

NDIA Infrastructure Conference

SEISMIC ISOLATION OF MISSION-CRITICAL INFRASTRUCTURE TO RESIST EARTHQUAKE GROUND SHAKING OR EXPLOSION EFFECTS

August 2005
St. Louis, Missouri

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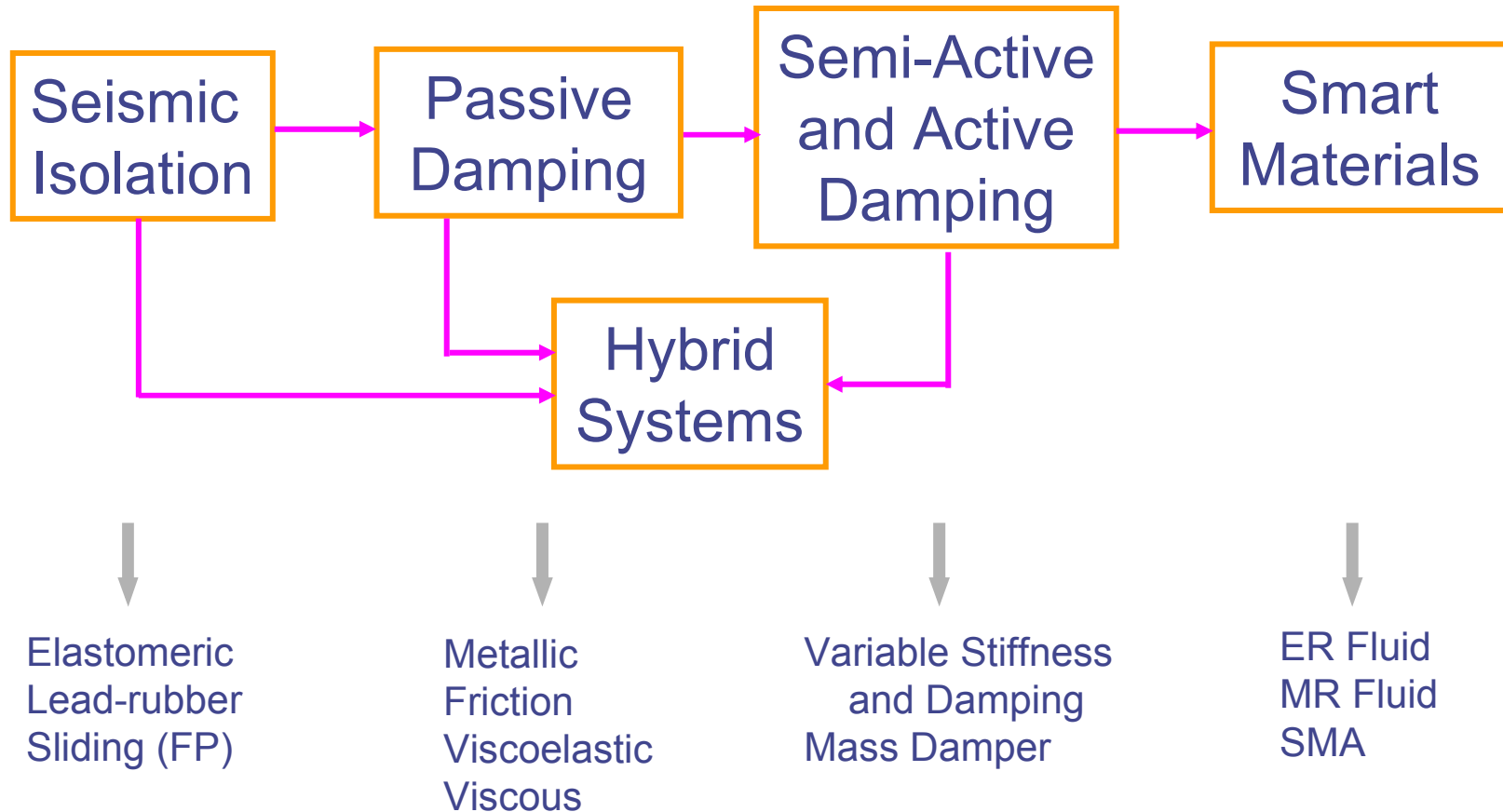
Andrew Whitaker
Michael Constantino
University at Buffalo



History

- ◆ 1906 US Patent - Earthquake Proof Building
 - Jacob Bechtold, Munich
- ◆ 1921 Imperial Hotel
 - Frank Lloyd Wright, 1923 Tokyo Earthquake, Insight or Hindsight
- ◆ 1960's Cheyenne Mountain
 - USACE & Black & Veatch

Protective systems



Blast vs. Seismic - Response and Protection

- ◆ Seismic
 - Protect Whole Structure or Nonbuilding Structure
 - Protect Nonstructural Components
 - ◆ Data Processing
 - ◆ Critical Components,
 - UFC 3-310-04, MC-1, MC-2, NMC
- ◆ Blast
 - Protect Nonstructural Components

Demand vs. Capacity NMD Lessons

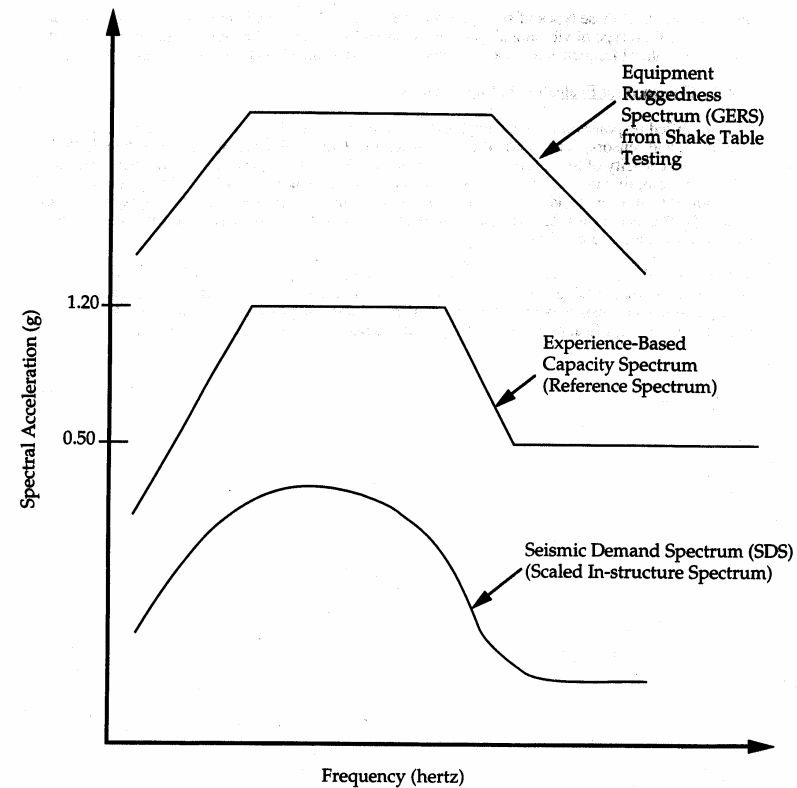
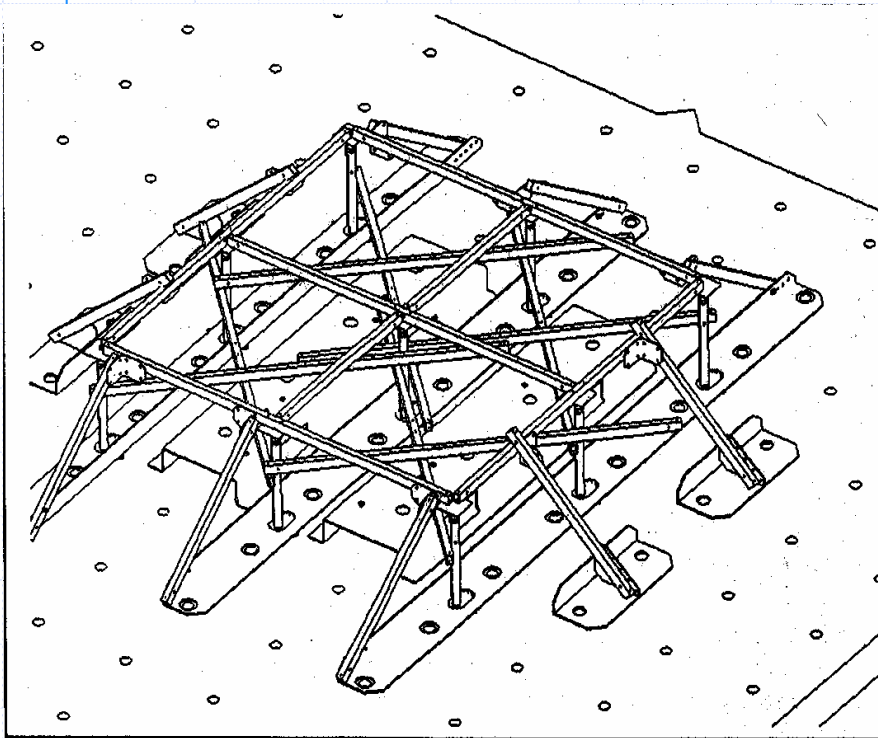
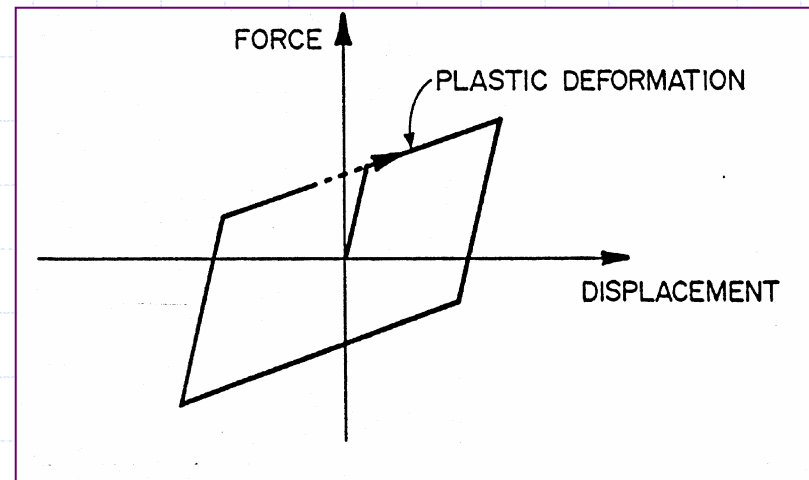
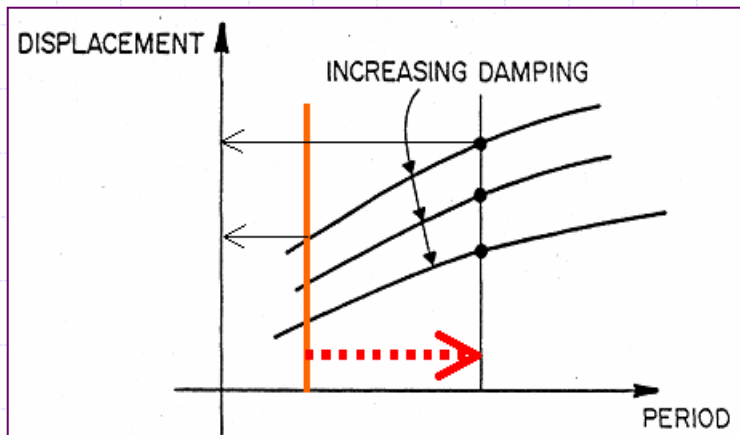
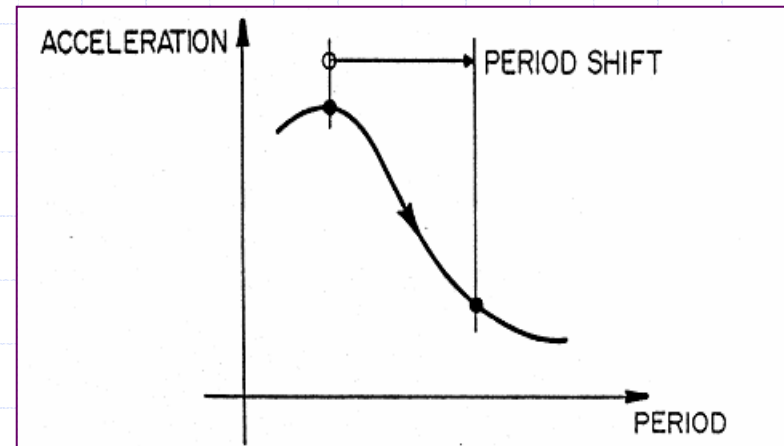
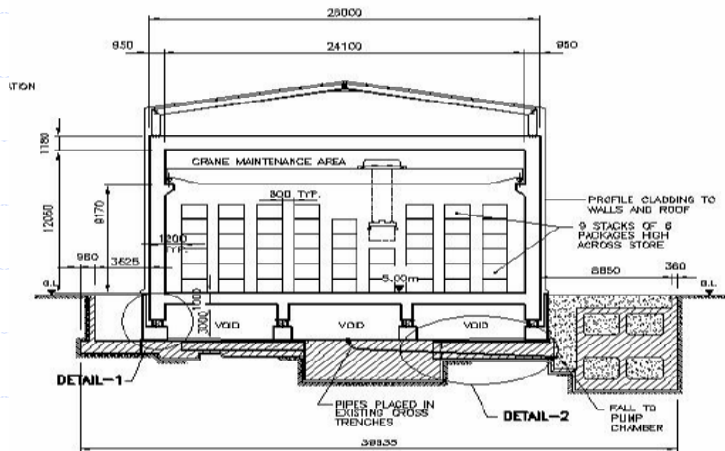


Figure 5.4-1 Comparison of Seismic Capacity Spectrum to Seismic Demand Spectrum

Seismic protective systems

- ◆ Seismic isolation
 - Hardware, applications, testing
- ◆ Supplemental damping systems
 - Hardware, applications, testing

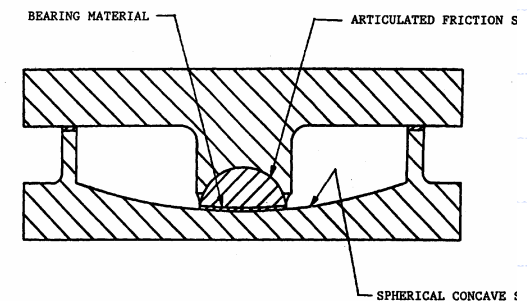
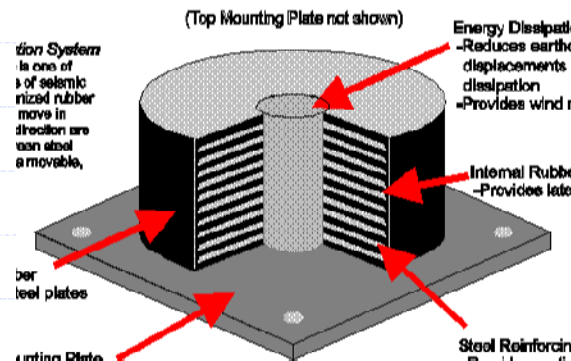
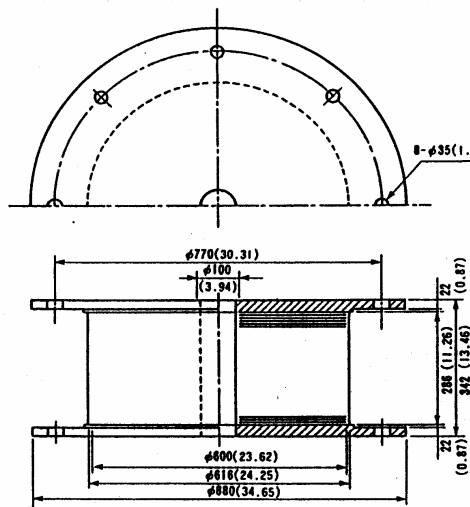
Principles of seismic isolation



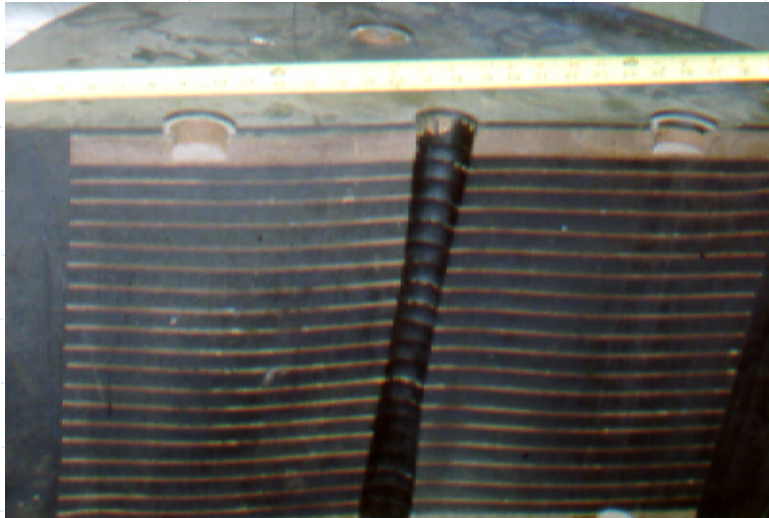
Seismic isolation hardware

- ◆ Elastomeric bearings
 - Low-damping rubber
 - High-damping rubber
 - Lead-rubber bearing

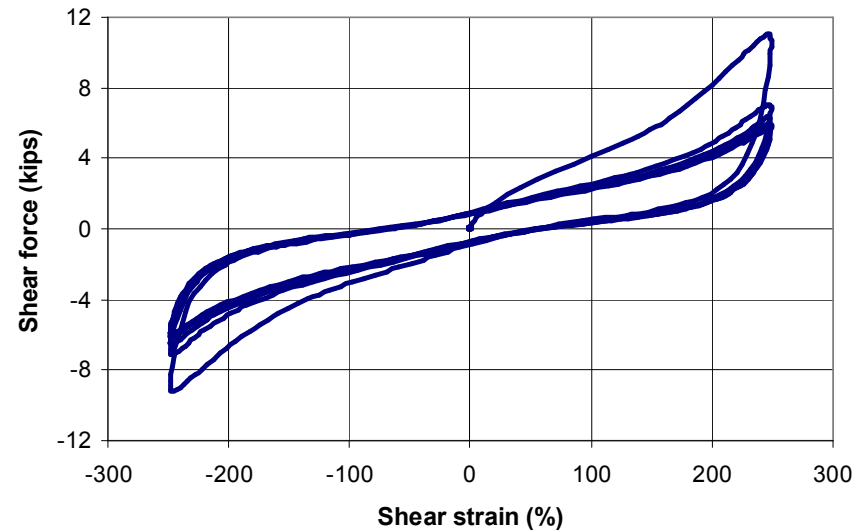
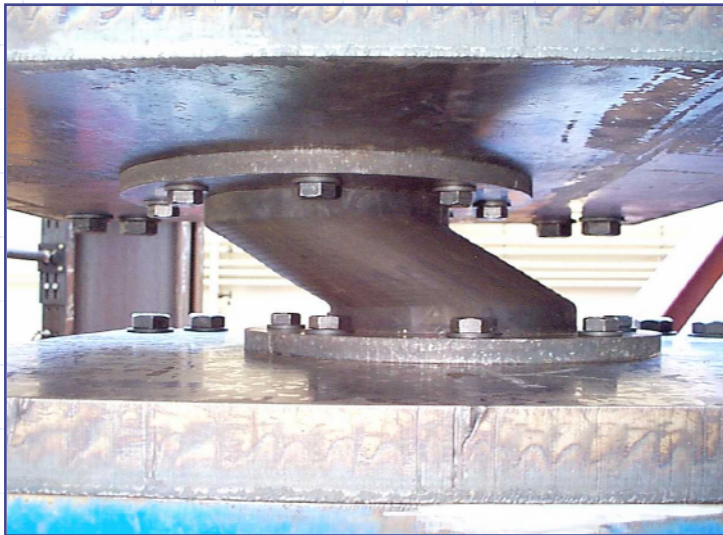
- ◆ Sliding bearings
 - Friction Pendulum™
 - Flat slider w/restoring force
 - ◆ Eradquake™
 - Flat slider w/yielding devices
 - ◆ FIP/Alga



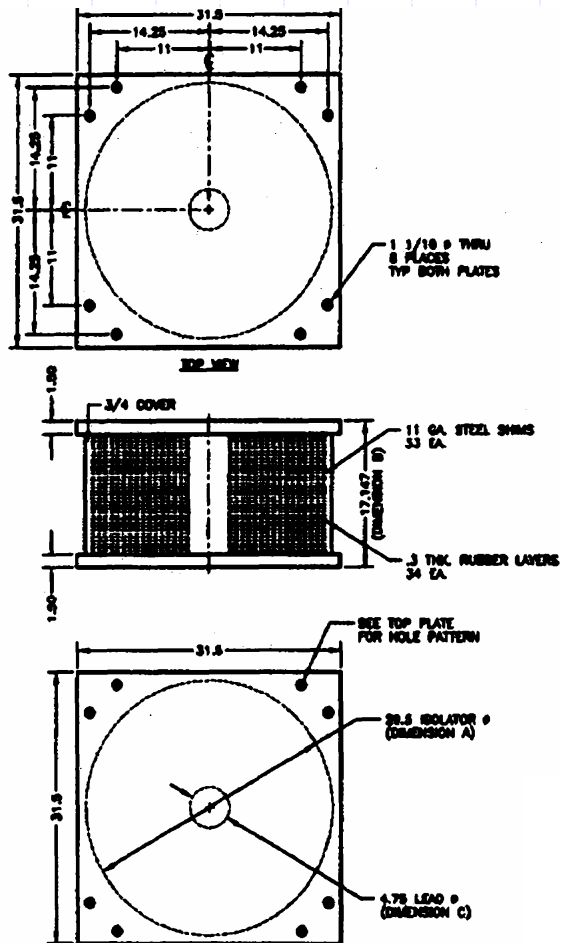
Elastomeric bearings



High-damping rubber bearings

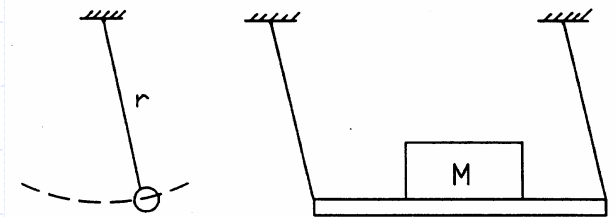
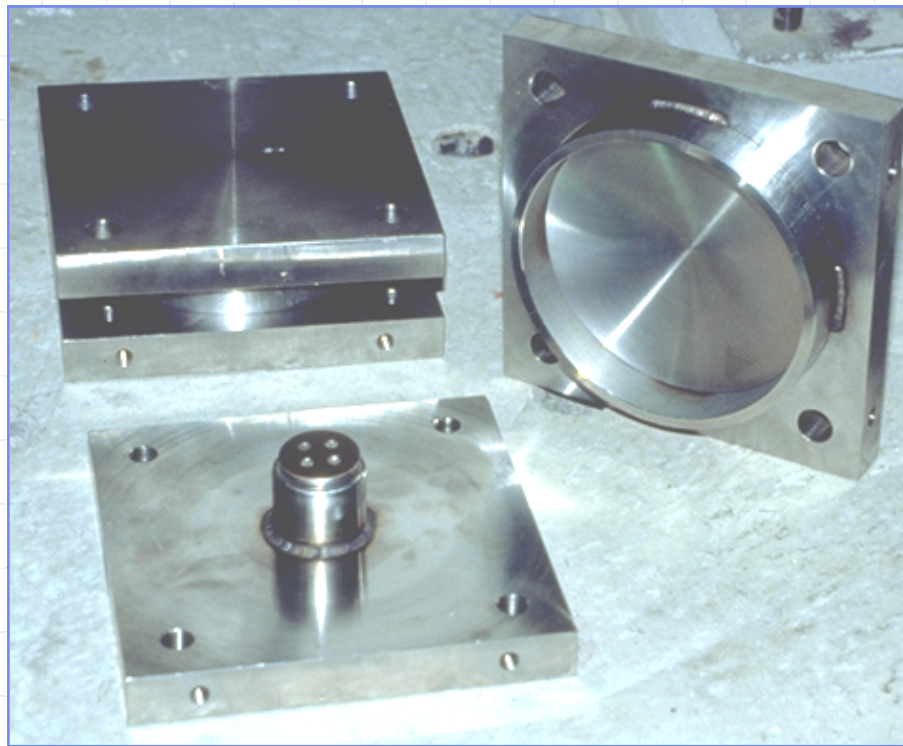


Lead-rubber bearings

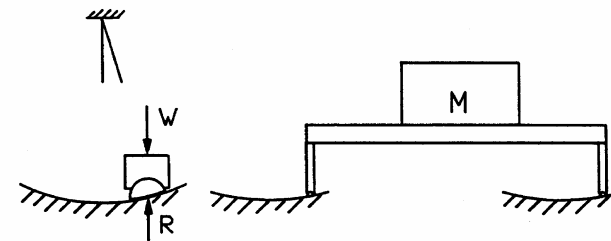


Sliding bearings

◆ FP bearing



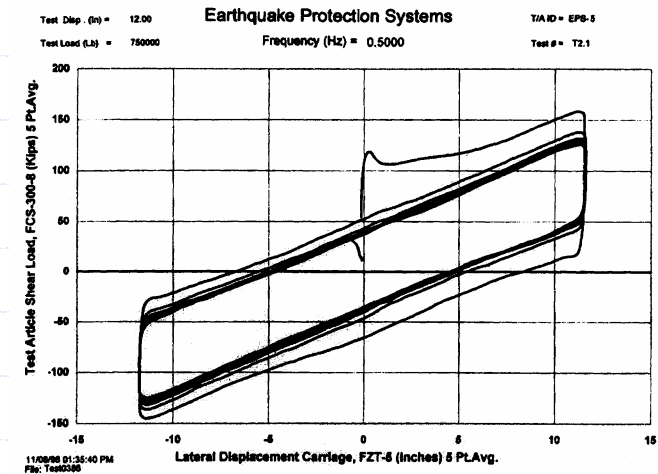
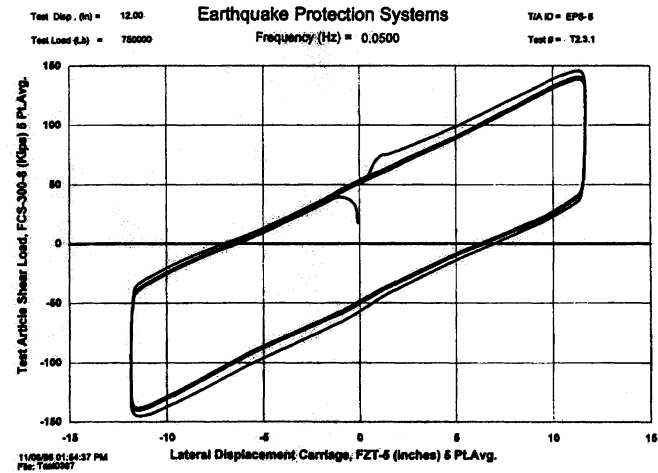
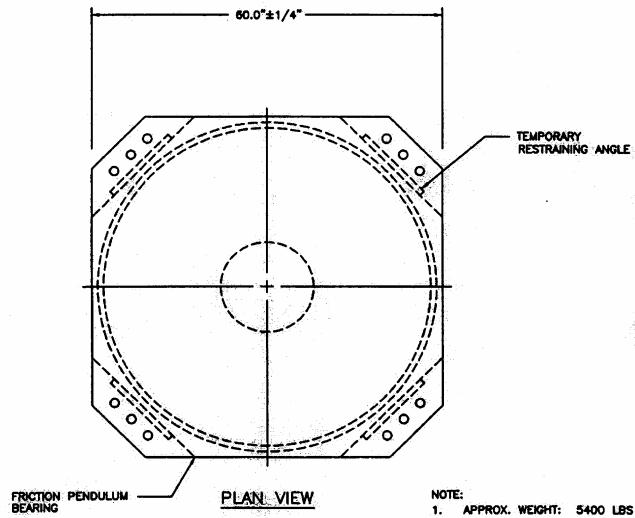
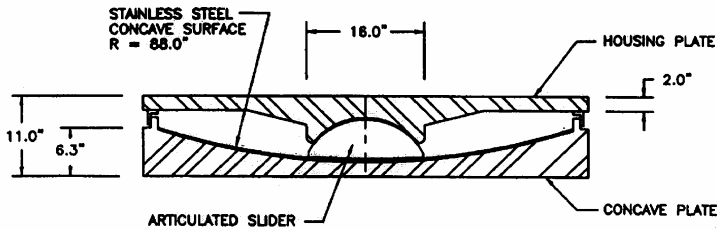
PENDULUM MOTION



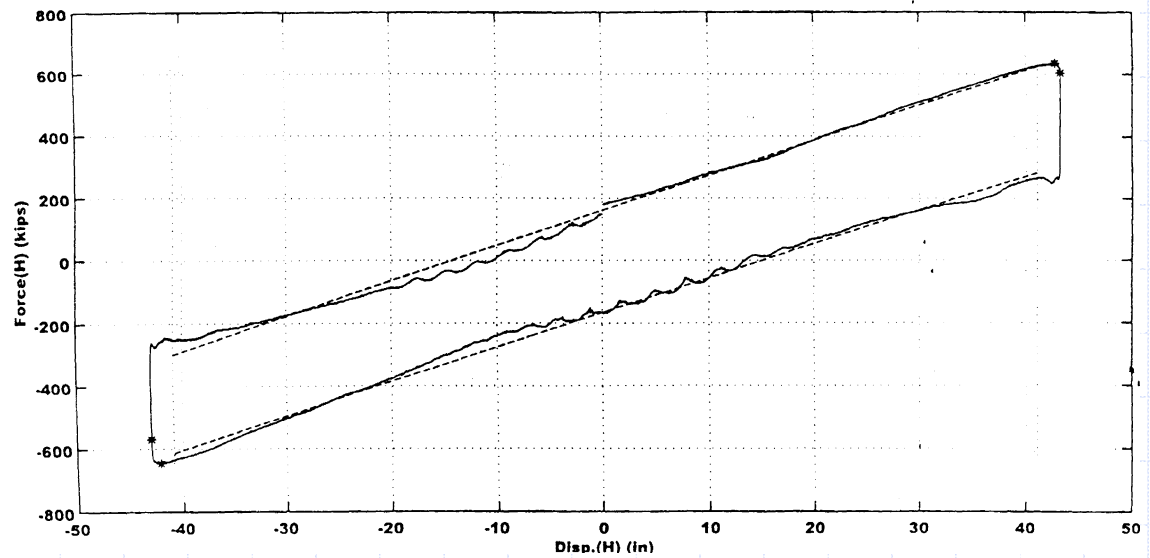
SLIDING PENDULUM MOTION

EQUATIONS: PERIOD $T = 2\pi\sqrt{r/g}$
STIFFNESS $k = W/r$

FP bearing



FP bearing

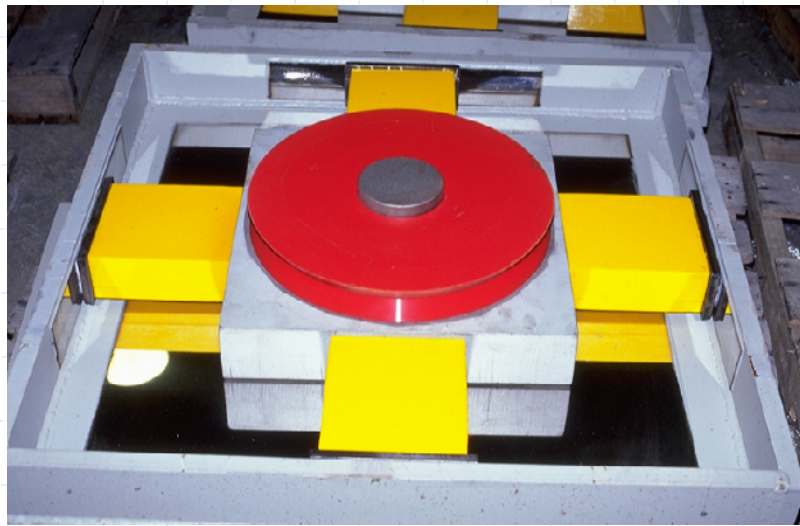


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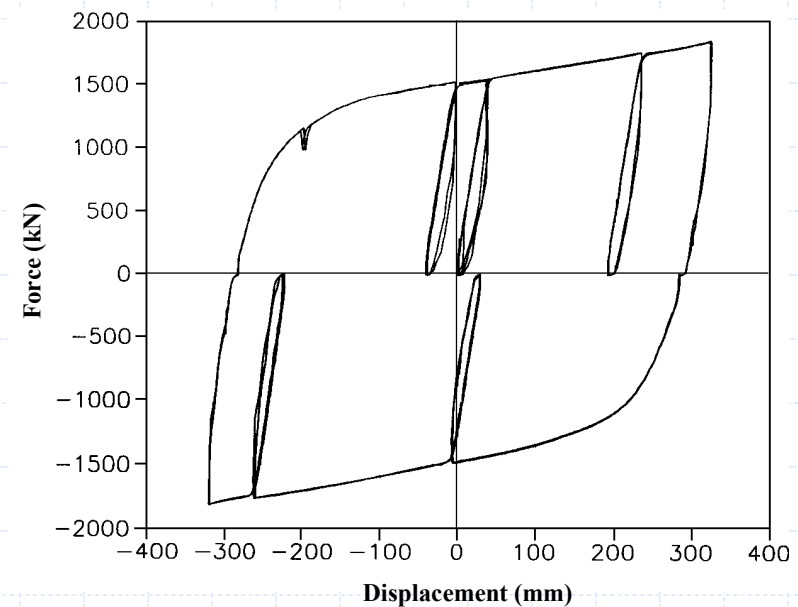
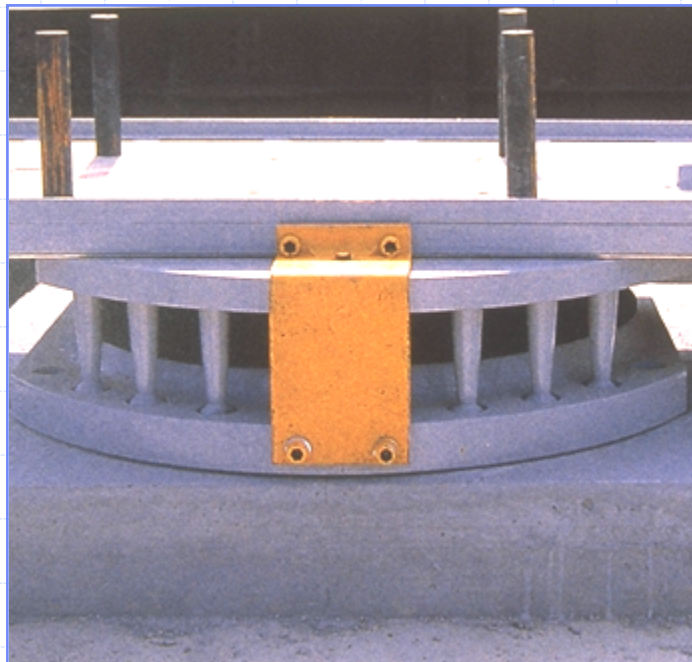
Sliding bearing

- ◆ Flat slider with restoring force
 - Eradiquake™



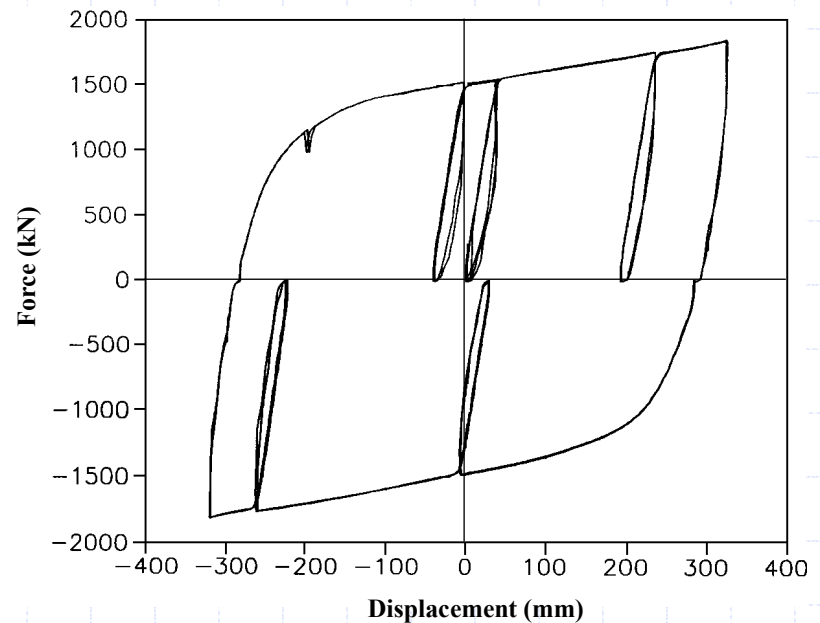
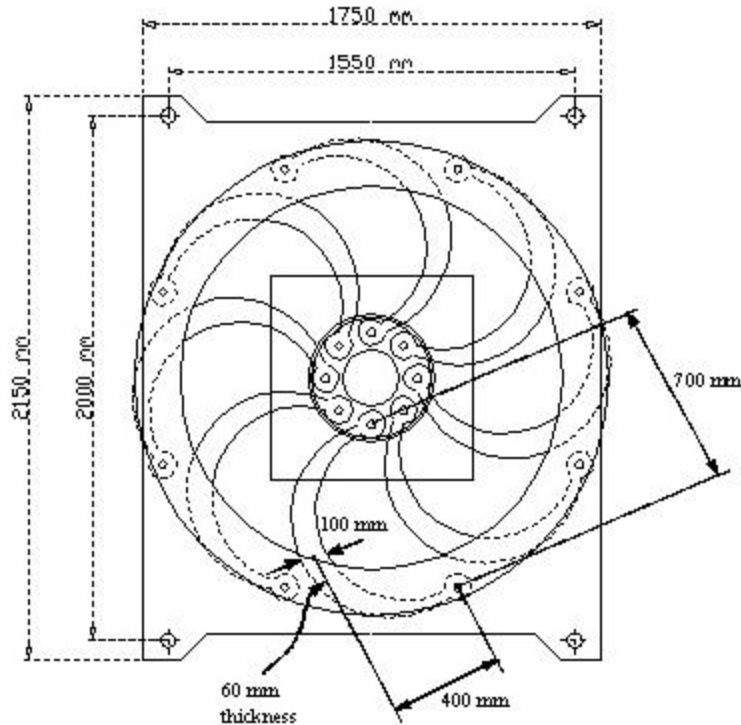
Sliding bearing

- ◆ Flat slider with yielding devices
 - FIP Industriale/Alga
 - ◆ Chirag I platform retrofit

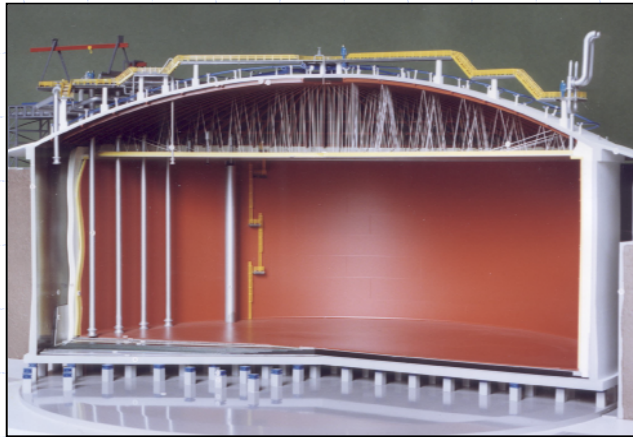


Sliding bearing

- ◆ Flat slider with yielding devices
 - Alga



Infrastructure applications



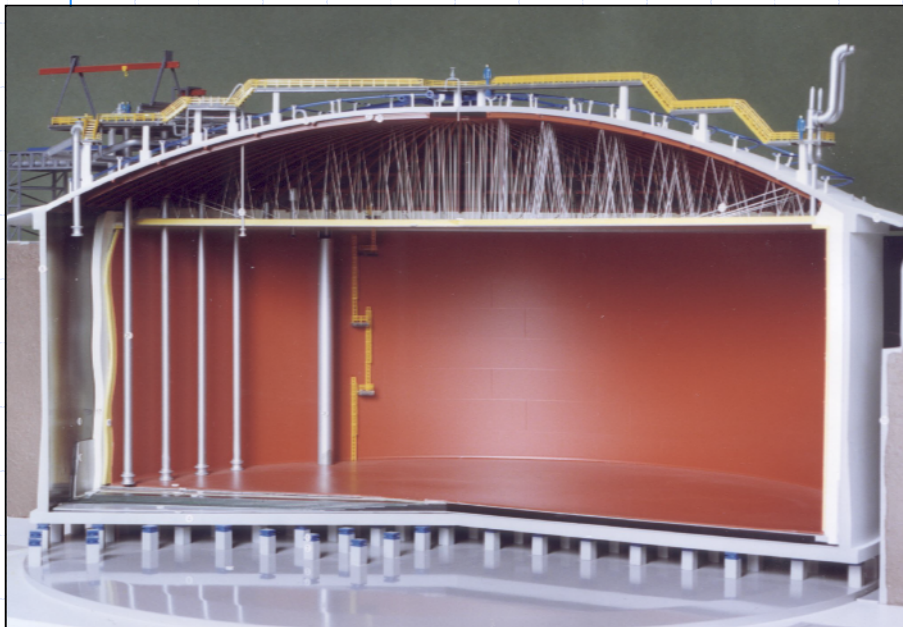
**LNG TANKS, REVITHOUSSA, GREECE
FP BEARINGS**



Revithoussa LNG design criteria

- ◆ Hazard characterization
 - SSE: 10,000 year return period
- ◆ Performance criteria for Cat. 1 components
 - Inner and outer tanks
 - ◆ Safety functions operational during and after SSE
 - ◆ No loss of structural integrity/damage during and after SSE
- ◆ Computer codes
 - ABAQUS, ANSYS, DYNA-3D, 3D-BASIS
- ◆ Modeling of isolation components
 - Per 1991 UBC but bilinear models used
- ◆ Bounding analysis to capture effects of variations in isolator properties

Revithoussa construction details



- ◆ 65,000 m³ (17 million gal) capacity
- ◆ 35 m (115 ft) high
- ◆ 9% nickel inner tank
 - Unanchored tank
- ◆ P_s_c outer tank
- ◆ 1-m (39 in) thick rc base
- ◆ Underground construction for safety reasons
- ◆ FP bearings

Infrastructure applications



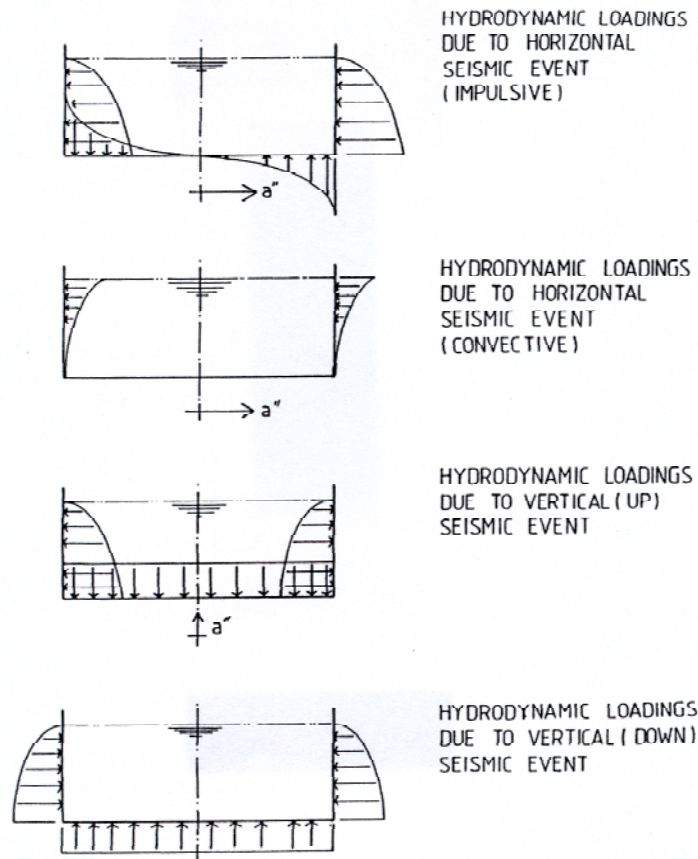
**LNG TANKS, INCHON, KOREA
ELASTOMERIC BEARINGS**



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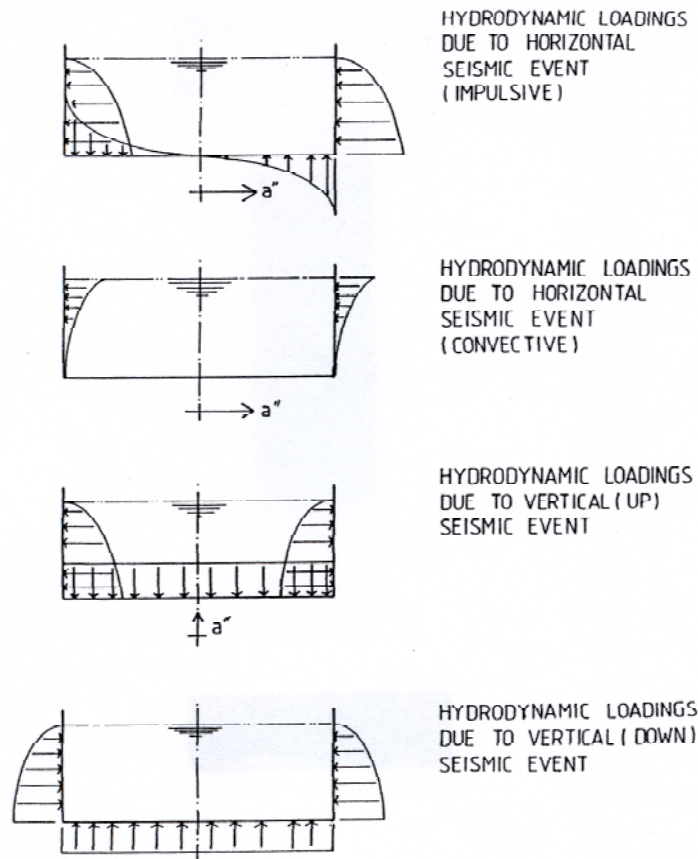
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University at Buffalo

Isolation of LNG tank facilities



- ◆ Hydrostatic and hydrodynamic loadings cause shell hoop tension
- ◆ Impulsive and convective liquid loading cause shell compression in the vertical direction
- ◆ Use of modification factors (R-factors) for shell hoop stress (e.g., API 620 utilizes a value 2.0) virtually guarantees shell elastoplastic buckling (elephant's foot buckling)

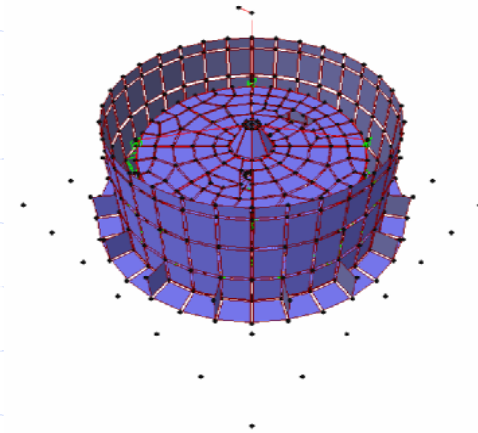
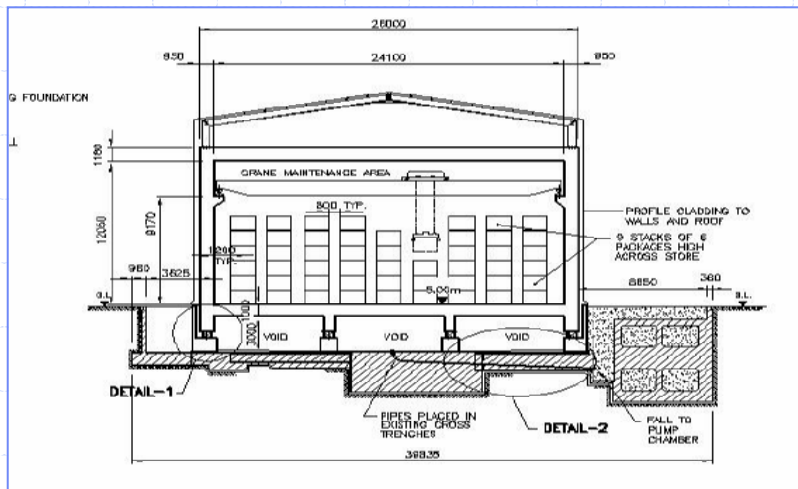
Isolation of LNG tank facilities



- ◆ LNG tanks are tested by filling with water. Since the density of water is twice that of LNG, tanks have additional shell thickness and thus an ability to resist modest earthquake forces
- ◆ Seismic isolation permits the use of *standard* LNG tank in regions of high seismicity without the need to anchor the tank or to change the diameter-to-height ratio

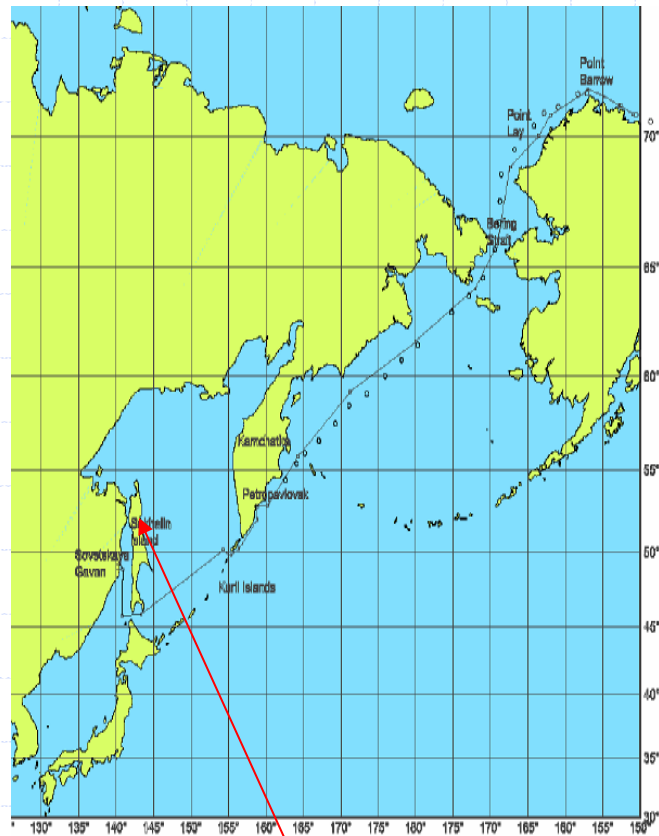
Infrastructure applications

ILWS, HUNTERSTON, UK FP or LEAD-RUBBER BEARINGS



RADAR FACILITY, ALASKA FP BEARINGS and VDDs

Sakhalin I Orlan platform



SAKHALIN ISLAND, RUSSIA

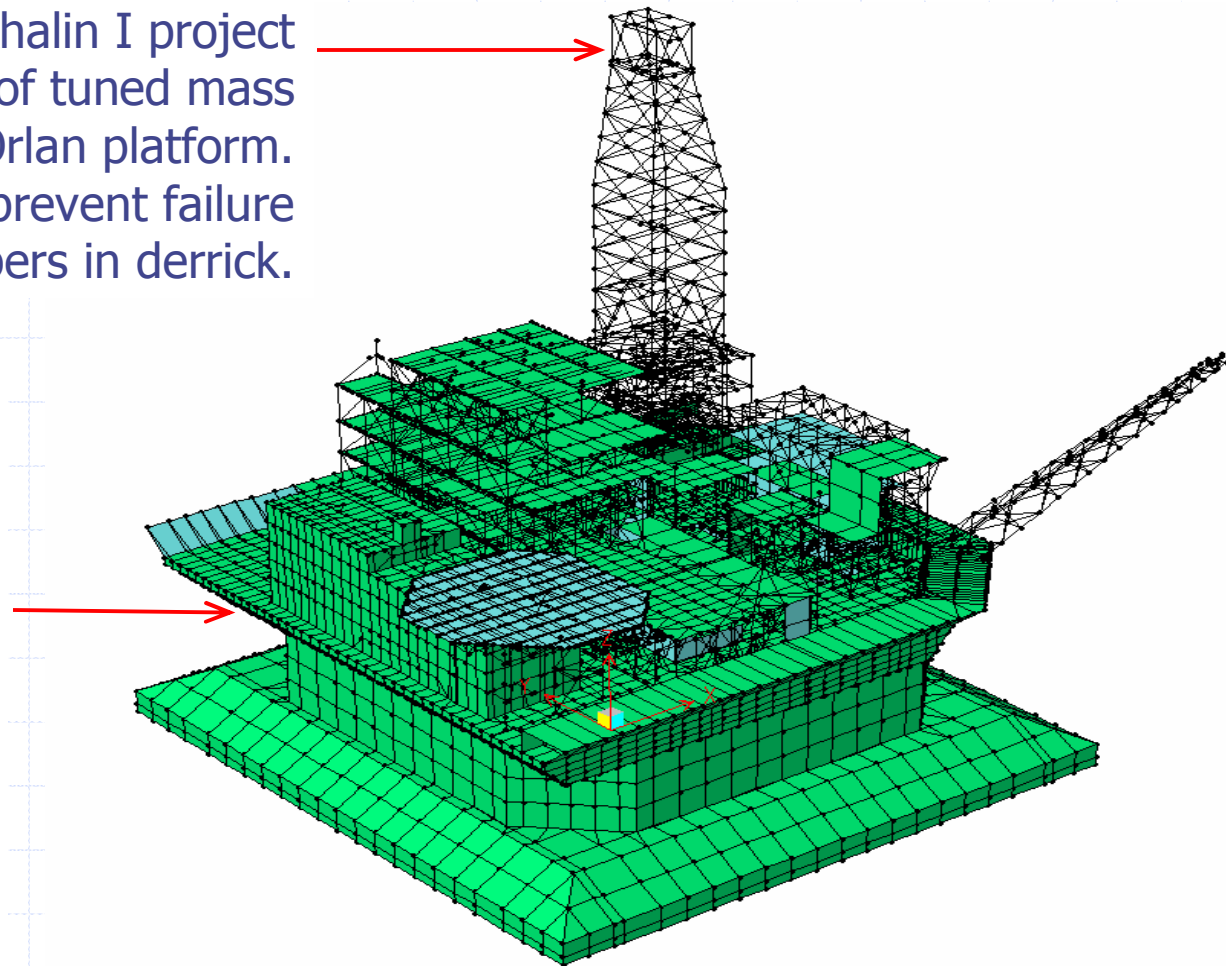


**OFFSHORE GAS PLATFORM WITH
CONCRETE GRAVITY BASE**

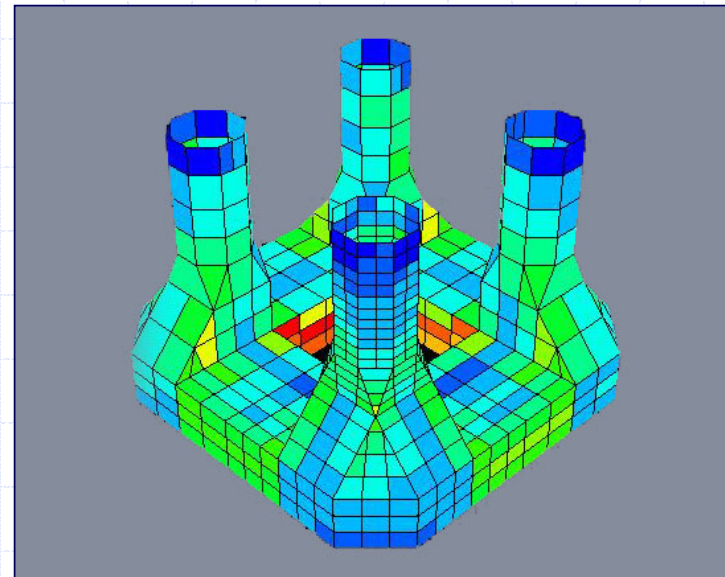
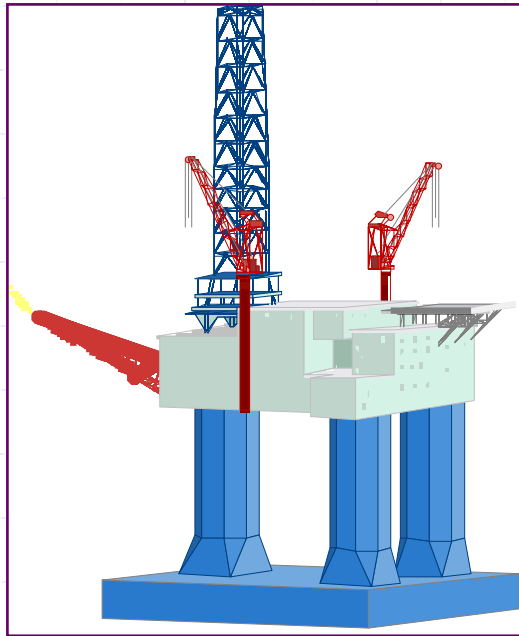
Sakhalin I Orlan platform

Sakhalin I project
Location of tuned mass
damper in Orlan platform.
Goal is to prevent failure
of members in derrick.

Sakhalin II project.
Location of seismic
isolation system in
Piltun and Lunskoye
platforms. Goal is to
protect entire
structure above
concrete gravity
base.



Sakhalin II gas platforms



**SAKHALIN II GAS PLATFORMS, RUSSIA
FP BEARINGS**

Infrastructure applications



**BENICIA-MARTINEZ BRIDGE
SAN FRANCISCO BAY AREA
FP BEARINGS**



Infrastructure applications



**KODIAK, ALASKA
FP BEARINGS**



Infrastructure applications

BOLU VIADUCT, TURKEY **FLAT SLIDERS with YIELDING STEEL DAMPERS**



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Building applications

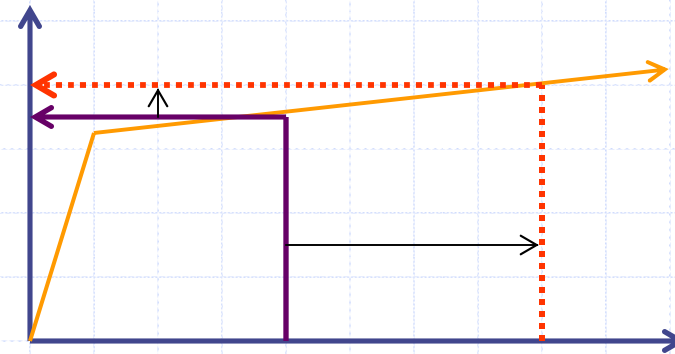
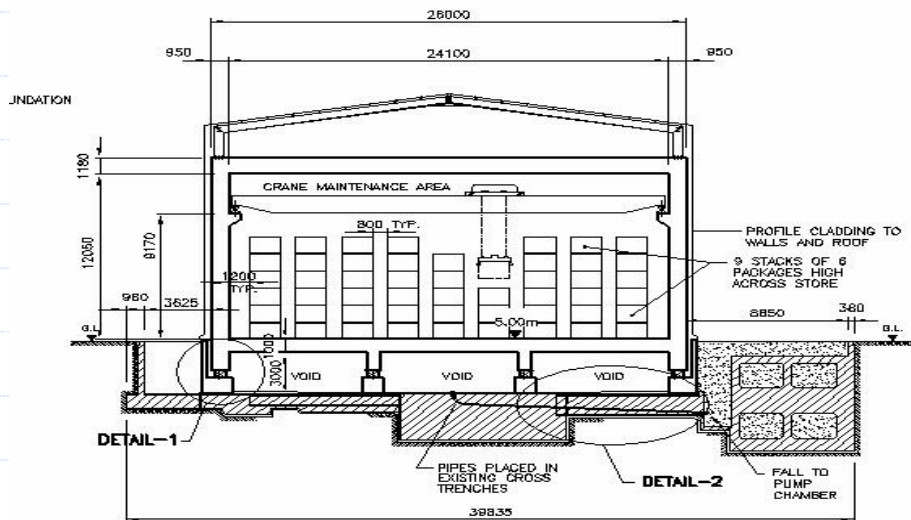


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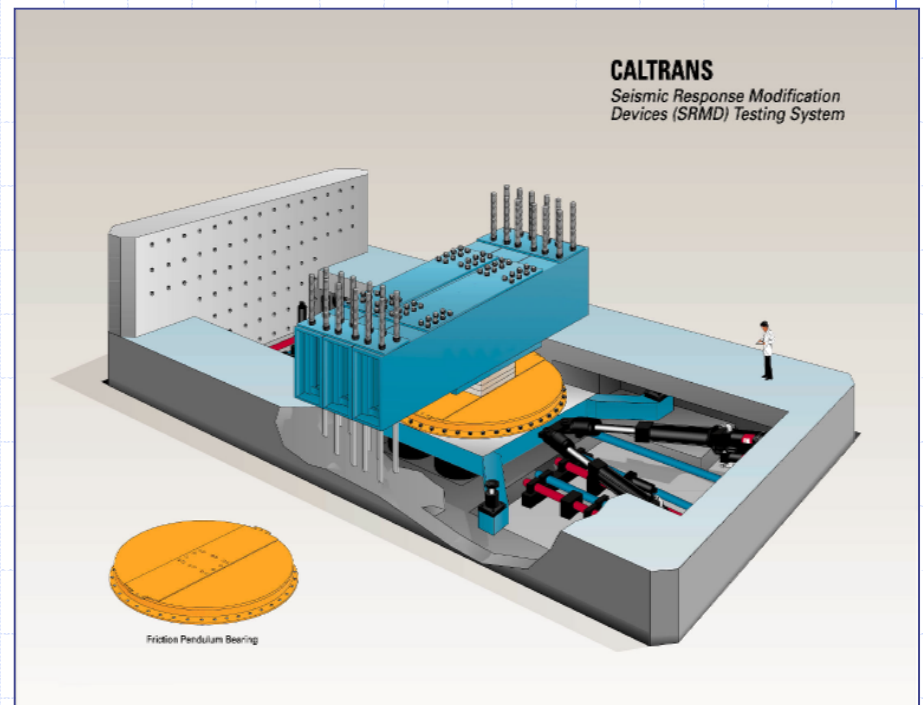
Beyond-design-basis demands

- ◆ Conventional
 - Margin required?
 - Additional strength and stiffness
 - Ductile detailing
- ◆ Isolation



Testing of seismic isolators

- ◆ Mandatory for
 - Buildings (NEHRP)
 - Bridges (AASHTO)
 - Nuclear (ASCE-4-98)
- ◆ Protocols
 - Prototype
 - Production
 - ◆ Quality control
- ◆ Velocity effects
 - Static testing
 - Dynamic testing

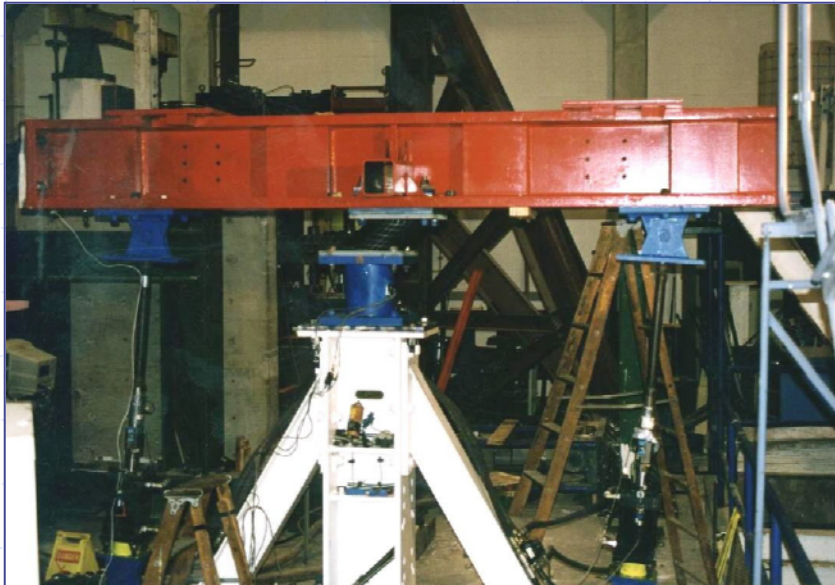


Full-scale dynamic testing

- ◆ Mission-critical hardware
 - Cyclic behavior
 - Degradation of response at high speeds
 - Construction quality
- ◆ SRMD Test Machine
 - Horizontal capacity
 - ◆ 4500 kN per actuator
 - ◆ 2500 mm stroke
 - ◆ 1.8 meters/sec
 - ◆ 19.3m³/min servovalves
 - Vertical capacity
 - ◆ 72 MN



Small-scale dynamic testing



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- 
- ◆ Seismic protective systems
 - Seismic isolation
 - ◆ Hardware, applications, testing
 - Supplemental damping systems
 - ◆ Hardware, applications, testing

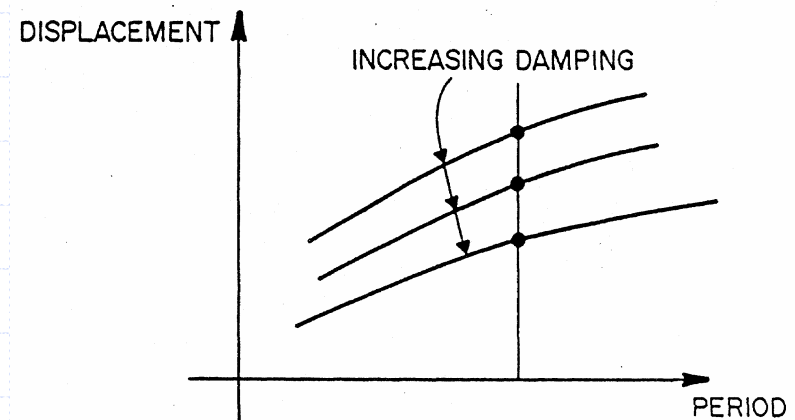
Principles of supplemental damping

- ◆ Reduce displacements
 - Eliminate nonlinear response in the gravity-load-resisting system
 - ◆ Possible?
 - ◆ Force inelastic action into specially designed and detailed, disposable components
- ◆ Reduce accelerations
 - Elastic systems?
 - Inelastic systems?

Effective Viscous Damping β
(percentage of critical damping)¹

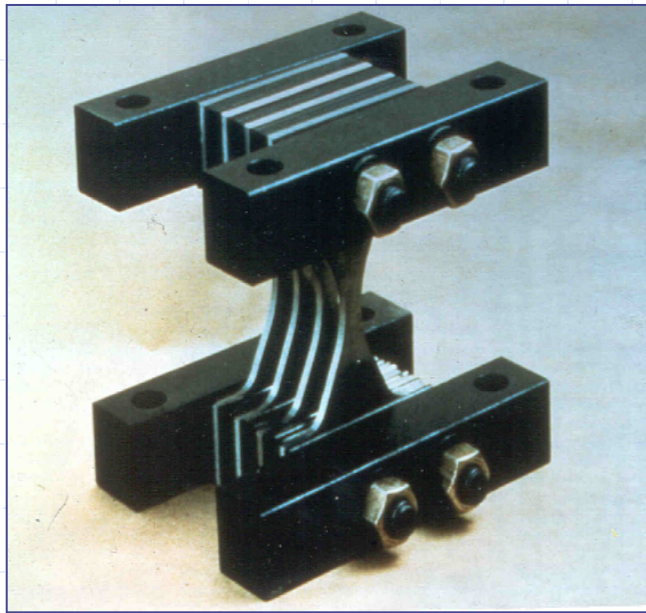
	B_S	B_1
≤ 2	0.8	0.8
5	1.0	1.0
10	1.3	1.2
20	1.8	1.5
30	2.3	1.7
40	2.7	1.9
≥ 50	3.0	2.0

1. Damping coefficients shall be based on linear interpolation for effective viscous damping values other than those given.

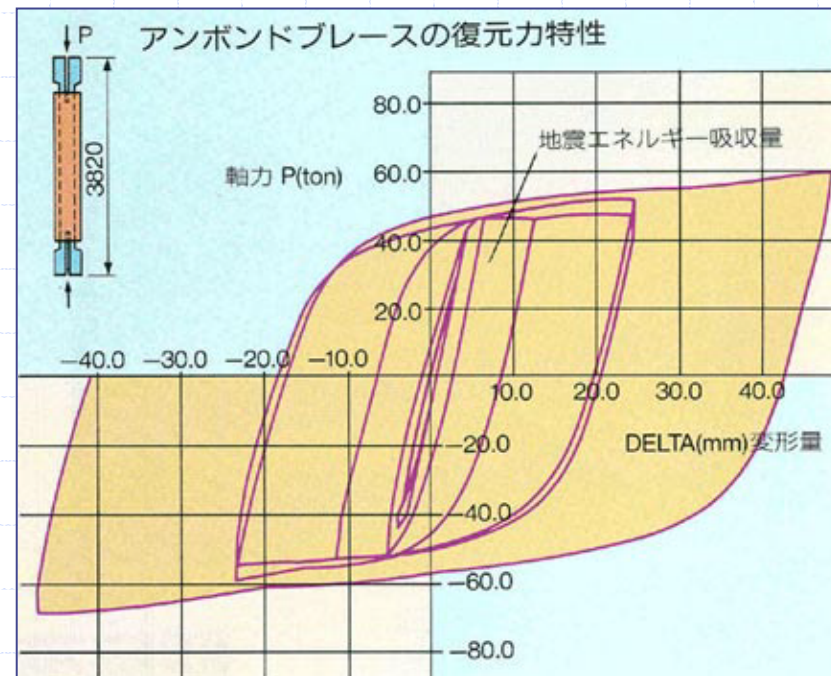
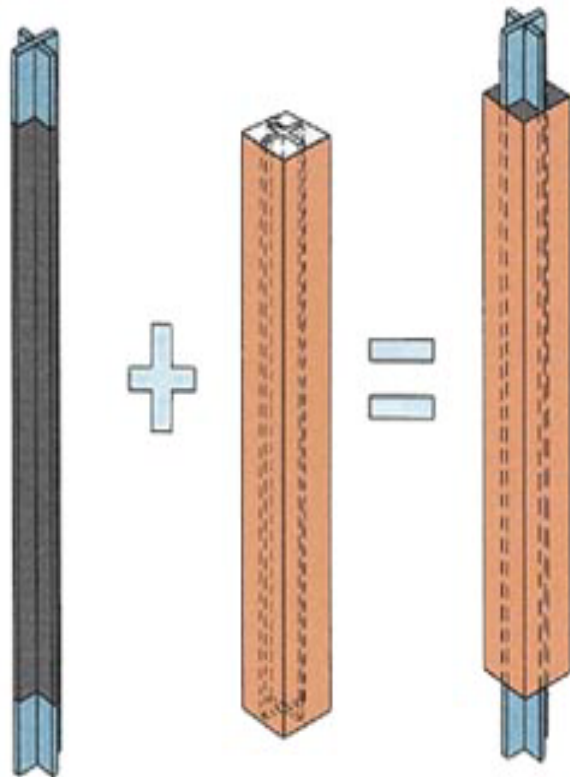


ADAS dampers

WELLS FARGO BANK, SAN FRANCISCO



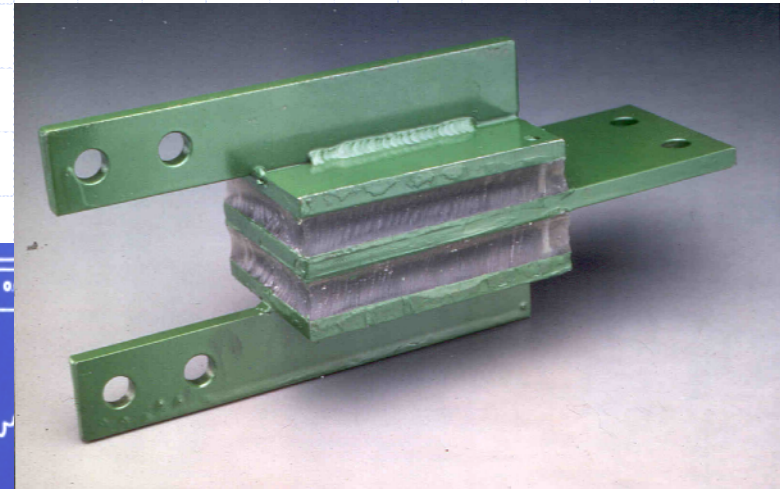
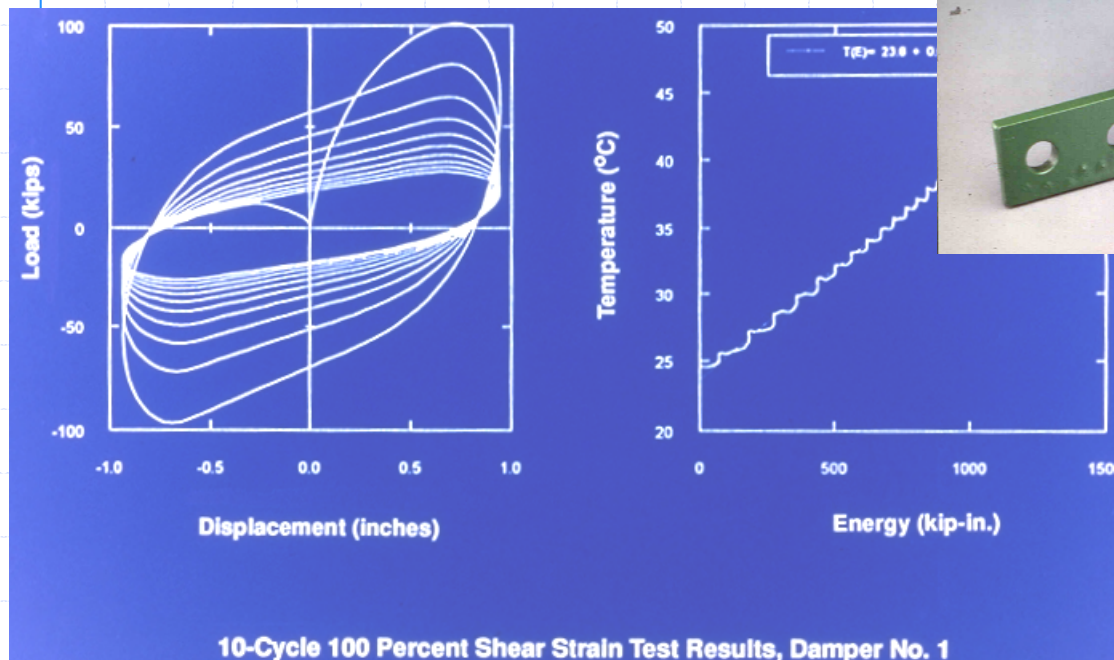
Unbonded braces



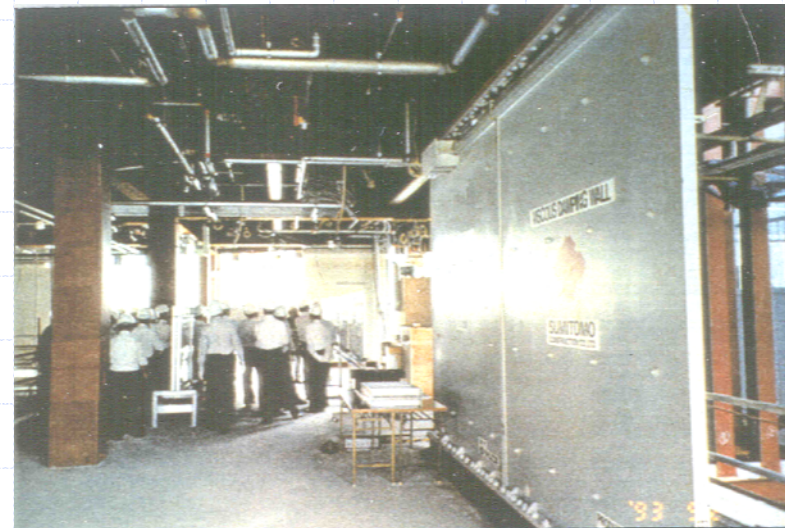
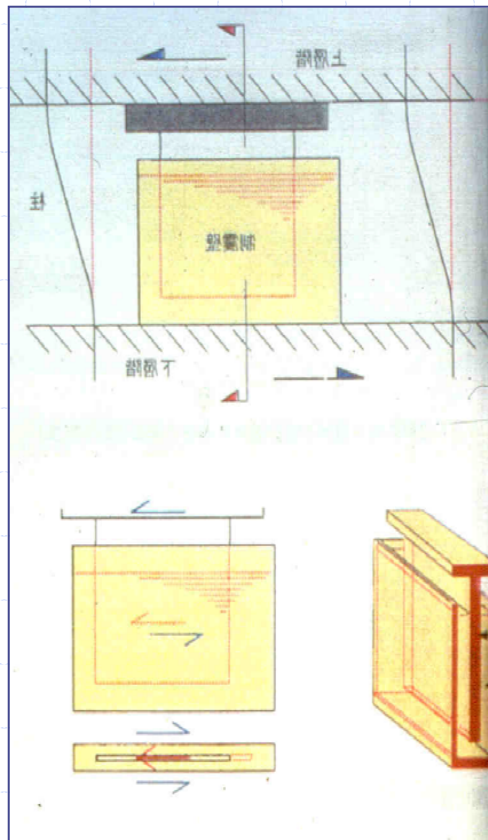
Unbonded braces



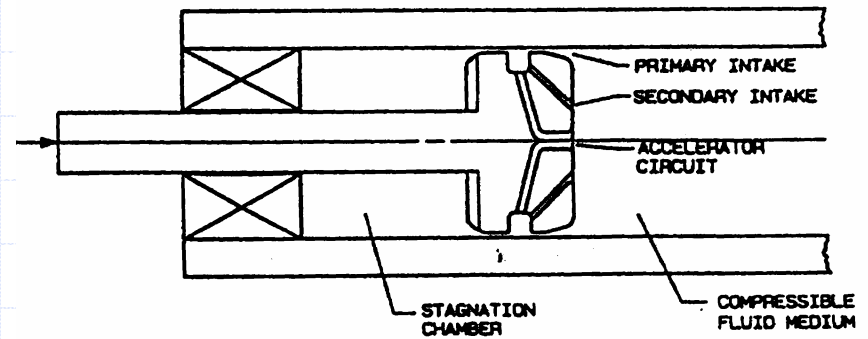
Solid VE dampers



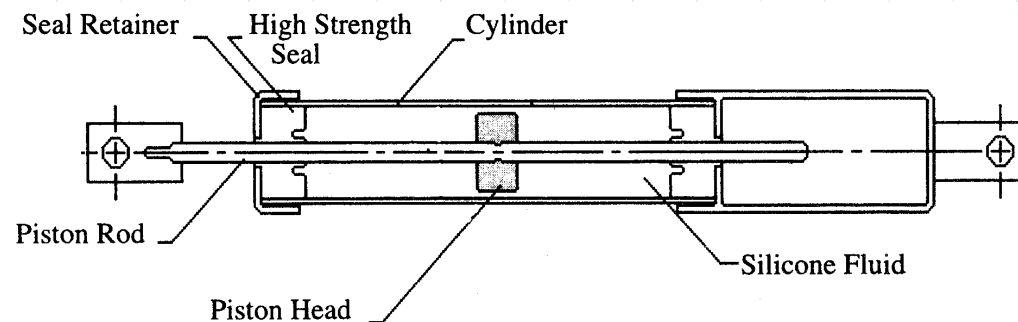
Fluid VE dampers



Fluid viscous dampers



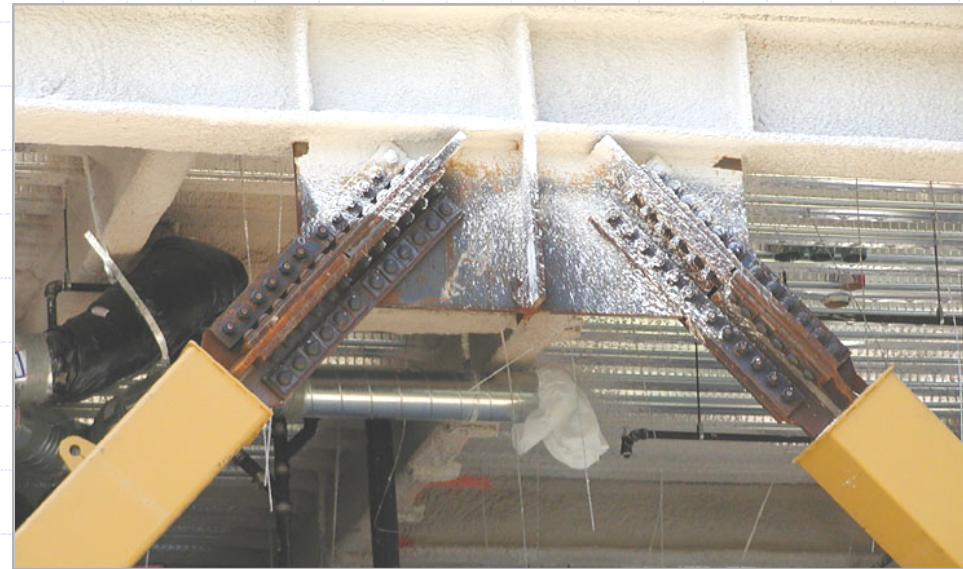
Fluidic Control Orifice



Building applications



**CENTRAL DINING FACILITY
UNIVERSITY OF CALIFORNIA, BERKELEY
UNBONDED BRACES**

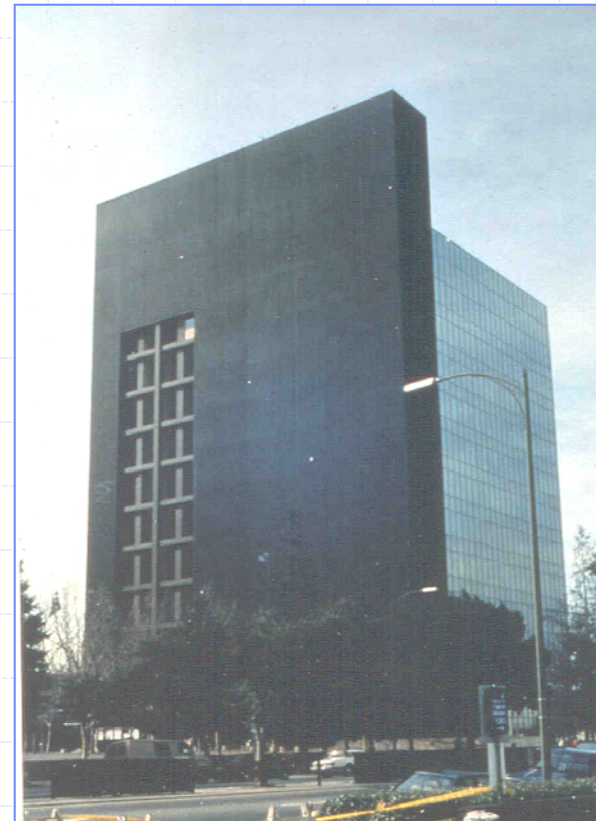
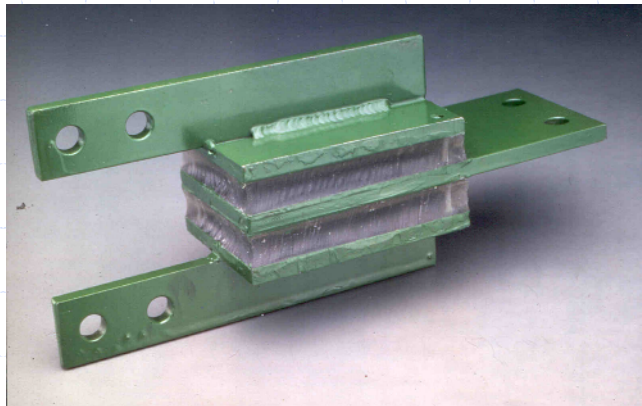


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Building applications

**SANTA CLARA COUNTY BUILDING,
SAN JOSE, CA,
SOLID VE DAMPER**



Building applications

SAN FRANCISCO CIVIC CENTER FLUID VISCOUS DAMPERS



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Building applications

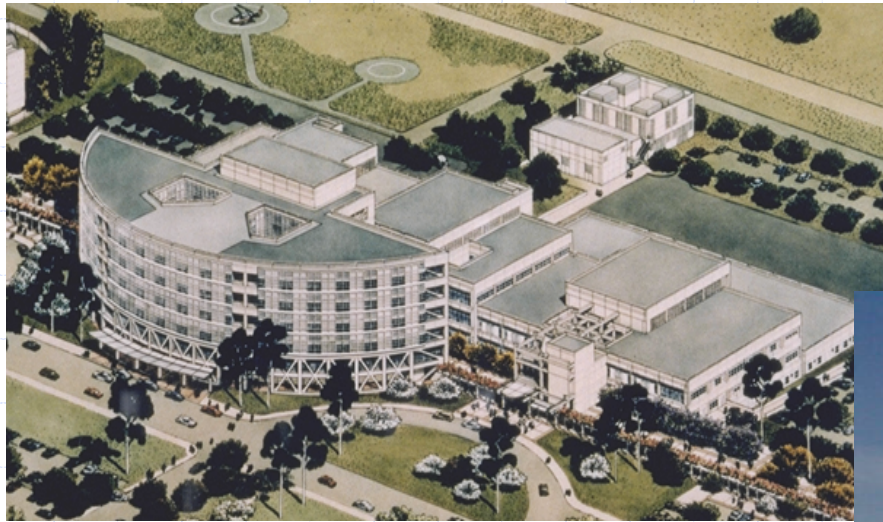
SAN FRANCISCO CIVIC CENTER FLUID VISCOUS DAMPERS



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Building applications (hybrid)



**SAN BERNARDINO HOSPITAL, CA,
ELASTOMERIC BEARINGS AND
FLUID VISCOUS DAMPERS**



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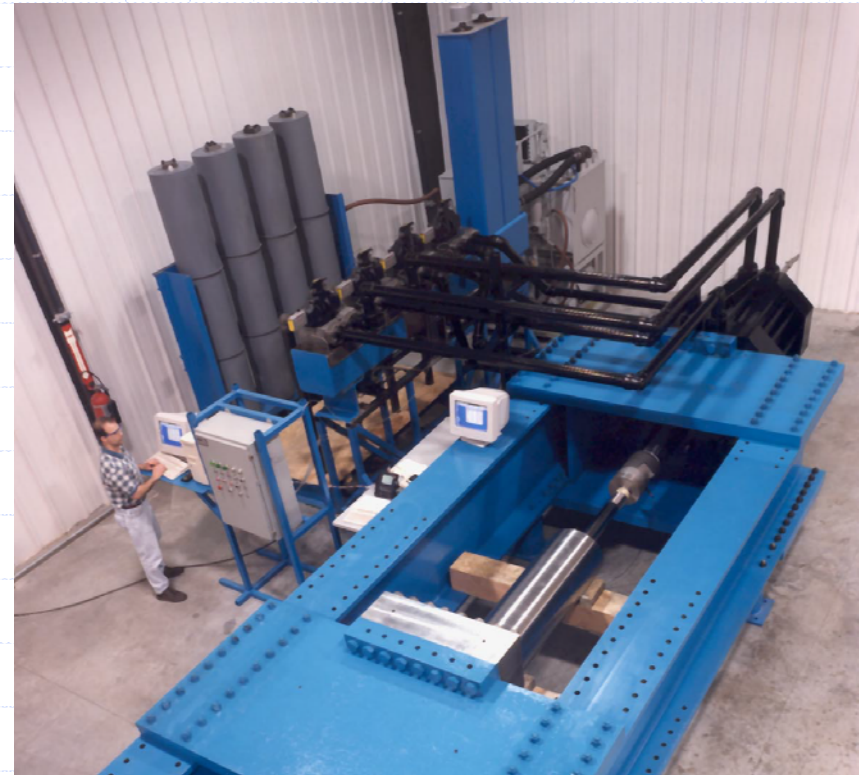
Building applications (hybrid)



**SAN BERNANDINO HOSPITAL, CA,
ELASTOMERIC BEARINGS AND
FLUID VISCOUS DAMPERS**

Testing of supplemental dampers

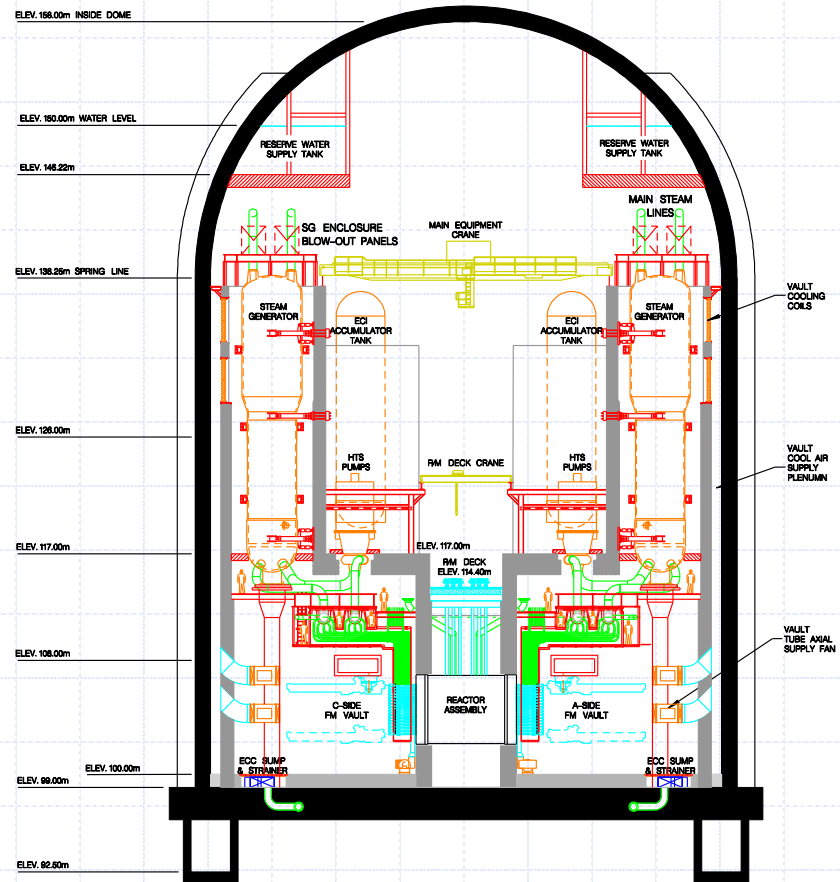
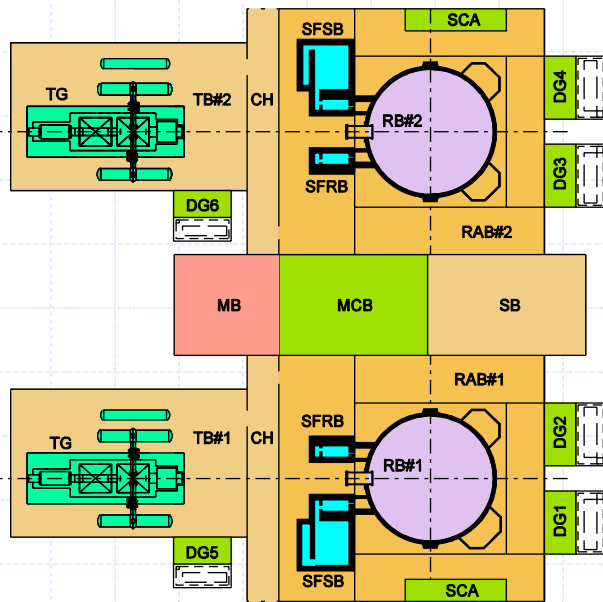
- ◆ Mandatory for
 - Buildings (NEHRP)
 - Bridges (AASHTO)
- ◆ Protocols
 - Prototype
 - Production
- ◆ Velocity effects
 - Static testing
 - Dynamic testing
 - ◆ Drop testing



Performance-based engineering

- ◆ Strategies for delivering performance
- ◆ Reliability
- ◆ Beyond-design-basis capability





ACR700

end