PERFORMANCE ASSESSMENT OF SEISMIC PROTECTIVE SYSTEMS FOR SENSITIVE EQUIPMENT IN MULTISTORY BUILDINGS

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General objectives:

• To examine the applicability of Passive Protective Systems (PPS, isolation and energy dissipation devices) in the form of platforms, floors, or individual systems to protect different equipment sets
• To study the optimal characteristics of PPS for seismic protection of equipment
• To study the interaction of PPS and the effects of building floor accelerations
• To fill current gaps: - on high-performance predictable options to protect vital equipment and - on knowledge on interrelationship among multiple variables controlling the behavior equipment within multistory building
Seismic vulnerability of equipment

Rocking  Swinging  Impacting  Overturning

Izmit, Turkey Earthquake, Aug. 17, 1999, Mw: 7.4

San Fernando, California earthquake, Feb. 9, 1971, Mw: 6.6

Maule, Chile Earthquake, Feb. 27, 2010, Mw: 8.8

(Courtesy of the National Information Service for Earthquake Engineering, EERC, University of California and Gilberto Mosqueda)

Need for dual isolation strategies

Vibration sensitive equipment: operation-induced vibrations and earthquake shaking

Damage to air conditioning equipment Santa Barbara earthquake, 1978, Mw: 5.7 (NISEE)

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Conventional options for local protection of equipment

Anchorages, restraints, wire bracing, mechanical mountings

Rupture and excessive acceleration
Restraint systems may control excessive displacement, but they also lead to high acceleration levels

Difficulties:
• (1) Variability of characteristics
• (2) Wide range of specific limits
• (3) Unfavorable dynamic characteristics of equipment
• (4) Lack of test data on systems characterization
• (5) Unique characteristics of the ground shaking
• (6) Severe amplification of ground motion within buildings’ floors
Sometimes conventional protection is not a reliable option. Conventional seismic protection are difficult to design, implement and achieve for large seismic events. Conventional fixed base options for local protection of equipment can not be realistically designed in large seismic events (in regions of high seismicity).
Nonstructural damage in fixed-base building

Ground motion is amplified by the structure
Interstory drift
Floor accelerations

Important considerations:
- Dynamic interactions between the NSC and building
- Fundamental periods of structure and the NSC-subsystems
- Damping in the structure and in systems
- Type of support and location of the NSC within the building

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PPS: seismic isolation with energy dissipation mechanisms

Simplicity: PPS effectiveness comes from having structural setting with flexible interfaces able to absorb seismic energy, to shift the natural frequency of the system away from the damaging shaking frequency ranges, and to control displacements through energy dissipation mechanisms.

- PPS have emerged to offer global structural protection against the damaging effects of earthquake
- PPS implemented in structures performed extremely well

**Target:** Obtain PPS-equipment responses insensitivity to the dynamic properties of equipment
Feasibility studies

(1) Predict demands on pieces of equipment that are likely candidates for grouped or individual implementation of protective measures

(2) Examine the applicability of PPS arrangements in the form of platforms, floors, or individual systems to protect different equipment sets

(3) Identifying optimal characteristics of the protective measures

Final target: high-performance predictable options; and knowledge on interrelationship among multiple variables controlling the behavior equipment and components within multistory building environments
Target equipment

Hospitals, data centers, emergency response centers, power plans, transportation management and telecommunication centers, fire and police stations.

Equipment and components in the scope

**HIGH-TECH EQUIPMENT**
Communication and computer systems, high precision equipment, generic hospital equipment and specialty equipment

**COMPONENTS**
Stairwell, tanks and reservoirs

**MECHANICAL, ELECTRICAL, AND PLUMBING**
Pumps, chillers, fans, air handling units, motor control centers, distribution panels, transformers, air compressors, batteries, generators, low voltage switchgear, valves
PPS strategies for equipment

- PPS have proven effective in isolating seismic vibrations on equipment for **nuclear plants** but the systems are rarely used in other applications

- Spherical shaped sliding bearings
- Roller frictional bearings
- Multi-stage rubber bearings with combination of pneumatic isolators.

Three-dimensional seismic isolation system (Uri et al., 1993)
A floor Isolation system

Interconnected floor modules with multi-linear coil springs, low friction casters roller supporters, and PTFE-stainless flat slider bearings.

Experimental earthquake shaking to obtain the system’s design optimization parameter. (SIE inc, 2007). The experiment confirmed a significant reduction in acceleration levels, up to 8.5 times smaller than those for fixed base conditions.

DIS isolation floor system (SIE inc, 2007). 2012-Structures Congress
The use of PPS to achieve complex performance objectives

- To achieve the desired long period and large displacements in comparison to the dimensions and weight of equipment
- To attain large effective isolation period and accommodate large displacements under low gravity load without instability problems
- Acceleration and displacement control in upper floors
- Unique characteristics of the ground shaking including strong vertical components may accentuate deficiencies in vibration sensitive equipment and disrupt functionality
- Rocking prevention of tall cabinets and equipment with tall center of masses
Dynamic simulations: ground motions

Near-field ground motions
Ground motion with large vertical acceleration components
Long-period, long-duration subduction-zone-type motions

Elastic response spectra for different damping ratios

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Isolation systems: PPS floor/platforms

- Single-layer PPS with and without dampers
- Double-layer PPS

What we are looking for:
PPS-equipment responses insensitivity to the dynamic properties of the equipment's

- Friction Pendulum: with high damping either by high friction or by addition of viscous damping
- Friction or roller type of bearings are the simple means to archive long period under load gravity without instability problems
- Rocking prevention of tall cabinets and equipment with tall center of masses

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Exploration with FP bearings and XY-FP

• FP bearings have more than one pendulum mechanism: double and triple FP bearings and the XY-FP bearings with tension resistance

• **FP type or roller bearings:**
  Their flexibility and energy absorption mechanisms are independent: flexibility controlled by geometry (R) and energy dissipation controlled by friction

\[ T = 2\pi \sqrt{\frac{R}{g}} \]

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Search for optimal placement

Defining effective locations for essential equipment in multistory facilities is always a challenge.

The tuned mass damper analogy
The equipment or components-PPS platforms/floors will represent the secondary systems (spring and mass), and the building is the primary structure.

Installing seismic isolators and damping devices to support equipment and components at roof level?

Dampers and isolators properties selected as vibration absorber.

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Search for optimal placement

Facts:

*The tuned mass damper analogy*

Roof isolation systems to reduce earthquake demands on the building (Roberto Villaverde)

Elastomeric bearings and viscous dampers connected at the roof of a 5-story building reduced interstory drift up to \( \approx 80\% \) for the moderate earthquake and up to \( \approx 35\% \) for a larger magnitude earthquake.

A recent application: 185 Berry Street in San Francisco: a 1989 3-story special concrete moment frame was retrofitted using seismic isolation with two additional floors above the roof on top of an isolation system without increasing the base shear demand.
Preliminary results

- Numerical analyses of lightweight cabinets over FP isolation systems with and without viscous dampers under near-field ground motions have confirmed previous findings on:
  - FP with low friction and additional damping performed better than FP bearings with higher friction coefficient without dampers.
  - Dampers with damping ratio of 50% were most effective controlling displacements.
  - These results do not reflect effects of building properties in both protective systems and equipment responses.
Future directions

NSF-CAREER: Passive Seismic Protective Systems for Nonstructural Systems and Components in Multistory Building (Award number CMMI-1150462)

- Evaluation of protective measures and feasibility studies
- Implementation of solutions and testing program definition
- Evaluation of methodologies for design and practical implementation

Thank you