Understanding Seismic Isolators

Loss Control TIPS

Introduction

An earthquake is a trembling or shaking of the ground caused by the sudden release of energy stored in the rock beneath the earth's surface. Great forces acting deep in the earth put stress on the rock, which then bends and changes the volume (strain) of the rock. Rock can only be deformed so far before it breaks. When the rock breaks, waves of energy are sent through the earth. These waves of energy, called *seismic waves*, are what causes the ground to tremble and shake during an earthquake.

As the earthquake's ground motions pass under each structure, they impart kinetic energy into the structure. Through its design and construction, the structure must absorb and control this energy as it is dissipated throughout the structure, else it will deform and perhaps collapse.

How Buildings Are Affected by Earthquakes

The forces that seismic waves impart into a structure are dependent on the weight of the structure and the acceleration of the supporting earth (Newton's second law, F=ma). Some structures, like small frame and steel buildings, are light and flexible enough to dissipate the seismic energy through nondestructive movement. But in larger and heavier buildings of all types, as their weight (mass=weight/gravity) increases and as their height (moment arm) increases, greater forces can enter the structure, resulting in higher levels of energy which must be dissipated.

Each structure also has a natural *frequency* or speed of vibration; that is, a natural "pitch" of natural resonance. If a structure's natural vibration frequency coincides with seismic waves of the same frequency, then even more of the seismic kinetic energy can enter the structure, causing greater potential for damage. For example, structures in the 10-story range have a similar natural frequency of some soils that are prone to amplify seismic vibration. During seismic activity, the structure and the soil will vibrate at the same rate, allowing increased amounts of kinetic energy to enter the structure. This energy must be safely dissipated to prevent damage to the structure.

Protecting Buildings By Design

For years, the design community has understood these forces, and have known how to design buildings so that they can better withstand seismic forces, but economics have restricted builders from using this knowledge. However, in recent years , building codes have required more conservative design criteria to account for the seismic forces that a structure must dissipate. These building code requirements are forcing building owners to use more conservative seismic-resistant designs.

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Given the latitude of the more conservative design, designers can follow either of two basic approaches when they consider seismic energy forces:

1. *design* the structure so that it can accommodate seismic energy that may enter it
2. *isolate* the seismic energy and reduce or divert it before it enters the structure.

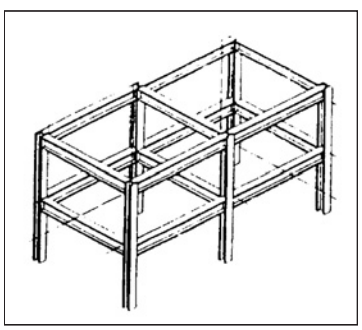
Both approaches can be used in a single structure.

Structural Design

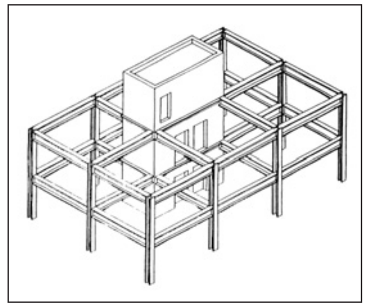
Since structures are already designed to resist the vertical forces of gravity, little additional vertical strength is needed to account for the vertical aspect of seismic forces. However, since seismic forces also impart horizontal forces, a successful structural design must also account for this additional horizontal force. Although buildings already incorporate horizontal strength components to resist wind forces, seismic forces are typically greater than wind forces; therefore, buildings require greater strength components to resist horizontal seismic forces. Several suitable structural forms which are frequently used for earthquake resistance design for horizontal forces are:

- Moment resisting frames
- Framed tube structures
- Structural walls (shear walls)
- Concentricity braced frames
- Eccentricity braced frames
- Hybrid systems

Moment Resistant Frames. Moment resistant frames are the most common form of modern structure. Beams are usually welded to columns or bolted solid so that column movement is imparted into the beams as bending moments because of the rigid connection between the two. Energy is dissipated throughout the length of the beams. The great advantage of seismic resistant moment resisting frame structures is that they avoid potentially brittle failure modes. A disadvantage is that they tend to sway excessively.

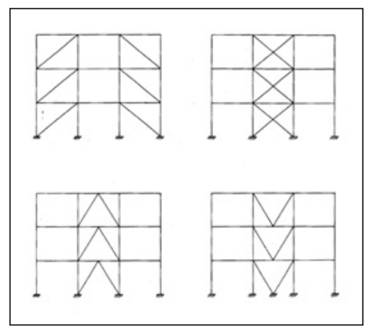


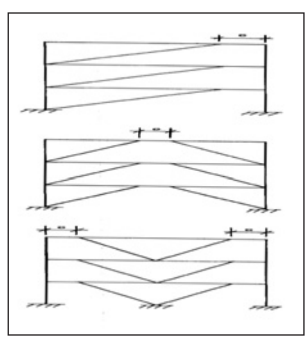
Framed Tube Structures. Framed tube structures are a special type of moment resisting frame. They are constructed with very wide columns closely spaced and with relatively deep beams. This type of framing is usually located on the perimeter of the structure. Because of the added strength of the wide columns and deep beams, this type of structure introduces more stiffness. This stiffness is used to overcome the potential problems caused by the horizontal sway which occurs during an earthquake. The framed tube method is frequently used in very tall buildings where swaying could be a major problem.



Shear Wall Structures. In structural wall (shear wall) structures, the resistance to horizontal forces is principally provided by walls. The walls are usually constructed of reinforced concrete, reinforced masonry, timber, or steel. The walls provide natural inter-story stiffness by limiting inter-story deflections. The use of lintels between coupled walls will also provide ductility and energy-dissipating characteristics to help protect the walls (and ultimately the structure) from excessive damage.

Concentricity Braced Frame Structures. In concentricity braced frame structures, the center lines of all intersecting members meet at a point. This traditional form is frequently used in towers, bridges, and buildings. The bracing takes the form of a single diagonal in a bay, or a double bracing in an X form. Braced frames have smaller deflections than moment resisting frames, but they are more prone to undesirable buckling and have less reliable ductility.





Eccentricity Braced Frame Structures. In eccentricity braced frame structures, the center lines of the intersecting members meet at a point. The bending forces in the beams are transmitted to the columns through the braces. If properly designed, this system provides good ductility while retaining the advantage of reduced horizontal deflection.

Hybrid Structures. Hybrid structures combine two or more of the previously described types of lateral resisting systems. The most common combination is the moment resisting frame combined with shear walls.

All these systems are designed to control the location and extent of the damage caused by the kinetic energy that enters a structure, while maintaining structural integrity for life safety (that is, to allow people to survive and escape).

Seismic Isolators

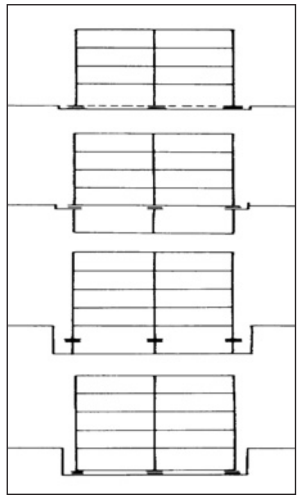
The second method of dealing with the kinetic energy that enters a structure during an earthquake is to actually reduce the amount of energy that enters the structure. This may be done by:

1. limiting the amount of energy at the point of entry by using energy-avoiding devices at the foundation level, and/or
2. providing energy-dissipating devices within the structure from the foundation upward.

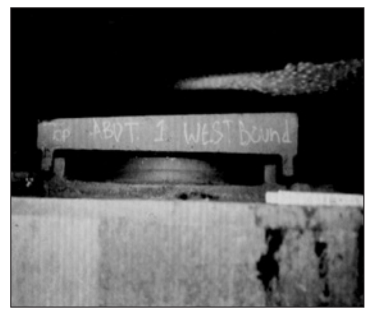
These devices, called *seismic isolators*, are not a new idea. Such devices have proved very effective in similar non-seismic applications for many years. For example, flexible bearings are used to protect bridges from movement caused by changes in temperature. Damping devices are used on machinery to prevent vibrations from being imparted from the machine into its supporting structure.

The principle of isolation is to provide a discontinuity between the two bodies so that energy from the movement of either body cannot be fully transmitted. The discontinuity also disrupts the transfer of natural frequency motion (that is, vibrations). The isolating device consists of a layer between the two bodies; the layer is made of material that has a low transfer medium when compared with the movement of the bodies. A discontinuity device can be used to isolate horizontal seismic motions of a whole structure, part(s) of a structure, or items mounted at or near the base of the structure.

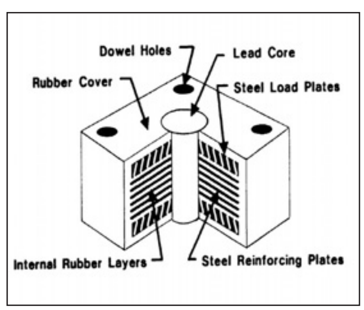
These isolators may take various forms, ranging from infinitely thin sliding surfaces (bearings), to multiple layers of rubber a few centimeters thick mounted in the base, to flexible or absorbing structural members of any depth. Because vertical stiffness is generally required for most gravity loads, seismic isolation is only appropriate for horizontal motions.



Ideally, the isolators should be located as low as possible in a structure so as to protect as much of the structure as possible. However, cost and practical considerations influence the choice of location. On bridges, it is mostly convenient to isolate only the bridge deck, because isolation to protect against movement caused by changes in temperature is required there anyway. In a building, the choice may lie between isolating at ground level, or below the basement, or at some point up the columns. Each location has advantages and disadvantages relating to accessibility and other very important design considerations such as cladding, partitions, and building services.

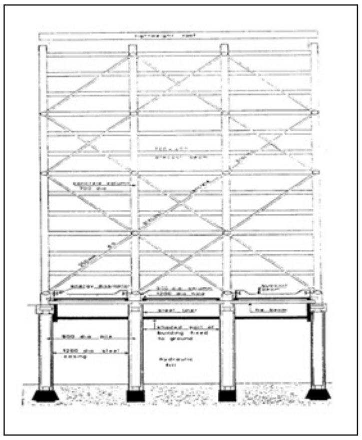


Base Isolation. A method of base isolation is to seat the base support structure in sliding bearings. These energy-dissipating devices, which isolate only horizontal forces, come in various shapes, forms, and sizes. This technology was developed for bridge construction to protect against thermal movement in the bridge deck. Bridges also use other type of isolator bearings, such as rocker or sliding plates. Some buildings incorporate the same approach.



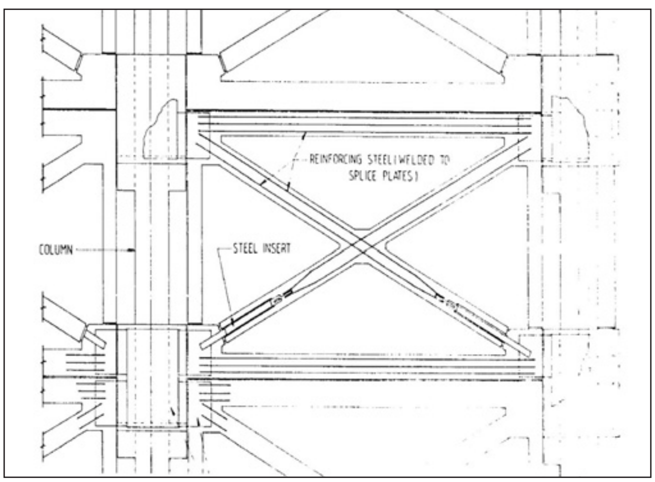
Another type of base isolator, the lead rubber bearing, was first used as a bridge isolator, but is becoming very popular as a building base isolator. When used in buildings for base isolation, lead rubber bearings provide flexibility and deflection control. This type of bearing has a lead plug energy dissipater in the core. Steel plates are laminated onto and into an elastomeric material. The lead core provides additional dampening behavior.

A number of other products emerging in the market are similar to the base isolators described.



Isolation Using Flexible Piles. Flexible piles are used on structures which require seismic lateral support and which, because of poor load-bearing soils, require end pile foundation support. End bearing piles are designed to flex when lateral forces are imposed on the structure. The piles are installed in a hollow tube, which separates them from the surrounding ground. Deflection control is accomplished at ground level using tapered steel energy dissipaters that are connected between each pile. Flexibility in the pile is attained by installation of a low moment hinge at the top and bottom of each pile.

Energy Dissipaters For Non Isolated Structures. Slotted reinforced concrete precast shear panels have also been used successfully in recent years in a number of Japanese high rise buildings. The panels are sandwiched between adjacent vertical columns and horizontal ductile beams. The panels are then connected to the beams of the steel frames, effectively stiffening the building.



Diagonal bracing incorporating energy dissipaters is frequently used to provide structural integrity and energy absorbing devices. This bracing method is frequently used in new construction and in seismic retrofits. The building obtains its lateral load resistance from energy dissipaters installed in the structure. Similar to the way very large shock absorbers are used in vehicles, one or a number of energy isolators are installed in the X or K bracing of the structure. The isolators, which may be installed in various configurations, come in various sizes and rated capacities and may be located throughout the structure.

Conclusion

As knowledge from past events is acquired, designers and builders are increasingly taking into consideration the effects of earthquakes and seismic energy on buildings. While early building codes were primarily concerned with life safety, recent codes now require more conservative designs to accommodate seismic forces.

A number of different methods and technologies are available for accommodating seismic energies. The two basic methods are 1) to minimize the amount of energy that actually enters the structure and/or 2) to dissipate the energy once it has entered the structure. New products are being developed to meet the demands of designers for seismic energy control, and even more stringent building codes are being developed. As scientists study each earthquake and its effects on structures, our knowledge increases. All of these factors will ultimately result in more cost-effective and safe buildings.

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