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Full Length Research Paper

Seismic isolation in buildings to be a practical reality: Behavior of structure and installation technique

A. B. M. Saiful Islam*, Mohammed Jameel and Mohd Zamin Jumaat

Department of Civil Engineering, University of Malaya, Kuala Lumpur, Malaysia.

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Although a great deal of research has been carried out regarding seismic isolation, there is a lack of proper research on its behavior and implementing technique in low to medium seismic region. The basic intention of seismic protection systems is to decouple the building structure from the damaging components of the earthquake input motion, that is, to prevent the superstructure of the building from absorbing the earthquake energy. This paper reviews a number of articles on base isolation incorporation in building structure. Lead rubber bearing (LRB), high damping rubber bearing (HDRB), friction pendulum system (FPS) have been critically explored. This study also addressed the detail cram on isolation system, properties, characteristics of various device categories, recognition along with its effect on building structures. Meticulous schoolwork has also been accomplished about installation technique for various site stipulations. The entire superstructure is supported on discrete isolators whose dynamic characteristics are chosen to uncouple the ground motion. Displacement and yielding are concentrated at the level of the isolation devices, and the superstructure behaves very much like a rigid body. Rigorous reckoning illustrated the isolation system as very innovative and suitable in buildings to withstand the seismic lateral forces and also contributed to safety ensuring flexibility of structures.

Key words: Seismic protection, base isolation, idealized behavior, hysteresis loop, ductility, installation technique.

INTRODUCTION

To minimize the transmission of potentially damaging earthquake ground motions into a structure is achieved by the introduction of flexibility at the base of the structure in the horizontal direction while at the same time introducing damping elements to restrict the amplitude or extent of the motion caused by the earthquake somewhat akin to shock absorbers. In recent years this relatively new technology has emerged as a practical and economic alternative to conventional seismic strengthening. This concept has received increasing academic and professional attention and is being applied to a wide range of civil engineering structures. To date there are several hundred buildings in Japan, New Zealand, United States, India which use seismic isolation principles and technology for their seismic design.

It may come as a surprise that the rubber foundation elements can actually help to minimize earthquake damage to buildings, considering the tremendous forces these buildings must endure in a major quake (Cheng et al., 2008; Islam and Ahmad, 2010). Contrasting the conventional design approach based on an increased resistance (strengthening) of the structures, the seismic isolation concept is aimed at a significant reduction of dynamic loads induced by the earthquake at the base of the structures themselves (Micheli et al., 2004, , Islam et al., 2010a, 2010b). Seismic isolation separates the structure from the harmful motions of the ground by providing flexibility and energy dissipation capability through the insertion of the isolated device so called isolators between the foundation and the building structure (Ismail et al., 2010).

Invention of lead rubber bearing (LRB, 1970's) and high damping rubber bearing (HDRB,1980's) gives a new dimension to the seismic base isolation design of BI structure (Islam, 2009; Hussain et al., 2010). ICBO (1997) included design specification for isolated structures as in Uniform building Code, UBC 1997. A

*Corresponding author. E-mail: abm.saiful@gmail.com. Tel: +60102573287. Fax: +60379675318.

significant amount of both past and recent research in the area of base isolation has focused on the use of elastomeric bearings, such as HDRB and LRB (Islam et al., 2011a, 2011b). Providakis (2008) investigated seismic responses of multi- storied buildings for near fault motion isolated by LRB. Dall'Asta and Ragni (2006, 2008), Bhuiyan et al. (2009) covered experimental tests, analytical model and nonlinear dynamic behavior of HDRB.

Although it is a relatively recent technology, seismic isolation for multi storied buildings has been well evaluated and reviewed (Barata and Corbi, 2004; Hong and Kim, 2004; Matsagar and Jangid, 2004; Komodromos, 2008; Lu and Lin, 2008; Spyrakos et al., 2009; Polycarpou and komodromos, 2010). Base isolator with hardening behavior under increasing loading has been developed for medium-rise buildings (up to four storeys) and sites with moderate earthquake risk (Pocanschi and Phocas, 2007). Nonlinear seismic response evaluation was performed by Balkaya and Kalkan (2003).

Resonant behaviour of base-isolated high-rise buildings under long-period ground motions was dealt by Ariga et al. (2006) and long period building responses by Olsen et al. (2008). Deb (2004), Dicleli and Buddaram (2007), Casciati and Hamdaoui (2008), Di Egidio and Contento (2010) have also given effort in progresses of isolated system. Komodromos et al. (2007), Kilar and Koren (2009) focused the seismic behavior and responses through dynamic analyses of isolated buildings. Wibowo et al. (2010) have done the failure and collapse modeling analysis of weak storey building. The low to medium earthquake risk region is prone to seismic hazard in the United States too. Many places at the Midwestern areas in US (Southern Illinois, Kentucky, Southern Indiana etc) experience low to moderate seismicity. However, for building construction in these zones, seismic base isolation can be a suitable alternative as it ensures flexibility of building and reduces the lateral forces in a drastic manner. Apart from this as the additional cost of using the system is favorable; these sites can also benefit from implementation of this base-isolation system, especially in such buildings as museums, data centers etc. Though the application of isolator is going to be very familiar all over the world, there is a lack of proper research to implement the device practically in low to medium risk seismic zone especially for local buildings in Dhaka, Bangladesh region as per the local requirements. So, this concern is a very burning matter for this study. Site specific earthquake data are also very important in seismic design. This study focused on the detail revise on isolation system, characteristics of various device categories, recognition along with its effect on building structures. Thorough schoolwork has also been accomplished about installation technique for various site stipulations.

SEISMIC ISOLATION COMING TO REALITY

Seismic isolation is intended to prevent earthquake damage to structures, buildings and building contents. One type of seismic isolation system employs load bearing pads, called isolators. They are located strategically between the foundation and the building structure and are designed to lower the magnitude and frequency of seismic shock permitted to enter the building. They provide both spring and energy absorbing characteristics. Figure 1 illustrates the behavior change of structure without isolator and with isolator incorporation.

The first seismic isolation system was proposed by Dr. Johannes Calantarients, an English medical doctor, in 1909. His diagrams show a building separated from its foundation by a layer of talc which would isolate the main structure from seismic shock. The oldest base isolated structure of the world, Mausoleum of Cyrus, is shown in Figure 2.

This technology can be used both for new structural design and seismic retrofit. In process of seismic retrofit, some of the most prominent U.S. monuments like Pasadena City Hall, San Francisco City Hall, Salt Lake City and County Building or LA City Hall. The seismic rehabilitation of the Los Angeles City Hall is a landmark event in the City's history. For Los Angeles City Hall (Figure 3a), in process of seismic upgrading, this high-rise building was placed atop a mechanical system of isolators, sliders and dampers called base isolation technology. Later on a few famous isolated buildings have also been shown in Figure 3. Bhuj Hospital (Figure 3b), New Zealand Assembly Library (Figure 3c) and New Zealand Parliament (Figure 3d) have been erected on Lead Rubber bearing type base isolator. Isolation system was also inserted at Te Papa Museum of New Zealand (Figure 3e). Figure 3f shows the practical construction of inserting seismic isolation system in Te Papa Museum building.

Early concerns were focused on the fear of uncontrolled displacements at the isolation interface, but these have been largely overcome with the successful development of mechanical energy dissipaters. When used in combination with a flexible device, an energy dissipater can control the response of an isolated structure by limiting both the displacements and the forces. Interest in base isolation as an effective means of protecting structures from earthquakes has therefore, been revived in recent years.

The following are the advance developments (Kelly, 1998) that have enabled base isolation to be a practical reality.

(a) The design and manufacture of high quality isolation bearings that are used to support the weight of the structure and at the same time, release it from earthquake induced forces.

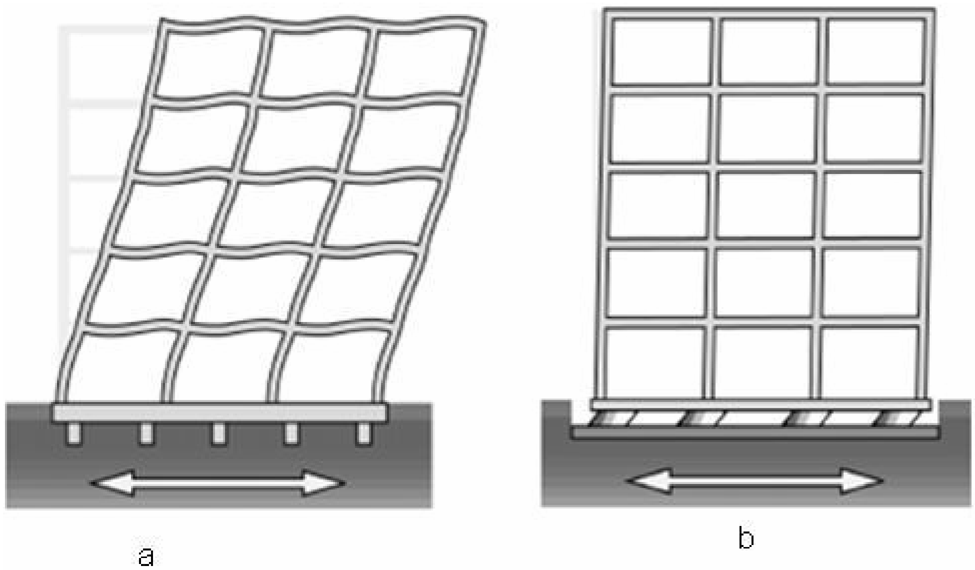


Figure 1. Behavior change while using isolator. (a) Conventional structure (b) base -isolated structure.

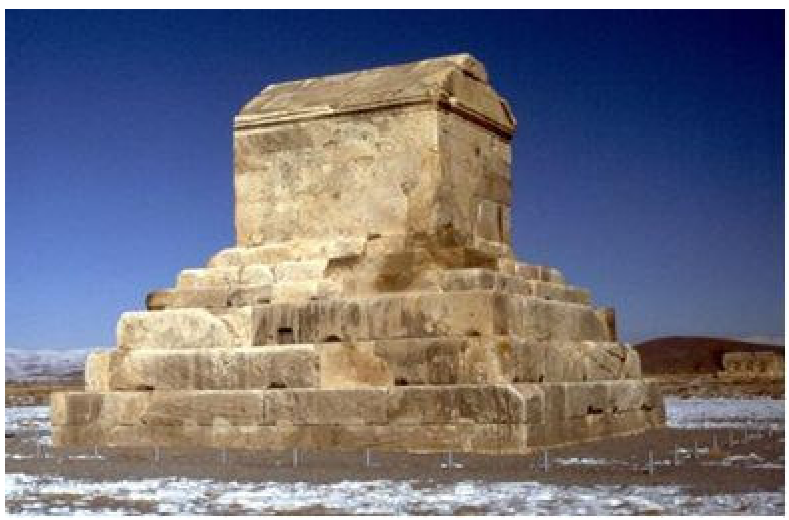


Figure 2. Mausoleum of Cyrus, the oldest base-isolated structure in the world.

(b) The design and manufacture of mechanical energy dissipaters (absorbers) that are used to reduce the movement across the bearings to practical and acceptable levels (4 to 6 inches) and to resist wind loads
(c) The development and acceptance of computer software for the analysis of base-isolated structure which includes nonlinear material properties and the time-varying nature of the earthquake loads.
(d) The ability to perform shaking table tests using real recorded earthquake ground motions to evaluate the performance of structures and provide results to validate computer modeling techniques.
(e) The development and acceptance procedures for estimating site-specific earthquake ground-motions for different return periods.

BASE ISOLATION SYSTEM

Basic elements of base isolation

Seismic Isolation increases the fundamental period of vibration so that the structure is subjected to lower earthquake forces. However, the reduction in force is accompanied by an increase in displacement demand which must be accommodated within the flexible

Figure 3. Some Renowned Base-isolated Structures, (a) Los Angeles City Hall, USA, (b) Bhuj Hospital, Gujrat, India, (c) New Zealand Assembly Library, (d) New Zealand Parliament, (e) Te Papa Museum of New Zealand, (f) Te Papa during Incorporation of Isolator.

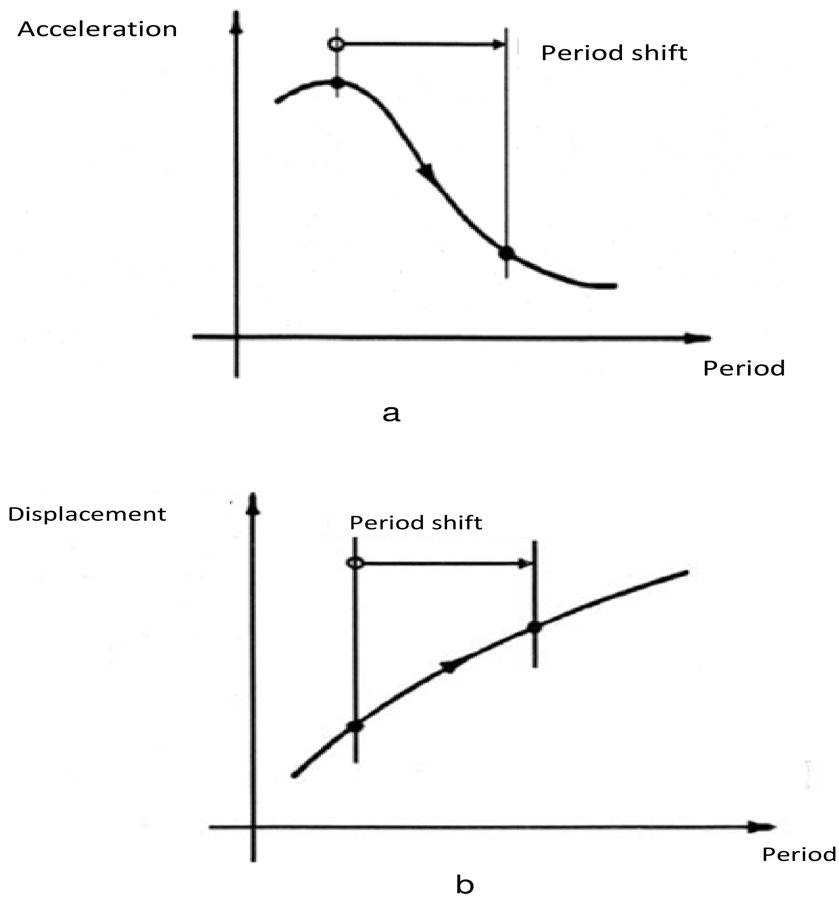


Figure 4. Impact of period elongation obtained by seismic isolation on accelerations. (a) Acceleration response spectrum, (b) displacement response spectrum and displacements of a structure.

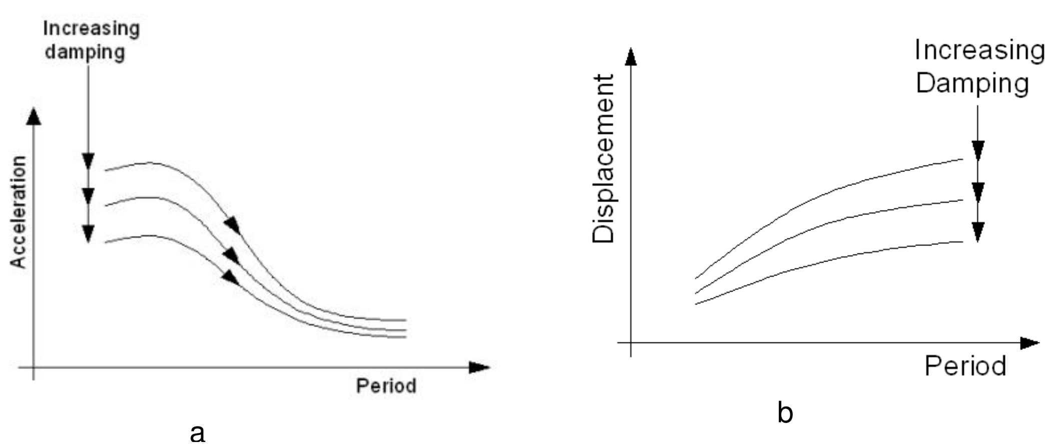


Figure 5. Acceleration and displacement response Spectrum for increasing damping. (a) Acceleration RS, (b) Displacement RS.

mount, Furthermore, longer period buildings can be lively under service loads. The following are three basic elements in any practical isolation system (Skinner et al., 1993), they are:

1. A flexible mounting so that the period of vibration of the building is lengthened sufficiently to reduce the force response.
2. A damper of energy dissipater so that the relative

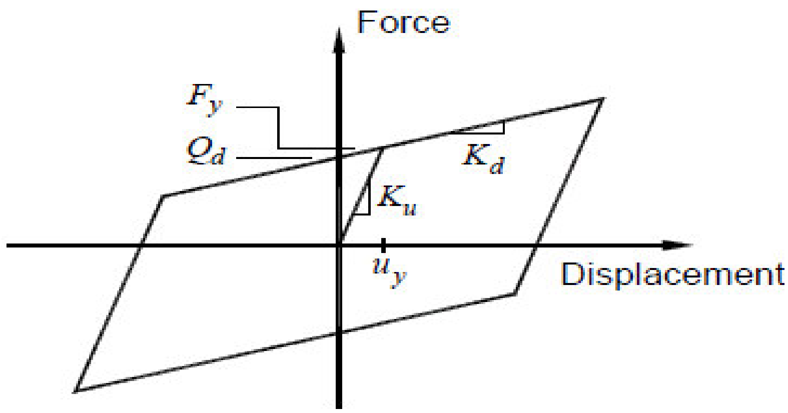


Figure 6. Idealized force-displacement (Hysteresis) Loop.

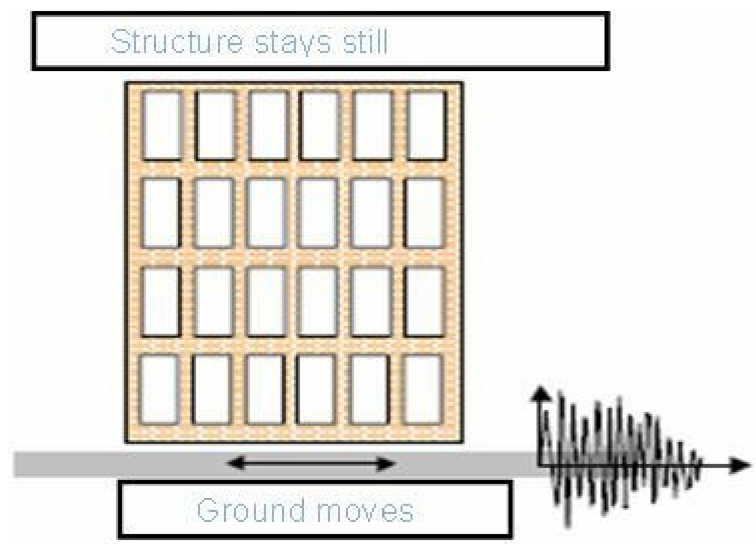


Figure 7. Base isolation strategy.

deflections across the flexible mounting can be limited to a practical design level.
3. A means of providing rigidity under low (service) load levels such as wind and braking force

Flexibility: Due to additional flexibility the period of structure is elongated. From the acceleration response curve shown in Figure 4a, it may be observed that reductions in base shear occur as the period of vibration of the structure is lengthened. The extent to which these forces are reduced is primarily dependent on the nature of the earthquake ground motion and the period of the non-isolated structure.

Energy dissipation: Additional flexibility needed to lengthen the period of the structure will give rise to large relative displacement across the flexible mount. Figure 4b shows an idealized displacement response curve from which displacements are seen to increase period (flexibility). Large relative displacements can be controlled if substantial additional damping is introduced into the structure at the isolation level. This is shown schematically in Figure 5. Also shown schematically in this figure is the smoothening effect of higher damping.

One of the most effective means of providing a substantial level of damping is through hysteric energy dissipation. The hysteric refers to the offset between the loading and unloading curves under cyclic loading. Figure 6 shows an idealized force-displacement loop where the enclosed area is a measure of the energy dissipated during one cycle of motion.

Rigidity under low lateral loads: While lateral flexibility is highly desirable for high seismic loads, it is clearly undesirable to have a structural system which will vibrate perceptibly under frequently occurring loads such as wind loads or braking loads. Mechanical energy dissipaters may be used to provide rigidity at these service

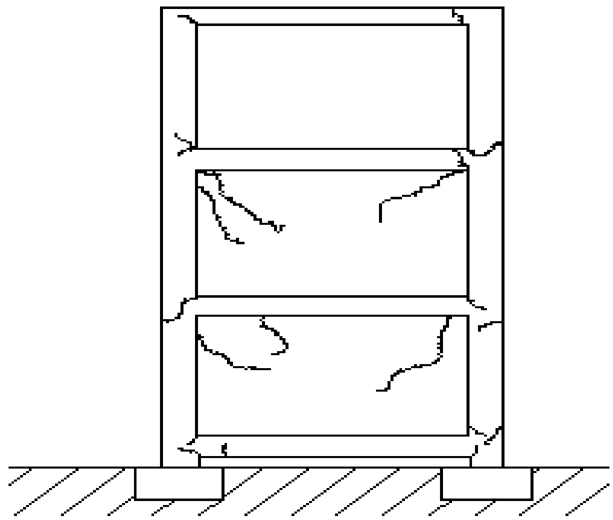


Figure 8. Failure pattern of a fixed based structure due to lateral seismic loading.

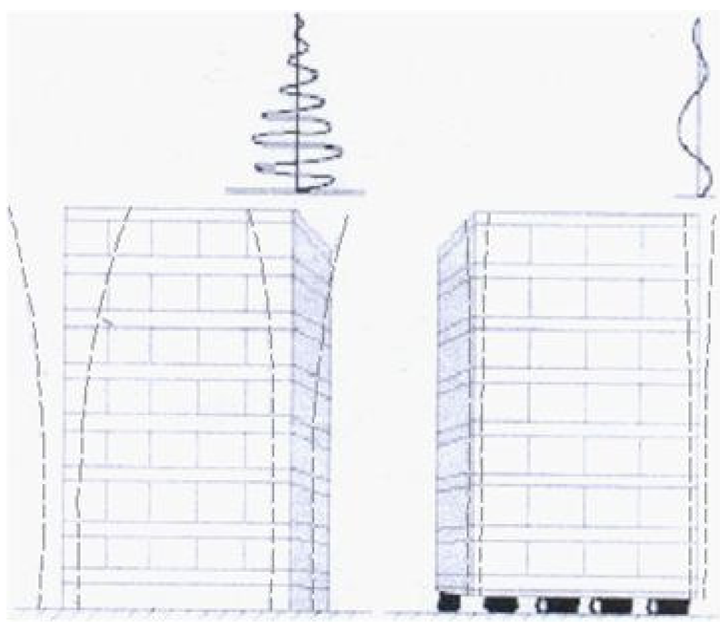


Figure 9. Fixed base and isolated base.

loads by virtue of their high initial elastic stiffness.

Fundamental concepts of base isolation

The term base isolation uses the word a) isolation in its meaning of the state of being separated and b) base as a part that supports from beneath or serves as a foundation for an object or structure. As suggested in the literal sense, the structure (a building, bridge or piece of equipment) is separated from its foundation. The original terminology of base isolation is more commonly replaced with seismic isolation nowadays, reflecting that in some cases the separation is somewhere above the base – for example, in a building the superstructure may be separated from substructure columns. In another sense, the term seismic isolation is more accurate anyway in that the structure is separated from the effects of the seism, or earthquake (Kelly, 2001).

The only way a structure can be supported under gravity is to rest on the ground. Isolation conflicts with this fundamental structural engineering requirement.

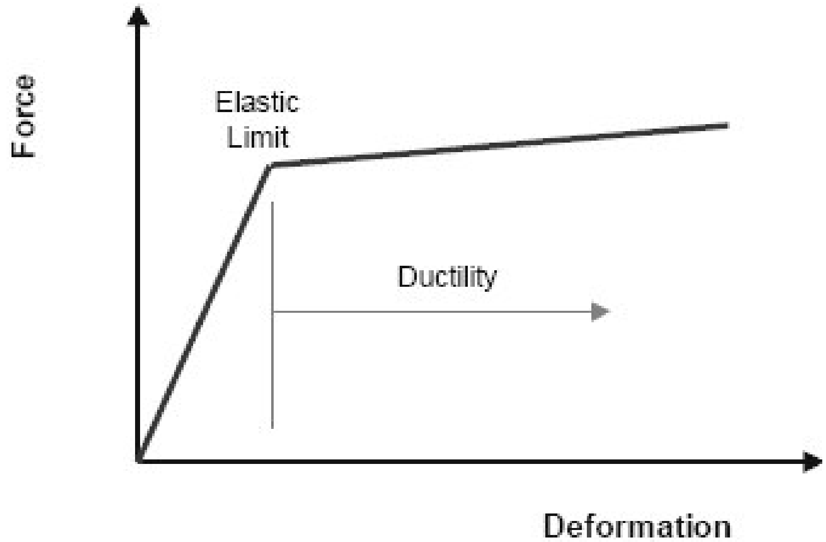


Figure 10. Ductility: deformation beyond elastic limit.

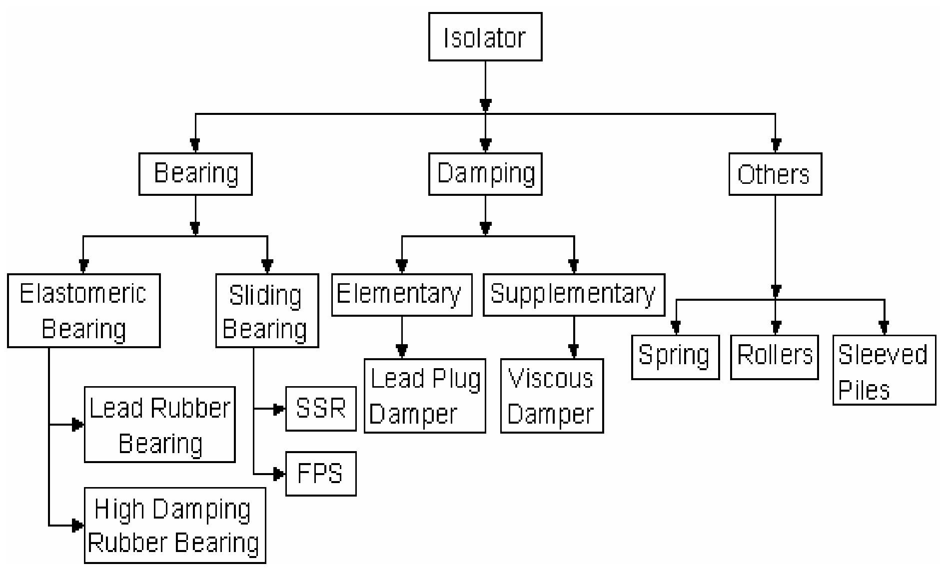


Figure 11. Schematic Diagram showing various types of Isolators used through out the world.

How can the structure be separated from the ground for earthquake loads but still resist gravity? It is practical isolation systems that provide a compromise between attachment to the ground to resist gravity and separation from the ground to resist earthquakes (Figure 7). Seismic isolation is a means of reducing the seismic demand on the structure:

Action of base isolation

Hence, "base isolation" or, seismic isolation separates upper structure from base or, from down structure by changing of fix joint with flexible one (Figure 10). Increasing of flexibility is done by the insertion of additional elements in structure, known as isolators. Usually, these isolators are inserted between upper structure and foundation (Figure 12). Seismic isolation system absorbs larger part of seismic energy. Therefore, vibration effects of soil to upper structure are drastically reduced. Figure 8 shows the failure pattern of a "fixed based" structure due to seismic loading.

But in case of isolated buildings as the ground moves, inertia tends to keep structures in place resulting in the imposition of structure with large displacements in different stories (Figure 9: left figure: dashed portion indicating displacements due to seismic loading).

For base isolated structure the situation is quite

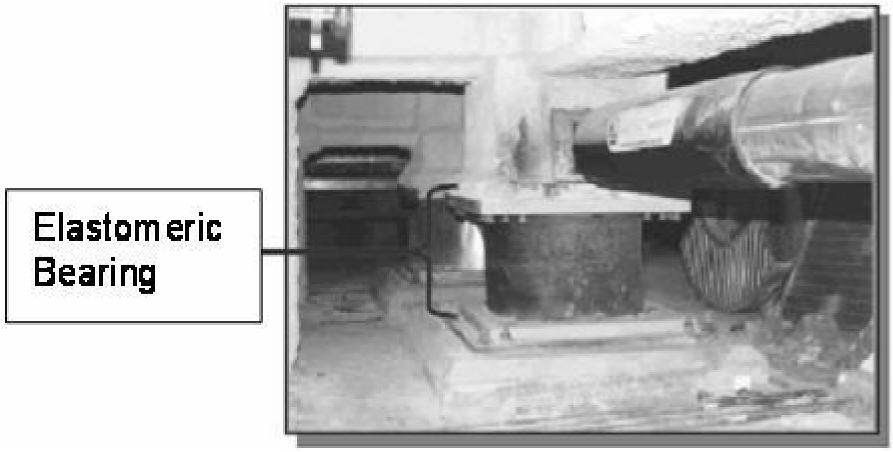


Figure 12. Installed elastomeric bearing.

different. In such cases, the whole upper structure gets a displacement (which naturally remains in limits) and the relative displacement of different stories is so small that the structure can withstand a comparatively high seismic tremor with a low seismic loading in a safe, efficient and economic manner.

Goal of base isolation

A high proportion of the world is subjected to earthquakes and society expects that structural engineers will design our buildings so that they can survive the effects of these earthquakes. As for all the load cases encountered in the design process, such as gravity and wind, should work to meet a single basic equation: CAPACITY > DEMAND. Earthquakes happen and are uncontrollable. So, in that sense, we have to accept the demand and make sure that the capacity exceeds it. The earthquake causes inertia forces proportional to the product of the building mass and the earthquake ground accelerations. As the ground accelerations increases, the strength of the building, the capacity, must be increased to avoid structural damage. But it is not practical to continue to increase the strength of the building indefinitely.

In high seismic zones the accelerations causing forces in the building may exceed one or even two times the acceleration due to gravity, g. It is easy to visualize the strength needed for this level of load – strength to resist 1 g means than the building could resist gravity applied sideways, which means that the building could be tipped on its side and held horizontal without damage.

Designing for this level of strength is not easy, nor cheap. So, most codes allow engineers to use ductility to achieve the capacity. Ductility is a concept of allowing the structural elements to deform beyond their elastic limit in a controlled manner (Figure 10). Beyond this limit, the structural elements soften and the displacements increase with only a small increase in force.

The elastic limit is the load point up to which the effects of loads are non- permanent; that is, when the load is removed the material returns to its initial condition. Once this elastic limit is exceeded changes occur. These changes are permanent and non-reversible when the load is removed.

A design philosophy focused on capacity leads to a choice of two evils:

1. Continue to increase the elastic strength. This is expensive and for buildings leads to higher floor accelerations. Mitigation of structural damage by further strengthening may cause more damage to the contents than would occur in a building with less strength.
2. Limit the elastic strength and detail for ductility. This approach accepts damage to structural components, which may not be repairable.

Base isolation takes the opposite approach, it attempts to reduce the demand rather than increase the capacity. We cannot control the earthquake itself but we can modify the demand it makes on the structure by preventing the motions being transmitted from the foundation into the structure above.

So, the primary reason to use isolation is to mitigate earthquake effects. Naturally, there is a cost associated with isolation and so it only makes sense to use it when the benefits exceed this cost. And, of course, the cost benefit ratio must be more attractive than that available from alternative measures of providing earthquake resistance.

Nowadays Base Isolation is the most powerful tool of the earthquake engineering pertaining to the passive structural vibration control technologies. It is meant to enable a building or non-building structure to survive a potentially devastating seismic impact through a proper initial design or subsequent modifications. In some cases, application of Base Isolation can raise both a structure's seismic performance and its seismic sustainability

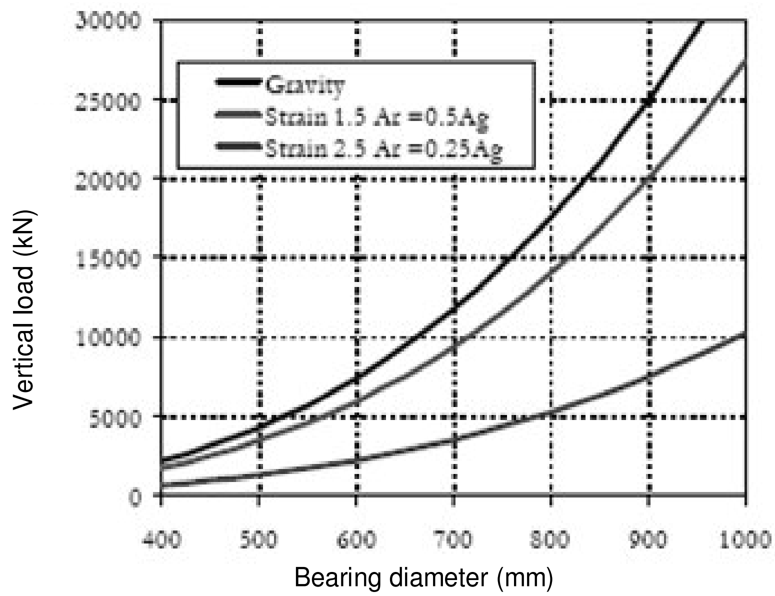


Figure 13. Load capacity of elastomeric bearings.

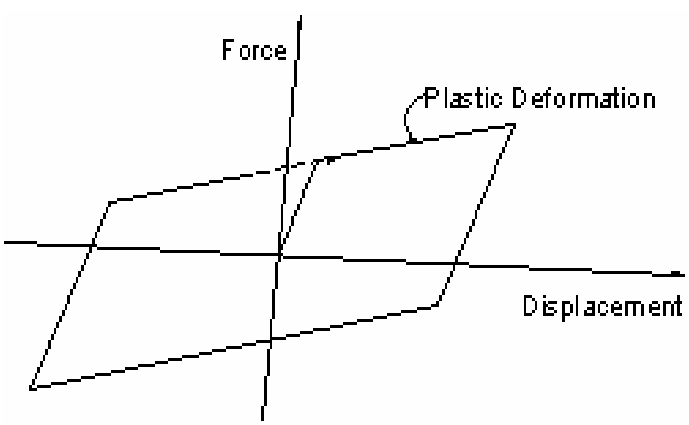


Figure 14. Area denoting dissipated energy.

considerably.

RECOGNITION OF ISOLATION TYPES

Many types of isolation system have been proposed and have been developed to varying stages, with some remaining no more than concepts and others having a long list of installed projects. A discussion of generic types of system and focus on different types (especially rubber bearing) of isolators along with their characteristics is provided subsequently.

Types of isolator

The development of isolators ensured the properties required for the achievement of perfect base isolation. The chart (Figure 11) details the various types of Isolators used through out the world. A brief description along with their basic functions and advantages is also included just after the chart. As the present research is mainly highlighting the use of LRB and HDRB type of isolator, so special attention is given to their characteristics.

Bearing type

Elastometric (rubber) bearings

Rubber bearings are formed of horizontal layers of natural or synthetic rubber in thin layers bonded between steel plates. The steel plates prevent the rubber layers from blown up or busting. In such mechanism the bearing is capable to support higher vertical loads with only smaller deflection (typically 1 to 3 mm under full gravity load).

The internal steel layers do not restrict horizontal deformations of the rubber layers in shear. So, the bearings are much more flexible under lateral loads than vertical loads. This is why; the bearing works as a flexible unit.

Characteristics of rubber isolator

As described earlier, isolation system works with the principle that a rigid mass is isolated from a flexible supporting structure.

Optimum isolation of a building from ground may be achieved by choosing a rubber bearing isolator based on the knowledge of its static and dynamic characteristics determined from laboratory experiments. For this reason, understanding the properties of rubber isolators is necessary for the vibration analysis. Some of the important properties are as follows.

Load capacity and size of rubber bearings

For most bearing types the plan size required increases as vertical load increases but the height or radius is constant regardless of vertical loads. This is because all bearings at such stages are subjected to the same displacement. Therefore, the bearing can be sized according to the vertical loads they support. Figure 13 (Kelly et al., 2006) gives a typical relationship between vertical load and bearing diameter where (vertical load absorbed as per bearing diameter). Three types of curves are seen in the plot. All the curves are showing that the lower the vertical load, the lower the required bearing diameter.

Absorption

Shocks originating due to the occurrence of an earthquake can be controlled if substantial additional damping is introduced into the isolation system. A high damping rubber isolator provides a substantial level of damping through hysteretic energy dissipation. Hysteretic refers to the offset between the loading and unloading curves under cyclic loading.

Figure 14 shows an idealized force- displacement loop where the enclosed area is measure of the energy dissipated during one cycle of motion.

Durability under cyclic loading

Rubber isolator remains more or less stable under cyclic loading. Results of cyclic displacement test applied, to a rubber isolator shows that at a speed equivalent to an actual seismic event the friction factor remains stable. Figure 15 shows a typical friction factor versus number of cycles in a cyclic loading test of rubber isolator. The figure represents that rubber isolator is durable. There are mainly two types of Rubber Bearing. They are LRB and HDRB.

Lead rubber bearing (LRB)

This type of elastomeric bearings consist of thin layers of low damping natural rubber and steel plates built in alternate layers and a lead cylinder plug firmly fitted in a hole at its centre to deform in pure shear as shown in Figure 16. The LRB was invented in New Zealand in 1975 and has been used extensively in New Zealand, Japan and United States. The steel plates in the bearing force the lead plug to deform in shear.

This bearing provides an elastic restoring force and also, by selection of the appropriate size of lead plug, produces required amount of damping. The force deformation behavior of the bearing is shown in Figure 16. Performance of LRB is maintained during repeated strong earthquakes, with proper durability and reliability.

Basic functions of LRB

(1) Load supporting function: Rubber reinforced with steel plates provides stable support for structures. Multilayer construction rather than single layer rubber pads provides better vertical rigidity for supporting a building.

(2) Horizontal elasticity function (prolonged oscillation period): With the help of LRB, earthquake vibration is converted to low speed motion. As horizontal stiffness of the multi- layer rubber bearing is low, strong earthquake vibration is lightened and the oscillation period of the building is increased.

(3) Restoration function: Horizontal elasticity of LRB returns the building to its original position. In a LRB, elasticity mainly comes from restoring force of the rubber layers. After an earthquake this restoring force returns the building to the original position.

(4) Damping function: Provides required amount of damping necessary.

LRB mainly are of two shapes. One is conventional round and the other type is square. Though their basic function remains same, yet changes in shapes are advantageous in many occasions as economy concern, reduced size, stability and capacity for large deformation.

High damping rubber bearing (HDRB)

HDRB is one type of elastomeric bearing. This type of bearing consist of thin layers of high damping rubber and steel plates built in alternate layers as shown in Figure 17. The vertical stiffness of the bearing is several hundred times the horizontal stiffness due to the presence of internal steel plates. Horizontal stiffness of the bearing is controlled by the low shear modulus of elastomer while steel plates provides high vertical stiffness as well as prevent bulging of rubber. High vertical stiffness of the bearing has no effect on the horizontal stiffness. The damping in the bearing is increased by adding extra-fine carbon block, oils or resins

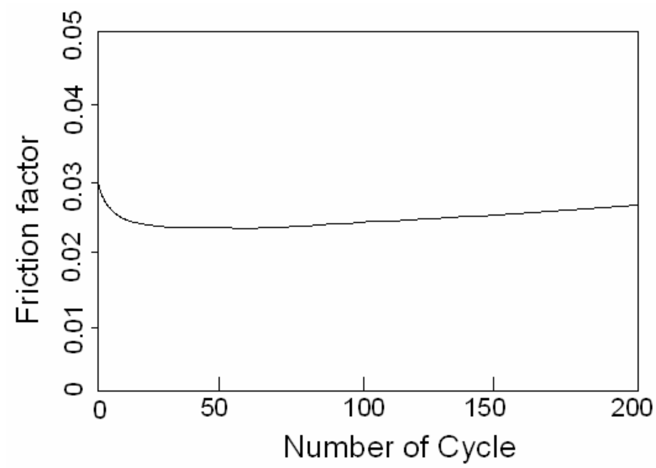


Figure 15. Typical cyclic durability test graph.

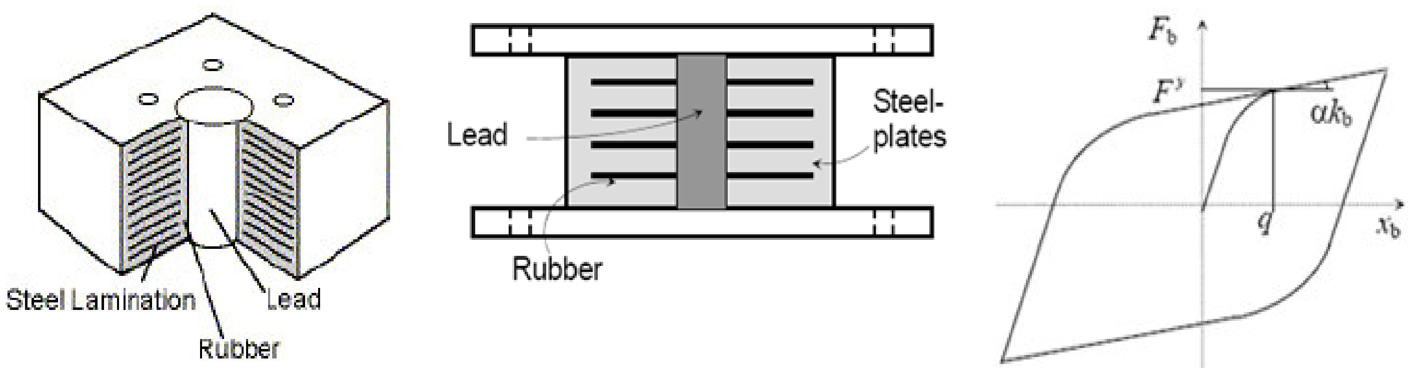


Figure 16. Geometry, schematic diagram and ideal force –deformation behavior of LRB.

and other proprietary fillers. The dominant features of HDRB system are the parallel action of linear spring and viscous damping. The damping in the isolator is neither viscous nor hysteretic, but some what in between. The ideal force deformation behavior of the bearing is shown in Figure 17.

Basic functions of HDRB

(1) Vertical load bearing function: Rubber reinforced with steel plates provides stable support for structures. Multilayer construction rather than single layer rubber pads provides better vertical rigidity for supporting a building.

(2) Horizontal elasticity function (prolonged oscillation period): With the help of HDRB earthquake vibration is converted to low speed motion. As horizontal stiffness of the multi- layer rubber bearing is low, strong earthquake vibration is lightened and the oscillation period of the building is increased.

(3) Restoration function: Horizontal elasticity of HDRB returns the building to its original position. In a HDRB, elasticity mainly comes from restoring force of the rubber layers. After an earthquake this restoring force returns the building to the original position.

(4) Damping function: Provides required amount of damping up to a higher value.

Sliding bearings

Sliding isolation system (Figure 18) is simple in concept and it has a theoretical appeal. A layer with a defined coefficient of friction will limit the acceleration to this value and the forces, which can be transmitted, will also be limited to the coefficient of friction multiplied by weight. Following are some of the utilities of using sliders:

(1) Sliding movement provides flexibility and the force-displacement traces a rectangular shape that is the optimum for equivalent viscous damping.

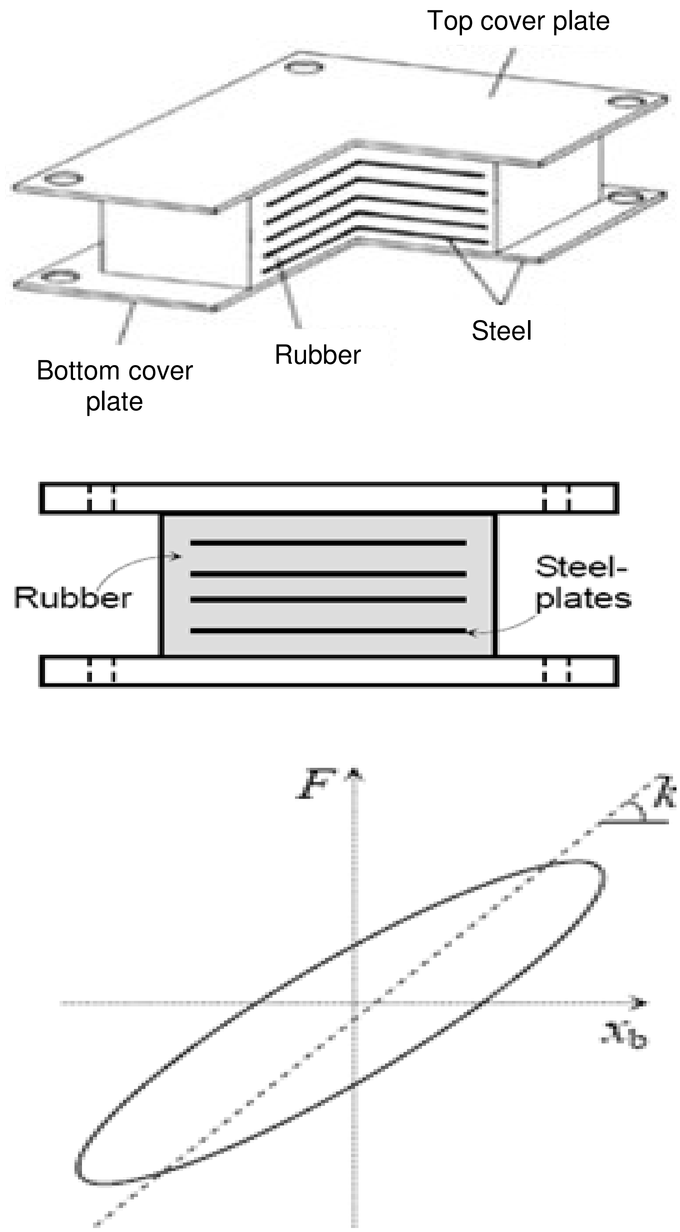


Figure 17. Geometry, schematic Diagram and ideal force – deformation behavior of HDRB.

(2) A pure sliding system will have unbounded displacements, with an upper limit equal to the maximum ground displacements for a coefficient of friction close to zero.

Two types of sliding systems are commonly used. A brief description with their basic functions, advantages and suitability is as follows.

Sliding support with rubber-pad (SSR)

When sliding base isolation system incorporates multilayer natural rubber pad then it is known as SSR.

Advantages of such bearings are:

(1) SSR can provide vibration isolation for light loads as well as large deformation performance like a large-scale isolation system.
(2) It provides protection against a wide range of tremors from small vibrations to major earthquakes.
(3) It can be used in conjunction with other isolation systems such as LRB, and HDRB.

Basic functions of SSR

For small vibrations, shear deformation of the rubber layers provides the same isolation effect as conventional multilayer rubber bearings.

For large vibrations, sliding materials slide to provide the same deformation performance as large-scale isolation systems.

Friction pendulum system (FPS)

Sliding friction pendulum isolation system (Figure 19) is one type of flexible isolation system suitable for small to large-scale buildings. It combines sliding a sliding action and a restoring force by geometry. Functions of FPS are same as SSR system.

Advantages of FPS include:

(1) It is possible to set the oscillation period of a building regardless of its weight.
(2) This system can reduce costs not only because of the low cost of its device but also due to the low cost of installation.
(3) The device is simple, works well and easy to install. Furthermore, it saves space and is practical for a seismic reinforcement.
(4) Performance of such device is stable due to the high durability of the device.
(5) As it requires only a simple visual check to maintain the device, maintenance is very easy.

Damping type

Damping provides sufficient resistance to structure against service loading. The effect of damping on dynamic response is beneficial. Generally all structural systems exhibit damping to various degrees. It is assumed that, structural damping is viscous by nature. Damping coefficient relates force to velocity. If damping coefficient is sufficiently large, it is possible to totally restrain the oscillatory motion. Damping that suppress totally the oscillatory motion is termed as critical damping. Damping is usually neglected in frequency and period calculations unless it exceeds about 20%.

Normally two types of damping are used in building. A

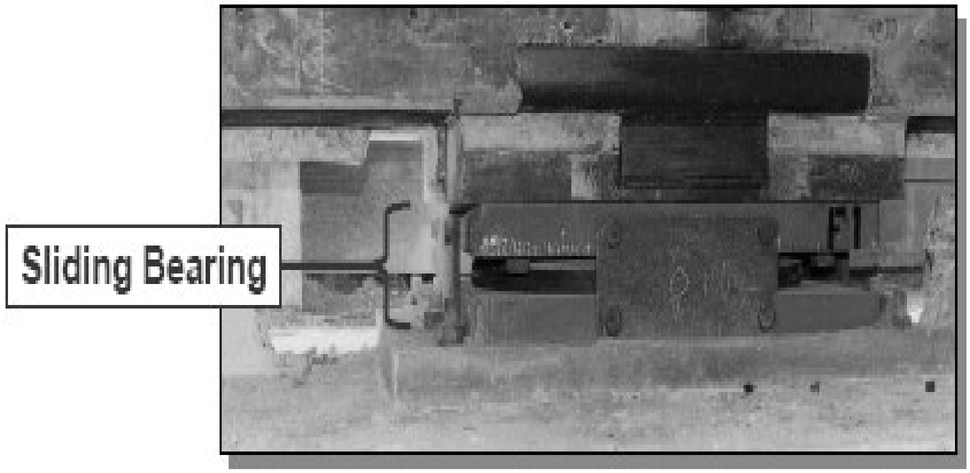


Figure 18. Installed sliding bearing.

brief description follows.

Elementary damping

This really means damping as a whole, i.e. the device (each and every element) itself acts as a purely damping device rather than an isolator. Purely damping devices can be used in low weight buildings to restrain the oscillating motion of the building. Another option may be using in conjunction with rubber bearing so-called as High Damping Rubber bearing.

In such devices amount of damping is significantly high, usually from 8 to 15% of critical damping. Lead plug damper is one of the forms of elementary damping.

The basic functions of such damper include:

(a) Vibration damping Junction: Lead plug damper absorbs large vibration of the building. As the layers of rubber are distorted, the lead plug is plastically deformed and at such stage it absorbs the earthquake energy and quickly damps the vibration.

(b) Trigger function: It also reduces vibration form source other than earthquake. For example, when vibration is generated by strong winds, the relative rigidity of the lead plug reduces the effect of such vibration.

Supplementary damping

There are some types of isolators (discussed in bearing portion), which are capable of providing flexibility but not significant damping, or resistance to service loads. In order to strengthen the damping phenomena, supplementary devices are included with general Isolators. Damping of such type can be termed as supplementary damping. One of the most popular types of supplementary damping is viscous damping. This device provides damping but not service load resistance. It does not have any elastic stiffness and for this reasons it adds less force to the system than other devices.

Other types

Apart from bearing and sliding type, there are some other types of isolators, which are also used in building but rarely. Springs, rollers, sleeved piles are some examples of such isolators. A brief description of them is also included here.

Springs

Spring isolators are devices whose working mechanism is based on steel springs. They are mostly used for machinery isolation. The main drawbacks of springs are two. Firstly, they are most flexible in both the vertical and horizontal directions. Secondly, springs alone have little damping and will move excessively under service loads.

Rollers

Cylindrical rollers and ball bearings are of this type. Like springs they are commonly used for machinery isolation. The resistance to movement and damping of rollers and ball bearings are sufficient under service loads.

Sleeved piles

The pin ended structural members, that is, piles inside a sleeve provide flexibility and allow movement of the soft first story in a building. This type of piles is known as sleeved piles. Sleeved piles provide flexibility but no

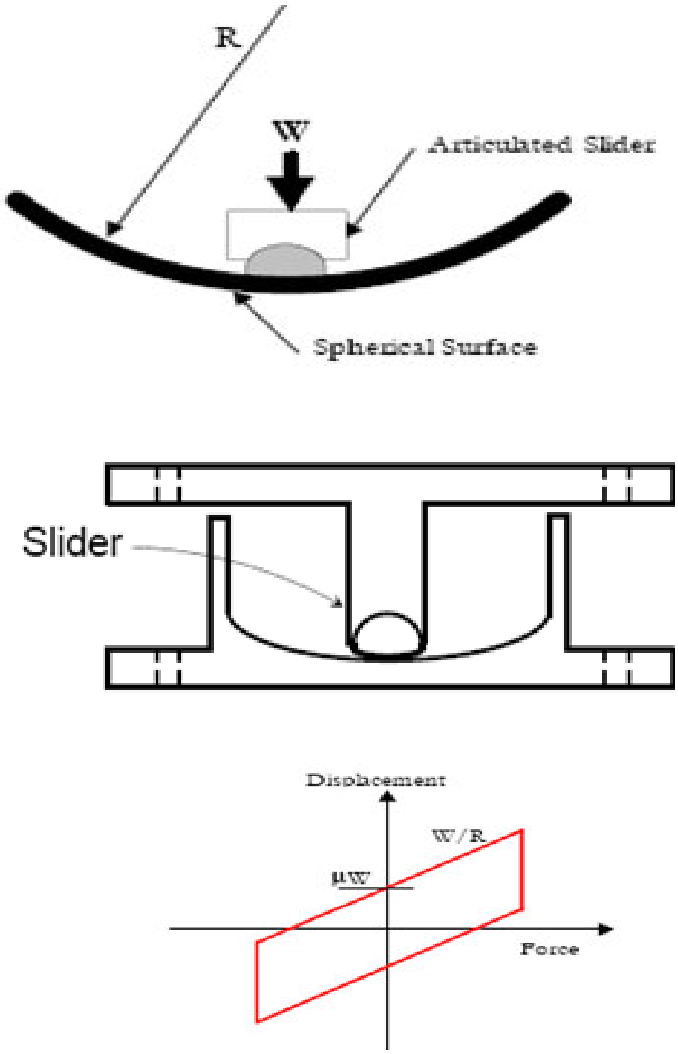


Figure 19. Geometry, schematic diagram and ideal force – deformation behavior of fps.

damping. Hence damping devices are required to use along with sleeved piles.

Design life of isolators

Most isolation systems are based on natural rubber bearings which have a long record of excellent in-service performance. As part of prototype testing, rubber tests including ozone testing and high temperature tests to simulate accelerated aging are performed to ensure the environmental resistance and longevity of the system. All steel components of the elastomeric based bearings are encased in a protective cover rubber except for the load plates. These plates are usually coated with a protective paint. The protective coating system adopted for the Museum of New Zealand, which had a specified 150 year design life, was a deposited metal paint system.

Fire resistance

Isolation bearings are generally required to achieve a fire rating equivalent to that required for the vertical load carrying assemblies.

One of two approaches can be used to provide acceptable fire rating with the method used decided on depending on specific project needs:

1. Design surrounding flexible protective "skirts" for the bearings as was done for Parliament Buildings.
2. Rate the resistance of rubber itself based on vertical load, dimensions and fire loading to determine whether it is more economical to provide the fire rating by providing extra cover rubber to the bearing.

Temperature range for installation

Base isolators are designed to resist the maximum seismic displacements plus the total R+S+T (creep, shrinkage and thermal) displacements. Therefore, the temperature of installation does not matter from a technical perspective. For aesthetic reasons it is desirable to install the bearings at as close to mean temperature as possible so that the bearings are not in a deformed configuration for most of their service life.

Availability of isolator

There are continual changes in the list of isolation system suppliers as new entrants commence supply and existing suppliers extend their product range. A large number of manufacturers of elastomeric bearings worldwide are also providing the requirements as these bearings are widely used. These manufacturers may offer to supply isolation systems such as lead-rubber and high damping rubber bearings, sliding bearings. However, standard bearings are designed to operate at relatively low strain levels of about 25%. Isolation bearings in high seismic zones may be required to operate at strain levels ten times this level, up to 250%. The manufacturing processes required to achieve the level of performance are much more stringent than for the lower strain levels. In particular, the bonding techniques are critical and the facilities must be of clean-room standard to ensure no contamination of components during assembly.

INSTALLATION OF ISOLATOR

The main requirement for installation (Figure 20) of a

Figure 20. Isolator installation in building.

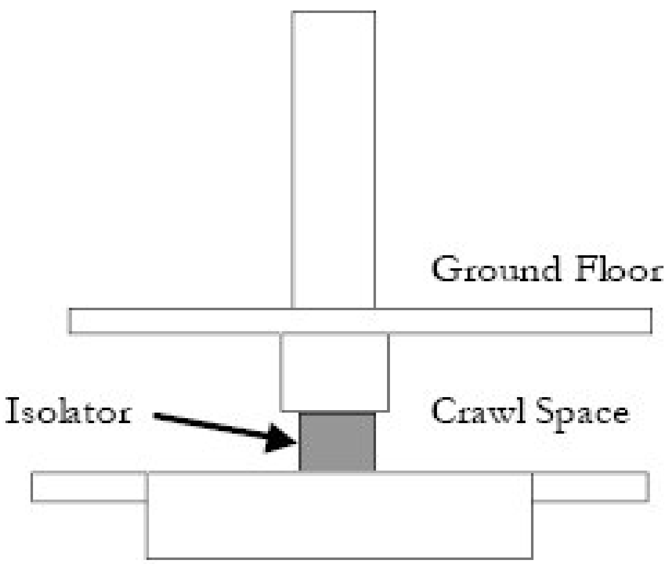


Figure 21. Isolator installation location in building with no basement.

base isolation system, that is, isolator is that the building be able to move horizontally relative to the ground, usually at least 100 mm and in some instance up to 1 m. A plane of separation must be selected to permit this movement. Final selection of the location of this plane depends on the structure.

Isolator installation techniques

The most common configuration is to install a diaphragm immediately above the isolators. This permits earthquake loads to be distributed to the isolators according to their stiffness. For a building without a basement, the isolators are mounted on foundation pads and the structure is constructed above them (Figure 21). If the building has a basement then the options are to install the isolators at the top, bottom or mid height of the basements, columns and walls (Figure 22).

In this study isolation technique is being discussed for a building without a basement as well as a building which has a basement presenting the practical example mentioning sequence in details.

Practical example of isolator installation in building

The installation technique for low to medium seismic region is of utmost importance. Here the gradual procedure about the installation of an isolator in an existing building is being introduced. The installation sequence of isolator into a reinforced concrete column is described below:

(a) Temporary steel columns on suitable foundations were installed to either side of the reinforced concrete column into which the bearing was to be installed (Figure 23). Hydraulic jacks were placed at the heads of the temporary columns, bearing onto the beams at first floor level, and stressed to a predetermined level, calculated as the gravity load in the permanent column from the analysis. The hydraulic fluid in the jacks is locked off.

(b) Bench marks were introduced on to the column just above and below the final position of the bearing, and measurements taken, to enable subsequent checks to be

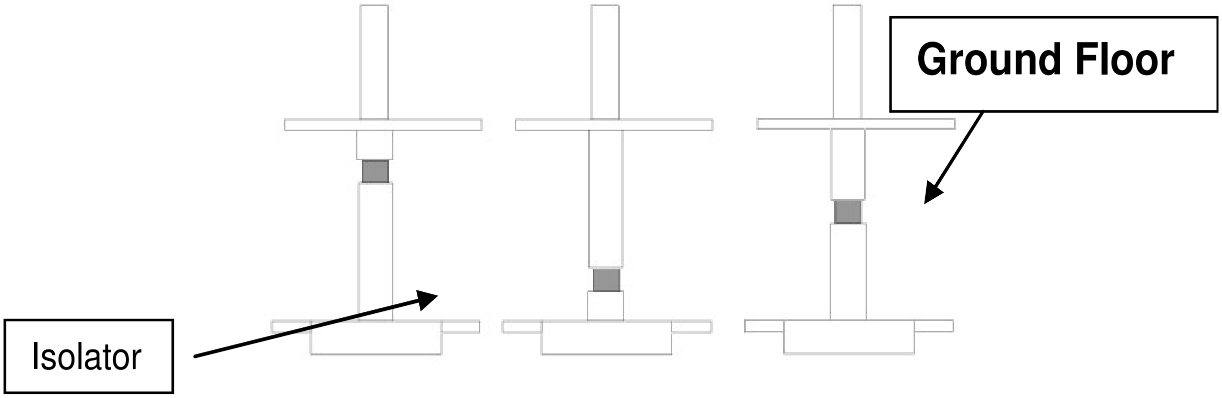


Figure 22. Isolator installation location in building having basement.

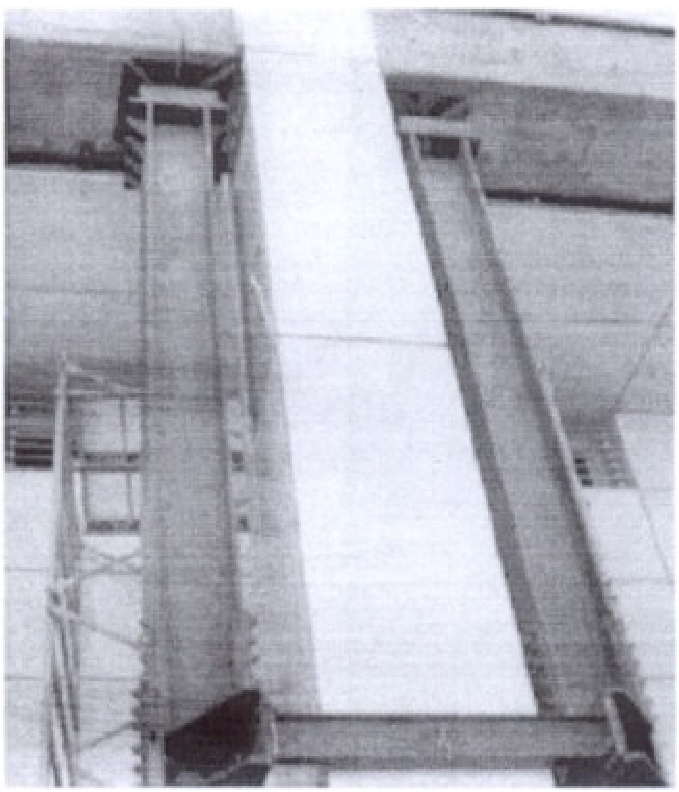


Figure 23. Installation of temporary steel column.

performed of possible movements of the column.

(c) Two horizontal cuts were made in the column using a diamond chain saw (Figure 24a). The block of concrete in between was removed (Figure 24b). The movements of the column above and below the cuts were then measured; in most cases this was small, but could reach as much as 6 mm (0.24 in.). This was considered acceptable.

A bed of epoxy mortar was placed on the lower half of the cut surface, and the LRB was then rolled into place on steel ball bearings. The gap above the bearing was then filled with epoxy mortar. The hydraulic jacks in the steel props were released and the props were removed after curing of the epoxy mortar.

(d) Steel jackets was welded into place above and below the bearing, and grouted to the column, to accommodate the stress concentrations at the cut surfaces of the column arising from the bearing and to replace the reinforcement that had been cut in Step c (Figure 25)

(e) The bearings were wrapped in fire insulation, and brackets introduced to support architectural finishes (Figure 26).

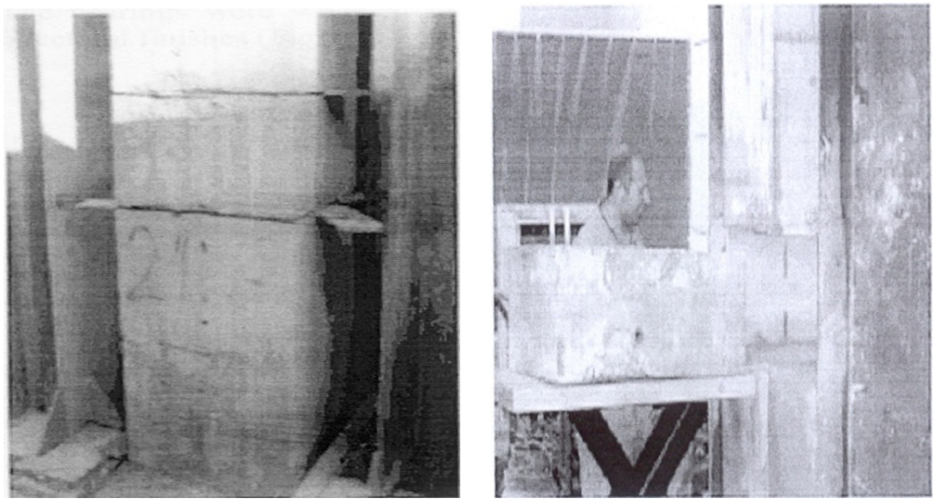
Conclusion

The obligations for practical isolation system to be incorporated in building structures are flexibility, Damping and resistance to service loads. Additional requirements such as durability, cost, ease of installation and specific project requirements influences device selection but all practical systems should contain these essential elements.

The entire superstructure is to be supported on discrete isolators whose dynamic characteristics are chosen to uncouple the ground motion. Displacement and yielding are concentrated at the level of the isolation devices, and the superstructure behaves very much like a rigid body. A through revise has been done performed in this research regarding the sequential development of seismic isolation systems.

This study also addressed the detail cram on isolation system, properties, characteristics of various device categories, recognition along with its effect on building structures. Meticulous schoolwork has also been accomplished about installation technique for various site stipulation at low to medium seismic region.

Rigorous reckonings illustrated the isolation system as very innovative and suitable in buildings to withstand the seismic lateral forces and also are contributed safety



(a) (b)

Figure 24. Cutting and removal of concrete block. (a) Saw cuts through concrete Column, (b) removal of concrete Block.

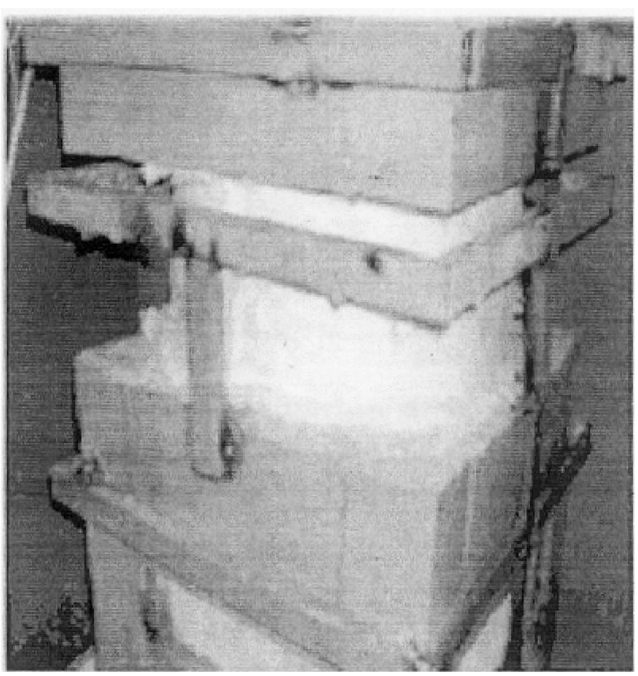


Figure 26. Installation of fire proofing elements.

ensuring flexibility of structures.

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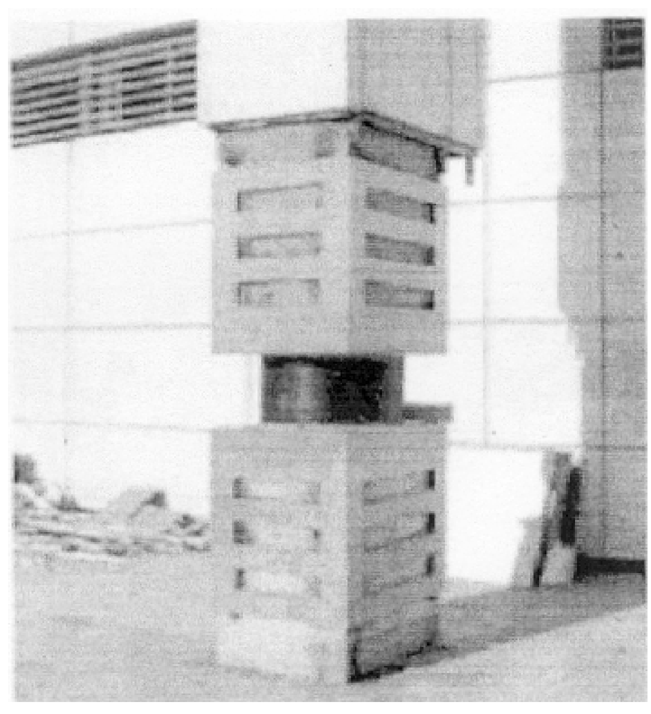

Figure 25. Steel jackets replacing severed reinforcing bars.

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