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SEISMIC ISOLATION AND ENERGY DISSIPATION SYSTEMS FOR SAFE STRUCTURES

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ABSTRACT

The seismic protection of buildings has been a successful strategy for the past 30 years. Seismic protection systems ensure the safety of any type of building even under most severe earthquakes. Seismic devices not only protect the buildings against earthquake damage, but also provide comfortable movement of the whole structure. Seismic protection devices ensure the proper functioning of the structure during all service condition such as effects of temperature, wind, braking forces or impacts. In the occurrence of an earthquake, the protection system will ensure the safety of the structure, by avoiding damage to structural elements.

KEYWORDS: energy dissipation, seismic isolation, damper device

1. INTRODUCTION

Earthquake resistant design of building structures has been based on a ductility design concept. The performances of the intended ductile structures during major earthquakes have proved to be unsatisfactory and below expectation. To enhance structural safety and integrity against severe earthquakes, more effective and reliable techniques for seismic isolation design of structures based on structural control concepts are desired. Among the structural control schemes developed, seismic base isolation and energy dissipation are the most promising alternatives. It can be adopted for new structures as well as the retrofit of existing buildings and bridges. Seismic isolation is most often installed at the base level of a building and is called base isolation. This concept meets all the criteria for a classic modern technological innovation: the necessary imaginative advances in conceptual thinking, new materials available to the industry and as it can be seen when using isolators, simultaneous development of the ideas worldwide.

2. SEISMIC ISOLATION

The principle of seismic isolation is to introduce flexibility at the base of a structure in the horizontal plane, while at the same time introducing damping elements to restrict the amplitude of the motion caused by the earthquake. The concept of seismic isolation became more feasible with the successful development of mechanical energy dissipators and elastomers with high damping properties.

The objective is to decouple the building structure from the damaging components of the earthquake input motion, i.e. to prevent the superstructure of the building from absorbing the earthquake energy. The entire superstructure must be supported on discrete isolators whose dynamic characteristics are chosen to uncouple the ground motion. Some isolators are also designed to add substantial damping.

There are three basic elements in any practical seismic isolation system. These are as follows:

- A flexible mounting so that the period of vibration of the total system is lengthened sufficiently to reduce the force response;

- A damper or energy dissipator so that the relative deflections between building and ground can be controlled to a practical design level;
- A means of providing rigidity under low (service) load levels, such as wind and minor earthquakes.

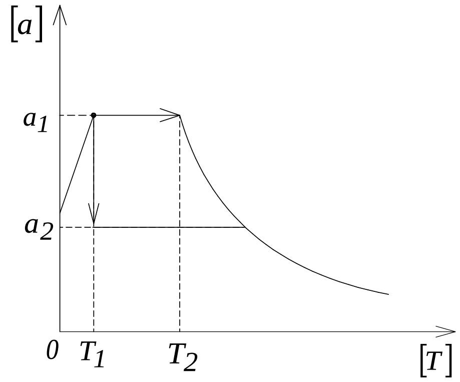

Fig. 1. Reduction of acceleration by seismic isolation

Seismic isolation achieves a reduction in earthquake forces by lengthening the period of vibration in which the structure responds to the earthquake motions. The most significant benefits obtained from isolation are thus in structures for which the fundamental period of the building without isolation is short-less than one. Seismic isolation can significantly reduce both floor accelerations and interstory drift and provide a viable economic solution to the difficult problem of reducing nonstructural earthquake damage, as illustrated in Fig.1 and 2.

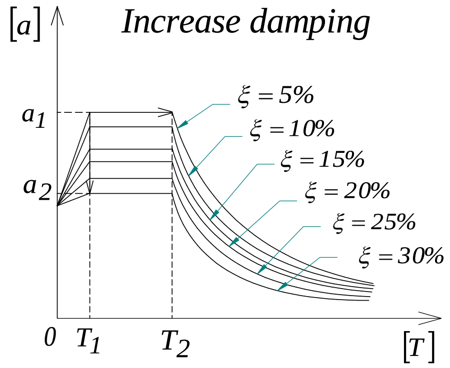

Fig. 2. Reduction of acceleration by additional damping

Displacement and yielding are concentrated at the level of the isolation devices, and the superstructure behaves very much like a rigid body. Some of the commonly used isolation systems are laminated rubber (or elastomeric) bearings and sliding isolation systems. A base isolated structure is supported by a series of bearing pads, which are placed between the superstructure and the building's foundation. There are different types of bearing pads, for example lead-rubber bearings.

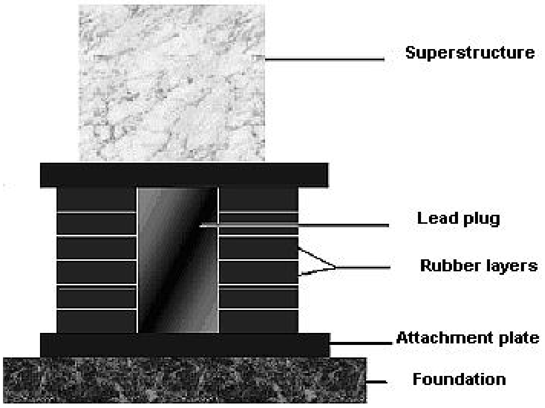

Fig. 3. Lead Rubber Bearing

Laminated rubber bearings are used with passive dampers for control of excessive base displacement. Laminated rubber bearings with inherent energy dissipation capacities are also developed. Lead rubber bearings and high damping rubber bearings are examples of this category of isolation system.

A lead-rubber bearing is a “sandwich” of many layers of rubber and steel. In the middle of this system there is a solid lead "plug". At the top and bottom, two steel plates attach the bearing to the building and foundation. The bearing is very stiff and strong in the vertical direction, but flexible in the horizontal direction.

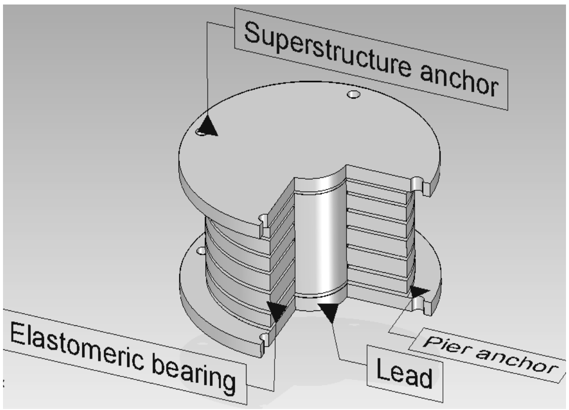

Fig. 4. 3D-Model of Lead Rubber Bearing

The forces, f, mobilized in the laminated rubber bearings can be modelled by a visco-plastic model such as:

$$f_x = k_p u_x + \left(k_e - k_p\right) u^y z_x \qquad (1)$$

$$f_y = k_p u_y + \left(k_e - k_p\right) u^y z_y \qquad (2)$$

where:

- k_e - pre-yield stiffness;
- k_p - post yield displacement;
- z_x , z_y - dimensionless hysteretic variables;
- u^y - yield displacement.

Sliding bearing is another type of seismic isolation. It is placed between the foundations and the superstructure of the building, and it is composed of two parts: the first one, fixed to the foundation, has got a low friction curved surface, so that the second part can slide on it.

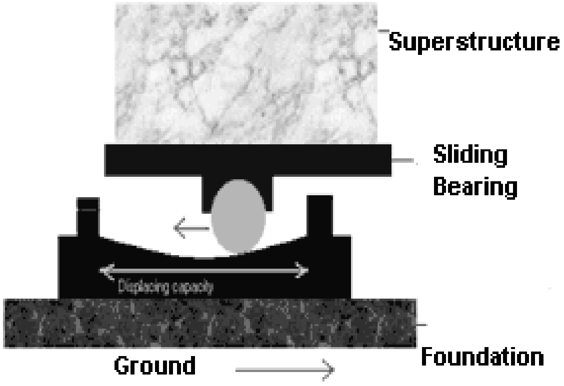

Fig. 5. Sliding Bearing

Sliding bearings mainly utilize PTFE with stainless steel plates, flat or spherical interface. Sometimes separate elements are provided for recentering the isolated system.

The forces, *f*, mobilized in the sliding bearings can also be modelled by a visco-plastic model such as:

$$f_x = k_p u_x + \mu N z_x \qquad (3)$$

$$f_y = k_p u_y + \mu N z_y \qquad (4)$$

where:

- μ - coefficient of friction;
- N - normal force.

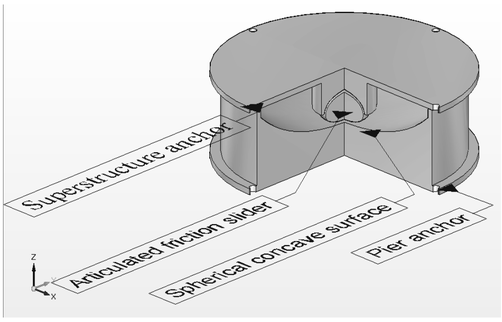

Fig. 6. 3D-Model of Sliding Bearing

The movement of the slider generates a dynamic friction force that provides the required damping for absorbing the energy of the earthquake. Assuming small deformations, the unidirectional force–deformation response of the sliding bearing is:

$$f = N\,\mu\,sgn\left(\delta\right) + \frac{N}{R}\delta \qquad (5)$$

$$f_R = \frac{N}{R}\delta\,;\; f_\mu = N\,\mu\,sgn\left(\dot{\delta}\right) \qquad (6)$$

where N is the normal force acting on the sliding surface, R is the radius of the concave surface, δ is the sliding deformation, $\dot{\delta}$ is the sliding velocity, and $sgn\left(\dot{\delta}\right)$ is the signum function, i.e., equal to $+1$, or -1 depending on whether $\dot{\delta}$ is negative or positive, respectively.

The fundamental parameters for the device design are the following:

- Isolated structure period *(T)*:

$$T = 2\pi\sqrt{\frac{R}{g}} \qquad (7)$$

- Horizontal stiffness of the device *(K)*:

$$K = \frac{W}{R} \qquad (8)$$

- Horizontal load given by the device *(H)*:

$$H = \mu W + K\delta \qquad (9)$$

- ξ_{eff} = effective damping of the isolation system;

$$\xi_{eff} = 2\left[\mu/\left(\mu+\delta\right)/R\right]/\pi \qquad (10)$$

The performance of base isolated buildings in different parts of the world during earthquakes in the recent past established that the base isolation technology is a viable alternative to conventional earthquake-resistant design of medium-rise buildings.

3. ENERGY DISSIPATION

While seismic isolation is a proven strategy to mitigate seismic damage, the complex dynamic response of the structure often requires additional devices in order to control the horizontal displacements. The best way to ensure a safe structure is by combining seismic isolation and energy dissipation. This allows to provide the structure with a higher damping, and therefore a better dynamic response during a seismic event. In structures where seismic isolation is not a recommendable solution (soft soils), damping systems with high dissipation capabilities become the best seismic protection alternative. The use of effective devices able to dissipate high amounts of energy ensures that other structural elements do not undergo excessive demands that could cause significant damage. These energy dissipation devices are fluid viscous dampers, friction dampers or yielding dampers.

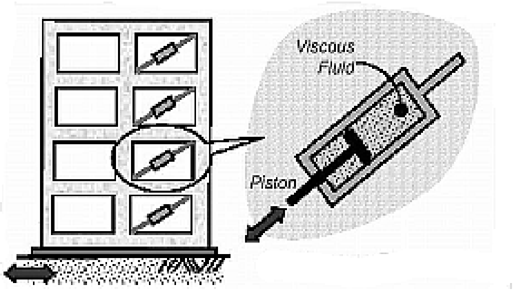

Fig. 7. Fluid viscous damper

Energy dissipation devices can absorb a portion of earthquake-induced energy in the structure and minimize the energy dissipation demand on the primary structural members such as beams, columns, or walls.

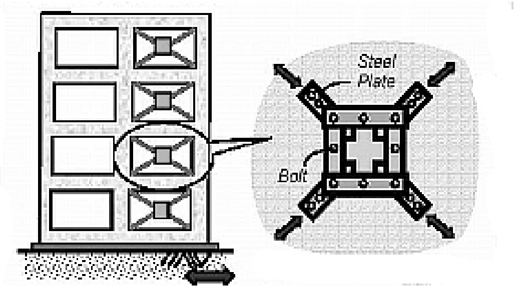

Fig. 8. Friction dampers

These devices can substantially reduce the inter-story drifts and consequently nonstructural damage. In addition, lower accelerations and smaller shear forces lead to lower ductility demands in the structural components.

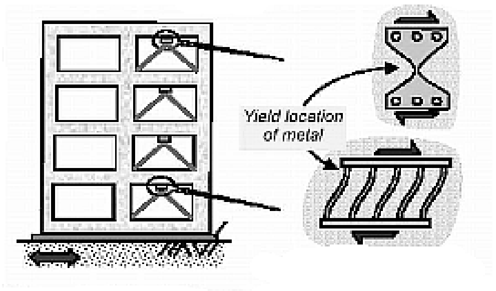

Fig. 9. Yielding dissipators

These systems include a range of materials and devices for enhancing damping, stiffness and strength. They are characterized by their capability to dissipate energy either by conversion of kinetic energy to heat or by transfer of energy among different modes of vibration.

4. CONCLUSIONS

The main feature of the base isolation technology is that it introduces flexibility in the structure. The isolators are designed to absorb energy and thus add damping to the system. This helps in further reducing the seismic response of the building.The base isolation bearings with considerable lateral flexibility help in reducing the earthquake forces by changing the structure fundamental period to avoid resonance with the predominant frequency contents of the earthquakes. The sliding bearings filter out earthquake forces via the discontinuous sliding interfaces, between which the forces transmitted to the superstructure are limited by the maximum friction forces, function of earthquake intensity. The sliding systems perform very well under a variety of severe earthquake loadings and are quite effective in reducing the large levels of the superstructure’s acceleration without inducing large base displacements. Seismic isolation and energy dissipation systems offer attractive alternatives to conventional design, and all these methods can be used to reduce the earthquake input energy and concentrate the inelastic deformations in the isolators or damping devices, protecting critical elements of the structural frame from damage.

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