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METHODS FOR ENHANCING THE BUILDINGS BEHAVIOUR AT SEISMIC MOTIONS

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ABSTRACT

Improving a building's behavior during seismic events represents a critical aspect of structural engineering, aiming to reduce damage, ensure safety and preserve functionality for the buildings. Several methods and technologies have been developed over the years to improve a building's performance in seismic motions. These methods can be categorized into design strategies, damping systems, base isolation and retrofit techniques if they are applied to old buildings. A numerical analysis is performed to highlight the isolation characteristics of buildings and how the response is modified in the event of seismic motion. The results are presented in terms of displacements, velocity, vibration period and energy which are decisive for defining the building's seismic behavior.

KEYWORDS: seismic action, seismic isolation, damping, displacement, velocity, energy dissipation, vibration period

1. INTRODUCTION

One of the most significant advancements in seismic protection was the development of base isolation systems. These systems decouple the building from ground motion by using flexible bearings or isolation pads between the building and its foundation.

The first major use of base isolators was in the 1970s, with the New Zealand seismic isolation project serving as a key milestone.

Elastomeric bearings, sliding bearings and spring-based isolators began to be developed, reducing seismic forces by allowing the structure to "float" above the ground and absorb ground motion.

The 21st century saw an explosion in the development of seismic dampers that help dissipate the earthquake energy. These systems include viscous-elastic dampers (using materials that absorb and dissipate seismic energy), friction dampers (using friction to resist motion), tuned mass dampers (TMD), which counteract building vibrations by using a mass that moves in opposition to the structure's motion.

Retrofitting older buildings to make them more earthquake-resistant became a priority in many seismic zones, while engineers began to design techniques that could be applied to existing buildings without major structural changes, including the addition of bracing systems, damping devices, and base isolators.

The introduction of smart materials like shape memory alloys (SMA) and fiber-reinforced polymers (FRP) has enhanced retrofitting, allowing buildings to flexibly resist seismic forces.

As digital technologies advanced, countries with significant seismic activity (Japan, Mexico, Chile and U.S.) began deploying Earthquake Early Warning Systems (EWS) since these systems can detect seismic waves and provide seconds to minutes of warning before the more destructive shaking arrives. This technology has helped reduce injuries and fatalities by alerting people to take cover, stopping trains and shutting down industrial operations.

The future of seismic protection lies in the emergence of smart buildings. Modern buildings are increasingly equipped with smart technologies that can monitor structural health in real-time. The desiderate can be fulfilled by sensors embedded in buildings that can detect vibrations, displacements and stress levels during an earthquake, helping to assess the building's response and guide maintenance and retrofitting decisions.

Future advancements are focused to nanotechnology and composite materials that could make buildings even more resilient and could be used to create buildings that automatically adjust to seismic forces.

2. SPECIFIC METHODS IN USE FOR BUILDINGS SEISMIC PROTECTION

2.1. Design strategies

There are proactive measures taken during the design phase of a building to enhance its earthquake resistance.

Strengthening and stiffening the structure leads to increase the building stability to resist seismic forces by designing with stronger materials (reinforced concrete, steel).

The goal is to optimize the structural layout to ensure uniform stiffness and strength distribution and avoid irregular shapes or floors with drastically different stiffness [1-4].

2.2. Damping systems

Damping systems dissipate the energy imparted to a building during seismic motion, reducing vibration amplitudes.

Visco-elastic damping systems consist of materials with both elastic and viscous properties, which absorb and dissipate vibrational energy, that are installed at strategic locations, such as the building's floors or along the structural frames.

Friction-based dampers are designed to absorb energy by creating controlled friction during seismic motions. These devices can be implemented at the connection points between structural elements.

Tuned Mass Dampers (TMD) is a device that uses a mass and spring system to counteract the oscillations of the building's structure. The damper is tuned to vibrate out of phase with the building's natural vibration, reducing overall movement.

Viscous dampers are using a fluid to convert kinetic energy into heat and can be installed in various parts of the structure to reduce motion during seismic events.

Base isolation decouples the building from ground motions by using flexible bearings or isolators between the foundation and the superstructure. This prevents the seismic waves from being transmitted directly to the building.

Elastomeric bearings are made of layers of elastomeric rubber and steel, these bearings allow the building to move independently of the ground shaking, reducing the seismic force transmitted to the structure.

Sliding bearings allow for horizontal displacement, using materials that slide under seismic motion, while the sliding motion reduces the forces transferred to the building.

Hybrid isolation systems combine both elastomeric and sliding bearings, often with additional damping devices, in order to provide a more effective isolation system [2-5].

2.3. Retrofitting techniques

Retrofitting techniques involves upgrading existing buildings in order to improve their seismic performance.

These techniques are using reinforced concrete or steel braces to strengthen structural elements (columns, beams, and walls) and shear walls or moment-resisting frames in order to enhance structure lateral stability.

Also it is considered adding damping systems to existing buildings by implementing friction or viscous dampers to existing structures and so it can significantly reduce their seismic response.

By strengthen foundations by increasing their mass or stiffness, or by adding additional pile foundations to resist uplift or lateral movement it is also possible.

For older buildings, base isolation systems can be added to decouple the building from seismic motions and is provided enhanced performance during earthquakes [3-7].

2.4. Seismic Bracing and Lateral Support

Shear walls strategically added increase the lateral strength and stiffness, while diagonal bracing systems (such as X-bracing or K-bracing) introduced add improved resistance to lateral forces and stabilize the structure.

Moment-resisting frames allow the structure to deform without failing during seismic motion, by relying on bending and flexural strength rather than shear [4-6].

2.5. Monitoring and Early Warning Systems

The so-called structural health monitoring systems (SHM) make use of sensors to monitor the real-time performance of the building, detecting vibrations, accelerations and displacements. All the received data from these systems can be used in order to adjust damping systems in real-time or can inform emergency protocols. These systems are able to detect initial seismic waves (P-waves) and further send alerts with seconds before the damaging waves (S-waves) arrive, giving building occupants time to take protective actions [5-8].

2.6. Building Materials Innovation

High-performance concrete (HPC) incorporates high-performance materials such as fiber-reinforced concrete, providing better ductility and energy dissipation under seismic forces.

Shape memory alloys (SMAs) are able to preserve their original shape after being deformed and can be used to create self-repairing systems for structural components.

Lightweight materials are using lightweight materials in non-structural components (walls, floors) reduces the overall mass of the building, which in turn lowers seismic forces acting on the structure [1-5].

3. BUILDING BEHAVIOUR IMPROVEMENTS WITH SEISMIC PROTECTION

Improving the seismic response of buildings considering various protective methods such as base isolation, damping and strengthening can be done by simulating the structure's behavior under seismic forces and applying appropriate measures according with the obtained results from numerical analysis and experimental research activities.

A numerical analysis is carried out to show the behavior of the structure when it has no seismic protection systems and analyze the seismic response of a building without any protective systems and then with installed protection systems that have the capacity to improve the seismic performance by incorporating base isolation and damping systems.

The unprotected building is modeled as a structural system under seismic load and the equation of motion for the building is:

$$m\ddot{x} + c\dot{x} + kx = F(t) \qquad (1)$$

where:
m - mass of the building;
c - damping coefficient;
k - stiffness of the building;
x(t) - displacement of the building;
F(t) - seismic force (ground motion).
Dynamic equation for base isolation:

$$m\ddot{x} + c\dot{x} + k_{isolation}x = F(t) \qquad (2)$$

Vibration period without seismic isolation is calculated using the basic formula:

$$T = 2\pi\sqrt{\frac{m}{k}} \qquad (1)$$

Vibration period with seismic isolation is introducing the reduced stiffness *Keff*, which represents the effect of seismic isolation [3-9].

4. NUMERICAL ANALYSIS RESULTS

A numerical analysis has been made considering the parameters involved for the building (before protection), building mass, building stiffness (k = 50000 N/m), damping coefficient, c=0.02 and seismic force as sinusoidal ground motion (F_seismic). Also the parameters for base isolation and damping are represented by base insulator stiffness (k_isolator = 5000 N/m), damping coefficient for viscous damper c_isolator = 0.15 and insulator mass (m_isolator).

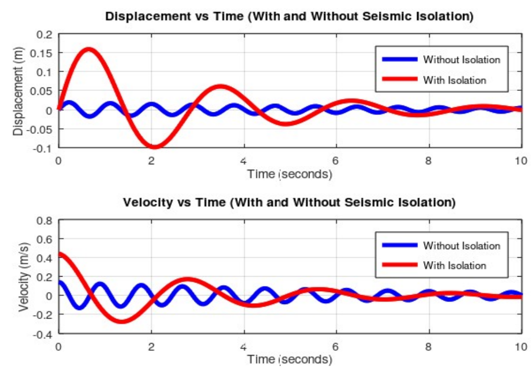

Fig. 1. Relative displacement and velocity results in time for buildings with and without isolation

Seismic isolation increases the vibration period, making the structure oscillate more slowly, (as shown results in figure 2). Damped vibration period *(T)* is slightly higher than the case without isolation due to damping effects and further the energy dissipation is stronger in the isolated case, leading to faster decay in oscillations.

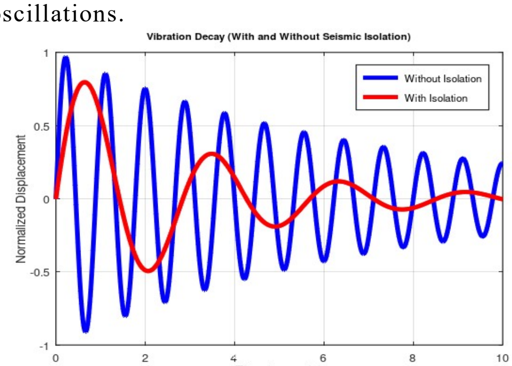

Fig. 2. Vibration period results for buildings with and without isolation

In seismic design, the kinetic energy from the structure motion and the potential energy from the structure deformation are considered. Seismic isolation is reducing the transmitted forces and consequently the total energy transferred to the structure.

When a base isolation system is installed on a structure, it has the ability to modify the building's response to earthquakes in the sense that it reduces seismic forces by allowing the building to remain stable while the ground moves and this behavior is made possible precisely by flexible bearings damping or isolation) and real-time monitoring.

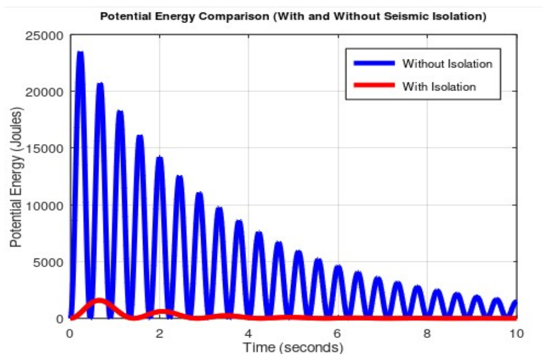

Fig. 3. Potential energy results for buildings with and without isolation

It can be seen from figure 3 that potential energy decreases over time due to damping.

The isolated system has lower peak potential energy since stiffness k is much lower.

Energy dissipation is stronger within the isolated system, meaning it loses energy faster, while the fixed-base building stores more energy due to its higher stiffness.

5. CONCLUSIONS

Without seismic isolation the building experiences higher forces due to shorter periods, which increases the risk of damage.

With seismic isolation the building experiences lower forces due to the longer periods and damping, reducing the potential for structural damage and increasing the safety of occupants.

Seismic isolation significantly improves safety by reducing both the displacement and velocity of the structure during an earthquake, ensuring that the forces transmitted to the building are lower and the damage is minimized.

By using a combination of the above mentioned protective methods buildings can be designed or retrofitted in order to perform better under seismic loads.

The key to successful seismic design lies in a balanced approach that combines preventive measures such as proper design, material selection and specific isolation equipment.

Each approach should be tailored to the specific needs of the building, the expected seismicity of the area, and the building’s function. Proper implementation of these technologies can significantly reduce the risk of structural damage, protect human lives and minimize post-event repair costs.

Seismic isolation represents an effective method to reduce the impact of earthquakes on buildings while it allows larger displacement with controlled motion and dissipation of energy, which reduces the forces acting on the structure.

By increasing the vibration period and damping energy, seismic isolation enhances the overall stability and safety of the building, protecting it from damage during seismic events.

Although seismic isolation results in larger displacements, it is important to note that the reduced velocities and energy dissipation mitigate the risk of structural failure, especially in buildings near active fault lines.

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