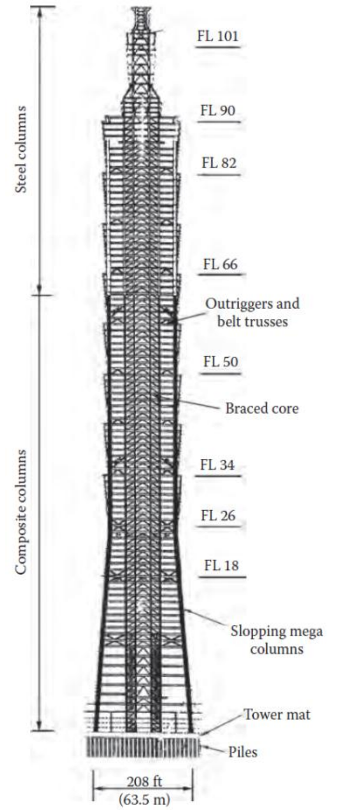
Abenobashi Terminal Building, Osaka, Japan

- **60-story building with total floor area 212,000 m^2 & 300 m maximum height, using friction dampers in the range 1500-5000 kN.**

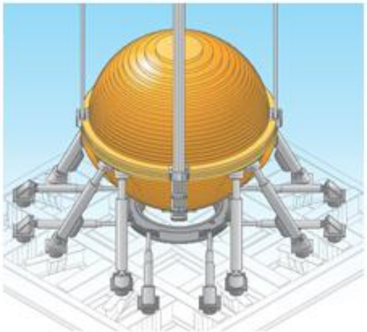
نمونه هایی از کاربرد سیستم های کنترل لرزه ای در جهان

Taipei 101, Taipei



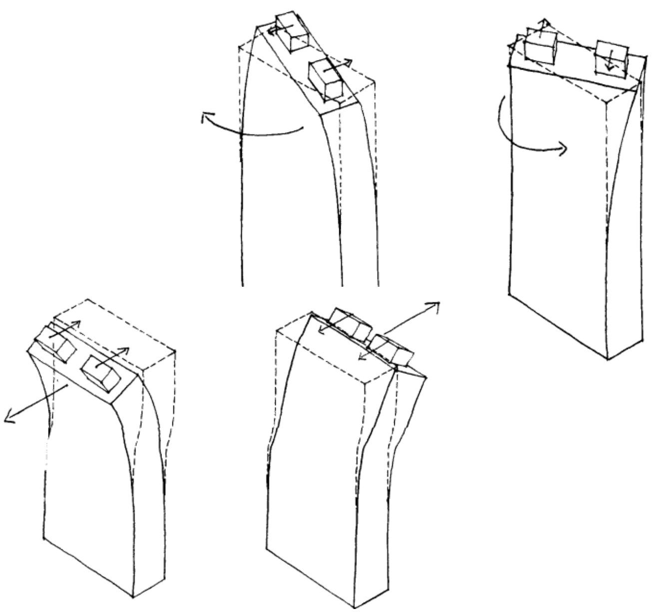


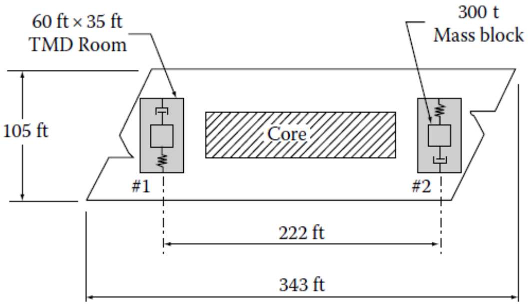
- **508 m, 101 stories**
- **Earthquake-induced & wind-induced responses + Residential comfort = TMD system**
- **TMD system: A ball shaped mass block of 600ton, 8 sets of steel cables for suspension of the mass block, eight primary viscous dampers, the bumper ring and 8 sets of snubbed dampers installed underneath the mass block**



John Hancock Tower, Boston, US

- **240m, 60 stories**
- **Using TMD because of the building’s shape, location, and vibration properties, its dynamic wind response is mainly in the east-west direction and in torsion about its vertical axis.**





Hotel Stockton, CA, US

- **مساحت پروژه** (m^2): ۱۳۴۷۰
- **تعداد طبقات:** ۶
- **سال ساخت:** ۱۹۱۰
- **سال مقاوم سازی:** ۲۰۰۴
- **سیستم مورد استفاده:**
  میراگر **ویسکوز**
- **هزینه مقاوم سازی:** ۱/۳ میلیون دلار

The San Francisco Civic Center, CA, US

- مساحت پروژه (m^2): ۷۵۰۰۰
- تعداد طبقات: ۱۴
- سال ساخت: ۱۹۱۵
- سال مقاوم سازی: ۱۹۹۵
- سیستم مورد استفاده:

میراگر **ویسکوز**

Wallace F. Bennett Federal Building, Salt Lake City, US

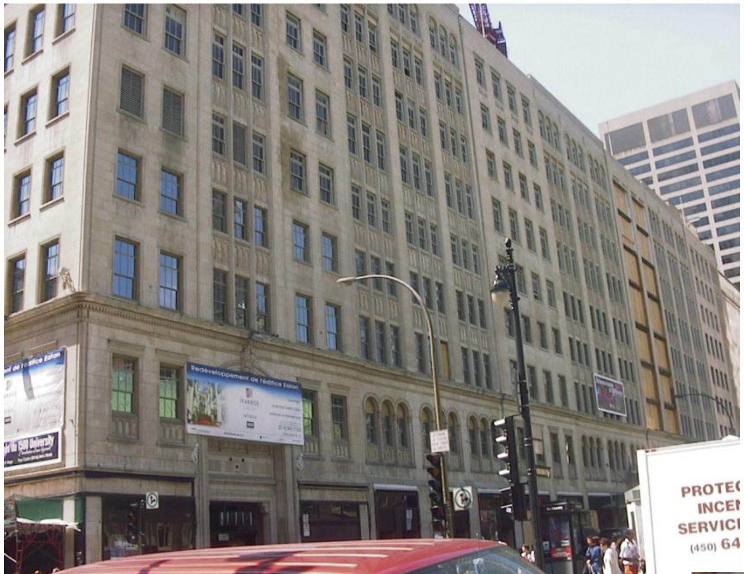
- **مساحت پروژه** (m^2): ۲۷۸۷۰
- **تعداد طبقات:** ۸
- **سال ساخت:** اوایل ۱۹۶۰
- **سال مقاوم سازی:** ۲۰۰۱
- **سیستم مورد استفاده:**
  مهاربندهای کمانش ناپذیر (BRB)
- **هزینه مقاوم سازی:** ۱/۹۶ میلیون دلار

Palais Des Congress Federal Building, Montreal, CA

- **مساحت پروژه** (m^2): ۱۲۷۰۰
- **تعداد طبقات:** ۹
- **تاریخ ساخت:** ۱۹۲۸
- **تاریخ مقاوم سازی:** ۲۰۰۰
- **سیستم مورد استفاده:**

  میراگر **اصطکاکی**
- **هزینه مقاوم سازی:** ۲۵۰ میلیون دلار

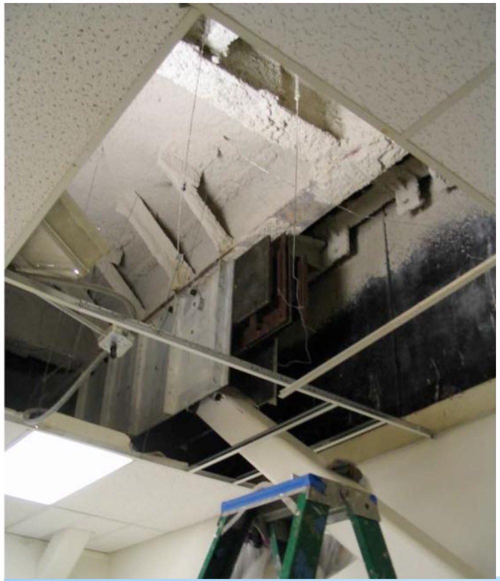
Eaton Building, Montreal, CA



- **تعداد طبقات: ۹**
- **تاریخ ساخت: ۱۹۲۵**
- **تاریخ مقاوم سازی: ۲۰۰۰**
- **سیستم مورد استفاده:** میراگر **اصطکاکی**
- **هزینه مقاوم سازی:**

۱۱۰میلیون دلار

San Mateo County Hall of Justice, CA, US

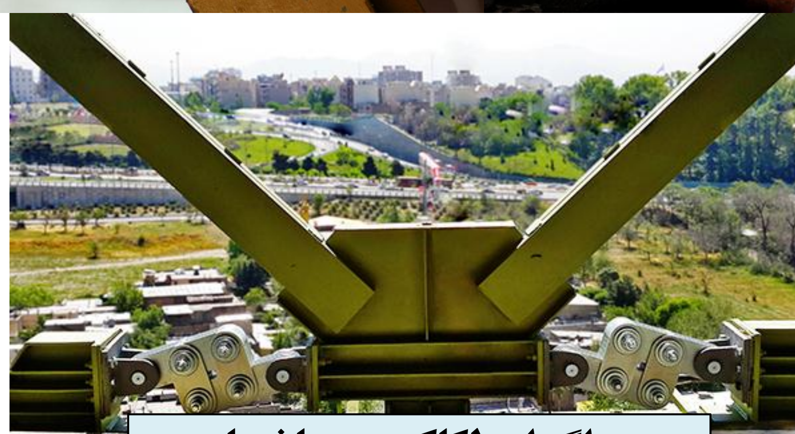


- **تعداد طبقات:** ۸
- **تاریخ ساخت:** اوایل ۱۹۶۰
- **تاریخ مقاوم سازی:** ۲۰۰۶
- **سیستم مورد استفاده:** میراگر **ویسکوالاستیک**
- **هزینه مقاوم سازی:** ۲/۰۵ میلیون دلار

کاربرد میراگر در ایران

- کمتر از ۱۰ ساختمان!؟


میراگر تسلیمی در ساختمان های مسکونی در شهر ری و زعفرانیه



میراگر اصطکاکی در ساختمان مرکزی بانک گردشگری

میراگر اصطکاکی در سفارت کانادا

میراگر ویسکوز در هتل پارسیان آزادی