Sensitivity Analysis of LBR Isolator for RC Shear Frame

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Abstract— In most earthquakes, the collapse of structures like houses, schools, hospitals, historic and public buildings results in the widespread loss of lives and damage. Earthquakes also destroy public infrastructure like roads, dams and bridges, as well as public utilities like power and water supply installations. Past earthquakes show that over 95 percent of the lives lost were due to the collapse of buildings that were not earthquake-resistant. Though there are building codes and other regulations which make it mandatory that all structures in earthquake-prone areas in the country must be built in accordance with earthquake-resistant construction techniques, new constructions often overlook strict compliance to such regulations and building codes. A large number of buildings in India have been constructed without due consideration to earthquake loads. Further, the earthquake loads are also under continual revision in successive revisions of codes. Buildings also deteriorate with time and get damaged due to earthquake, flood, fire, blast, etc. All these circumstances require evaluation and retrofitting of existing building.

Keywords: LBR Isolator, RC Shear Frame

I. Introduction

A primary goal of seismic provisions in building codes is to protect life safety through prevention of structural collapse. To achieve these goal major factors, which results in uncertainties of the structural responses should be recognized. Uncertainty is generally costly in earthquake engineering because of the large amount of the parameters that should be considered for its calculation. Endurance time method is basically a dynamic procedure that tries to predict seismic performance of structures by analyzing their resilience when subjected to predesigned intensifying dynamic excitations.

In most earthquakes, the collapse of structures like houses, schools, hospitals, historic and public buildings results in the widespread loss of lives and damage. Earthquakes also destroy public infrastructure like roads, dams and bridges, as well as public utilities like power and water supply installations. Past earthquakes show that over 95 percent of the lives lost were due to the collapse of buildings that were not earthquake-resistant. Though there are building codes and other regulations which make it mandatory that all structures in earthquake-prone areas in the country must be built in accordance with earthquake-resistant construction techniques, new constructions often overlook strict compliance to such regulations and building codes. A large number of buildings in India have been constructed without due consideration to earthquake loads. Further, the earthquake loads are also under continual revision in successive revisions of codes. Buildings also deteriorate with time and get damaged due to earthquake, flood, fire, blast, etc. All these circumstances require evaluation and retrofitting of existing building.

A. Past earthquake in India

India's high earthquake risk and vulnerability is evident from the fact that about 59 percent of India's land area could face moderate to severe earthquakes. During the period 1990 to 2006, more than 23,000 lives were lost due to 6 major earthquakes in India, which also caused enormous damage to property and public infrastructure. The occurrence of several devastating earthquakes in areas hitherto considered safe from earthquakes indicates that the built environment in the country is extremely fragile and our ability to prepare ourselves and effectively respond to earthquakes is inadequate. During the International Decade for Natural Disaster Reduction (IDNDR) observed by the United Nations (UN) in the 1990s, India witnessed several earthquakes like the Uttarkashi earthquake of 1991, the Latur earthquake of 1993, the Jabalpur earthquake of 1997, and the Chamoli earthquake of 1999. These were followed by the Bhuj earthquake of 26 January 2001 and the Jammu & Kashmir earthquake of 8 October 2005. In addition to recent earthquake in India, moderate earthquake near the East Nepal/India board (5magnitude), strong earthquake in Kashmir (5.6magnitude), moderate earthquake near the India/Tibet board (5.1magnitude) Uttaranchal, etc.

All these major earthquakes established that the casualties were caused primarily due to the collapse of buildings. However, similar high intensity earthquakes in the United States, Japan, etc., do not lead to such enormous loss of lives, as the structures in these countries are built with structural mitigation measures and earthquake-resistant features.

B. Retrofitting strategies

There are fundamental ways that structures can respond to the energy input by a seismic event. Structures can absorb, dissipate, or avoid the input energy.

First, think of the structure as a solid block of granite heavy enough to remain stationary during a seismic event. After construction Sensor A is attached to the top of the block, Sensor B is attached to the midpoint, and Sensor C to the ground nearby. When the earthquake occurs the block moves exactly with the ground. In other words, all three sensors display the same displacements, velocities, and accelerations at the same times (Figure 1.1).

This solid block is a single degree of freedom (SDOF) system. All locations of the block moves like a rigid body. For a structure to react this way it would have to be built with members and connections that are very stiff. The structure would be strong enough to withstand the input energy. There are some problems with this design methodology. Firstly, it is impossible to design and construct a building over a few stories or a bridges that would work as a SDOF. Secondly, assuming it is possible; the cost of doing so would be enormous.

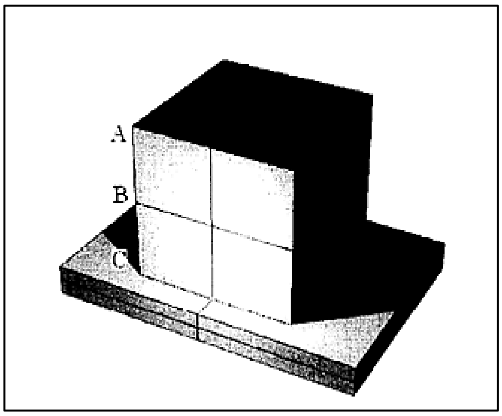


Fig. 1.1: A single degree of freedom system.

Thirdly, if an earthquake of a greater magnitude than the design quake hits the structures it will undergo deformation of the members and failure of the connections. In the Northridge Earthquake 12, 5000 buildings sustained moderate to severe damage while 7,000 more were deemed unsafe. The reason for much of the damage was to the use of moment frames in buildings. When the seismic energy exceeded the capacity of the moment frame the joint failed. Finally, there are safety issues associated with this design methodology. Although the structure will move with the ground motion things inside the building will not. Bookshelves, filing cabinets, computers, sophisticated machinery, and people would all be thrown back and forth by the quake.

Next, think of the structure as a masses connected by springs, which are lumped at points along the structure (Figure1.2). Each mass is able to move independently of the others. This is called a multiple degree of freedom (MDOF) system. A MDOF system reacts differently than a SDOF system to an earthquake. Again Sensors A, B, and C are attached to the top, middle, and ground respectively. When the structure is seismically excited the three sensors do not all read the same displacement, velocity, and accelerations. Sensor B feels less maximum displacement, velocity, and acceleration than the ground and Sensor A feels less than B.

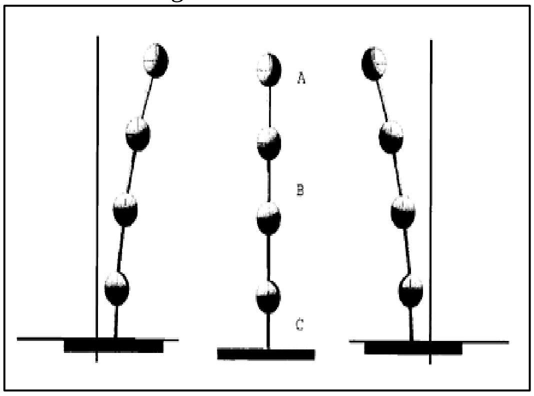


Fig. 1.2: A multiple degree of freedom subjected to ground motion.

This system has two methods of dealing with the energy input by the seismic event: it can absorb the energy with strength and it can dissipate some of the energy with dampers. Dissipation is available in the MDOF because of the differential displacement between stories Viscous or hysteretic dampers can be installed as a diagonal brace in a frame. In viscous damping force is equivalent to the time rate of change of the displacement .The function of a viscous damper is analogous to the way a revolting door works. If the door is pushed gently it begins to revolve. However, if the door is pushed very hard it does not move. That is because the velocity of the door is higher in the second case.

Hysteretic damping occurs when metal yield. The damping is a function of the yield strength and ductility of the material. Ductility, is the ratio of the absolute displacement to the displacement at yielding. From a safety point of view hysteretic damping caused by structural members yielding is a good thing. It dissipates energy and increases the damping of the structure. However, from a cost perspective yielding of structural members is negative. Repairing the damage caused is extremely expensive. It is possible to dissipate energy before the structural steel can yield if a material with a lower yielding strength is used, such as lead or low quality steel.

The final method of coping with the input energy from an earthquake is to avoid the energy. The effect of energy. The effect of energy input in the system is magnified when the frequency of the input energy is equal to the fundamental frequency of the system. This effect is called resonance. The fundamental frequency of the system is equal to the square root of the stiffness divided by the total mass.

Although buildings have many modes of vibration the mode is generally the most important when designing structures for dynamic excitation. By definition the first mode always has the lowest frequency of vibration and it also usually has the greatest percentage of mass participation. In general structural engineers deal with periods rather than frequencies. Frequencies can be converted to a period by dividing the frequency (in radians per second) by 2Pi.

There are two methods of shifting the period sufficiently to avoid the major portion of the input energy. First increasing the mass of the system will raise its period. This solution does not seems like the best solution. Adding mass would increase the dead weight of the building, waste space and material, and is not a very elegant solution. Secondly reducing the total stiffness of the system will increase the period. Decreasing the stiffness of the columns would increase the period, but at the risk of reducing the strength of the system. Isolating the base of the structure on springs can also reduce the total system stiffness (Figure 3).

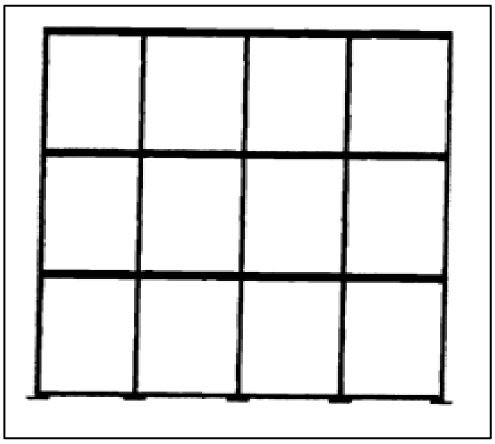


Fig. 1.3: A frame sitting on isolators.

C. Sensitivity Analysis

To evaluate the behavior of models a sensitivity study was performed by perturbing each of the random parameters (Vamvatsikos and Cornell, 2002). The sensitivity of each parameter is evaluated using Incremental Dynamic Analysis (IDA). IDA is a powerful analysis method that can provide accurate estimates of the complete range of the model's response, from elastic to yielding, then to nonlinear inelastic and finally to global dynamic instability (Vamvatsikos and Fragiadakis, 2010). The selection of earthquake ground motions with an appropriate earthquake ground motion intensity measure is an important issue, hence, in order to investigate the sensitivity of engineering demand parameters, a set of earthquake ground motions are selected.

II. Base Isolation

A. 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 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.

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 2.1 illustrates the behavior change of structure isolator and with isolator incorporation.

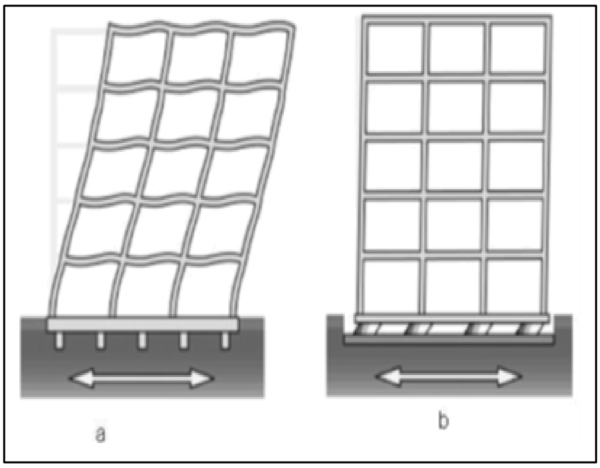


Fig. 2.1: Behavior change while using isolator. (a) Conventional structure (b) base –isolated structure.

B. Seismic Isolation Coming to Reality

The first seismic isolation system was proposed by Dr. Johannes Calantarients, an English medical doctor, in1909. 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

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 historey. For Los Angeles City Hall (Figure 2.3a), 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 2.3. Bhuj Hospital (Figure 2.3b), New Zealand Assembly Library (Figure 2.3c) and New Zealand Parliament (Figure 2.3d) have been erected on Lead Rubber bearing type base isolator. Isolation system was also inserted at Te Papa Museum of New Zealand (Figure 2.3e). Figure 2.3f shows the practical construction of inserting seismic isolation

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

1) 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.
2) 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
3) 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.
4) 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.
5) The development and acceptance procedures for estimating site-specific earthquake ground-motions for different return periods.

C. 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 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 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.

1) Flexibility:

Due to additional flexibility the period of structure is elongated. From the acceleration response curve shown in Figure 2.4a, 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.

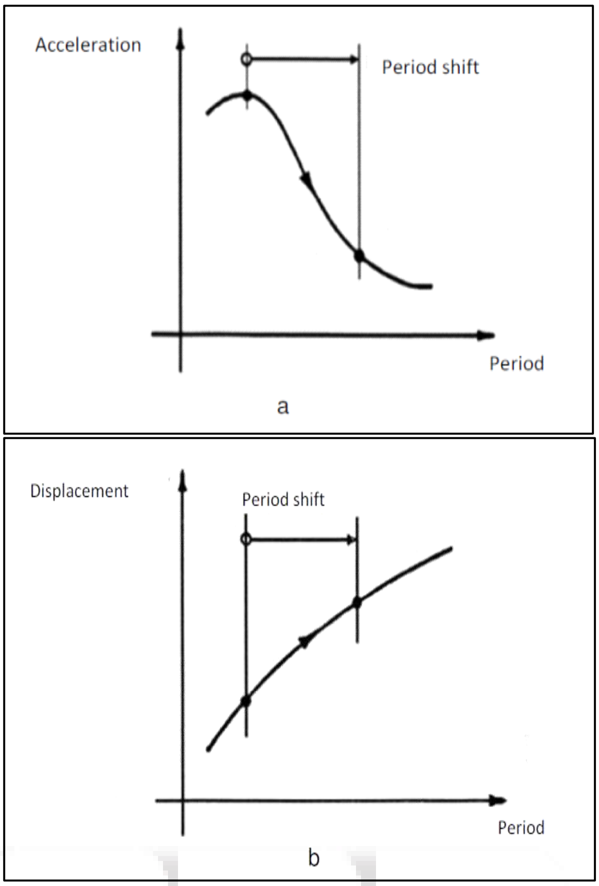


Fig. 2.4: Impact of period elongation obtained by seismic isolation on accelerations. (a) Acceleration response spectrum, (b) displacement response spectrum and displacements of a structure.

2) Energy dissipation:

Additional flexibility needed to lengthen the period of the structure will give rise to large relative displacement across the flexible mount. Figure 2.4b 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 2.5. 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 2.6 shows an idealized force-displacement loop where the enclosed area is a measure of the energy dissipated during one cycle of motion.

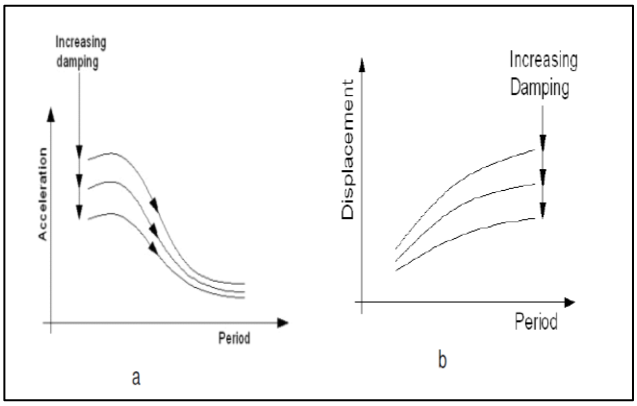


Fig. 2.5: Acceleration and displacement response Spectrum for increasing damping. (a) AccelerationRS, (b) Displacement RS.

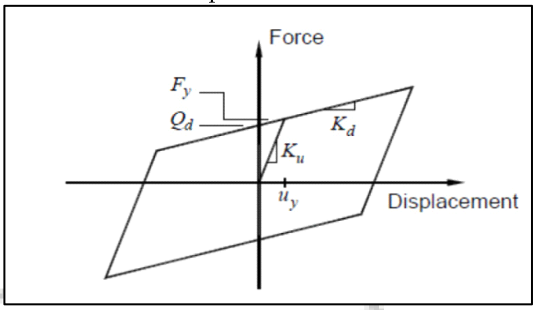


Fig. 2.6: Idealized force-displacement (Hysteresis) Loop.

3) 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 loads by virtue of their high initial elastic stiffness.

4) Fundamental concepts of base isolation

The term base isolation uses the word

1) isolation in its meaning of the state of being separated and
2) 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. 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 2.7). Seismic isolation is a means of reducing the seismic demand on the structure:

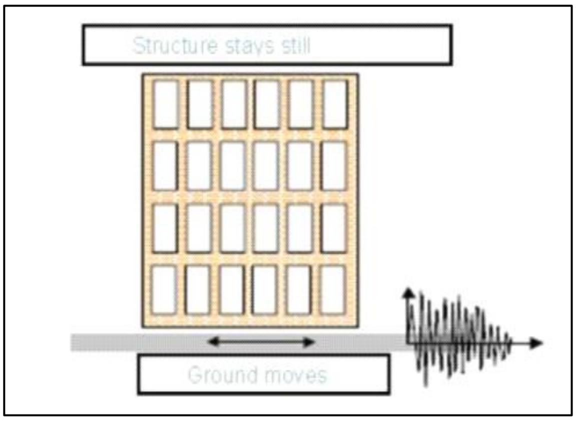


Fig. 2.7: Base isolation strategy.

D. *Action of base isolation*

"Base isolation" or, seismic isolation separates upper structure from base or, from down structure by 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 2.8). Seismic isolation system absorbs larger part of seismic energy. Therefore, vibration effects of soil to upper structure are drastically reduced. Figure 2.9 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 2.10) left figure: dashed portion indicating displacements due to seismic loading).

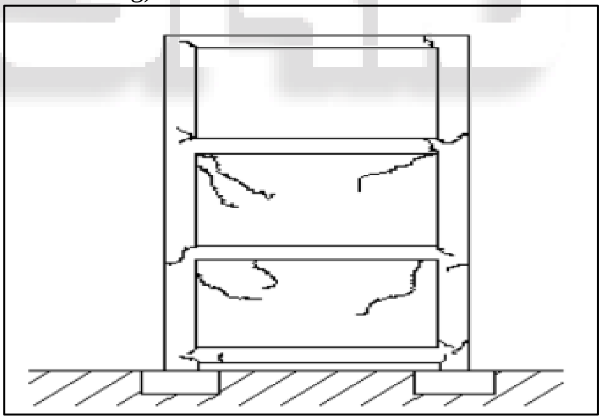


Fig. 2.8: Failure pattern of a fixed based structure due to lateral seismic loading.

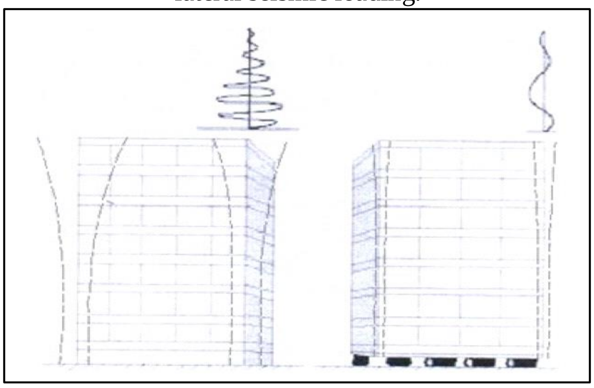


Fig. 2.9: Fixed base and isolated base.

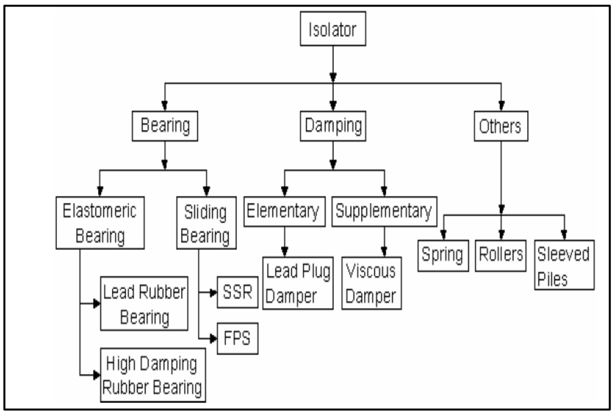


Fig. 2.11: Schematic Diagram showing various types of Isolators used throughout the world.

E. 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 13). 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.

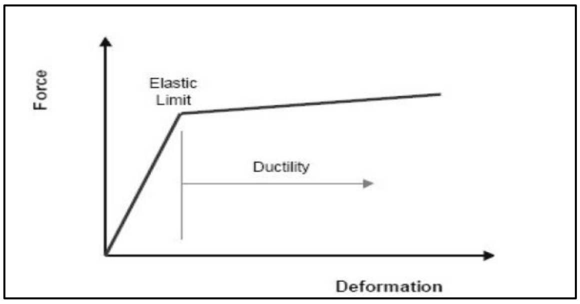


Fig. 2.10: Ductility: deformation beyond elastic limit.

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 required for the achievement of perfect base isolation. The chart (Figure 14) details the various types of Isolators used throughout the world.

F. Lead Rubber Bearing

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 center to deform in pure shear as shown in Figure 2.13. 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 2.13. Performance of LRB is maintained during repeated strong earthquakes, with proper durability and reliability.

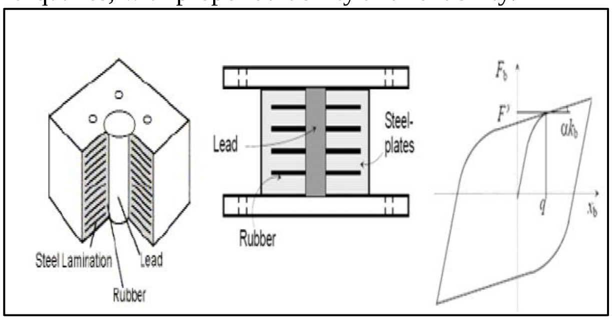


Fig. 2.12: Geometry, schematic diagram and ideal force – deformation behavior of LRB.

1) 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.

III. Present Work

To check the performance of a base isolated structure with LRB isolator by sensitivity approach.

- To check the performance of LRB for the following cases
- Sensitivity of mass on LRB isolator.
- Sensitivity of stiffness on LRB isolator.
- To compare the performance of a base isolated structure with fixed base to conclude the effectiveness of base isolation using LRB.
- To find out the response of the RC frames by TIME HISTOREY ANALYSIS using finite element based on software ETABS.
- To determine the parameters like frequency base shear force stiffness for 1B1S,1B5S,1B10S,2B1S,2B5S&2B10S FOR THE FOLLOWING CASES
- With fixed base
- With base isolation
- To determine the variation of natural frequency with respect to mass and stiffness
- To compare the performance of base isolated structure with fixed base to conclude the effectiveness of base isolation using LRB.

IV. Literature Review

A. Introduction

The concept of protecting a building from the damaging effects of an earthquake by introducing some type of support that isolates it from the shaking ground is an attractive one, and many mechanisms to achieve this result have been proposed. Although the early proposals go back 100 years, it is only in recent years that base isolation has become a practical strategy for earthquake-resistant design. In this chapter we study the dynamic behavior of buildings supported on base isolation systems with the limited objective of understanding why and under what conditions isolation is effective in reducing the earthquake-induced forces in a structure. Base isolation is currently an active and expanding subject, however, and a large body of literature exists on various aspect of base isolation: testing and mechanics of hardware in isolation systems, nonlinear dynamic analysis, shaking table test, design projects, field installation, and field performance.

B. Review of research works

M.Hirasawa, (1988), author present in this paper an actual example of aseismic design of a base isolated building and results of verification tests of the isolator and the building. Loading tests of the isolator indicate that the hysteretic loops are stable under repeated loading and the equipment damping ratio is large. As results of earthquake response analysis. The maximum acceleration response of the isolated building is about one fourth of that of non-isolated one. Results of forced vibration test and earthquake observation of the building has longer period and larger damping and reduces acceleration response as compared with non-isolated one.

C. Summary

Conventional seismic design attempts to make buildings that do not collapse under strong earthquake shaking, but may sustain damage to non-structural elements (like glass facades) and to some structural member in the building. This may render the building non-functional after the earthquake, which may be problematic in some structures, like hospital, which need to remain functional in the aftermath of the earthquake. Special techniques are required to design building such that they remain practically undamaged even in a severe earthquake. Buildings with such improved seismic performance usually cost is justifies through improved earthquake performance.

V. Modelling and Analysis

A. Introduction

ETABS is a sophisticated, yet easy to use, special purpose analysis and design program developed specifically for building systems. ETABS Version 9 features an intuitive and powerful graphical interface coupled with unmatched modeling, analytical, and design procedures, all integrated using a common database. Although quick and easy for simple structures, ETABS can also handle the largest and most complex building models, including a wide range of nonlinear behaviors, making it the tool of choice for structural engineers in the building industry.

1) History and Advantages of ETABS

Dating back more than 30 years to the original development of TABS, the predecessor of ETABS, it was clearly recognized that buildings constituted a very special class of structures. Early releases of ETABS pro-vided input, output and numerical solution techniques that took into consideration the characteristics unique to building type structures, providing a tool that offered significant savings in time and increased accuracy over general purpose programs. As computers and computer interfaces evolved, ETABS added computationally complex analytical options such as dynamic nonlinear behavior, and powerful CAD-like drawing tools in a graphical and object-based interface. Although ETABS Version 9 looks radically different from its predecessors of 30 years ago, its mission remains the same: to provide the profession with the most efficient and comprehensive software for the analysis and design of buildings. To that end, the current release follows the same philosophical approach put forward by the original programs, namely:

- Most buildings are of straightforward geometry with horizontal beams and vertical columns. Although any building configuration is possible with ETABS, in most cases, a simple grid system defined by horizontal floors and vertical column lines can establish building geometry with minimal effort.
- Many of the floor levels in buildings are similar. This commonality can be used to dramatically reduce modeling and design time.
- The input and output conventions used correspond to common building terminology. With ETABS, the models are defined logically floor-by-floor, column-by-column, bay-by-bay and wall-by-wall and not as a stream of non-descript nodes and elements as in general purpose programs. Thus the structural definition is simple, concise and meaningful.
- In most buildings, the dimensions of the members are large in relation to the bay widths and storey heights. Those dimensions have a significant effect on the stiffness of the frame. ETABS corrects for such effects in the formulation of the member stiff-ness, unlike most general-purpose programs that work on center-line-to-centerline dimensions.

The results produced by the programs should be in a form directly usable by the engineer. General-purpose computer pro-grams produce results in a general form that may need additional processing before they are usable in structural design.

B. *Design of Lead Rubber Bearings*

Lead rubber bearings (LRBs) are usually made of alternating layers of steel plates and natural rubber with a central hole into which the lead core is press-fitted. When subjected to lateral shear forces, the lead core deforms almost in pure shear, yields at low level of shear stresses, approximately 8 to 10 MPa at normal (20°C) temperature, and produces rather stable hysteretic deformation behavior over a number of cycles. One feature of the lead core is that it can recrystallize at normal temperature and will not encounter the problem of fatigue failure under cyclic loadings. Sufficient rigidity is always ensured by the LRBs for the structure under service loads. In this section, the design procedure for LRBs is outlined.

1) *Materials of LRB*

Materials of lead rubber bearing modelled as bilinear model

1) Rubber
2) steel
3) Lead cores
4) Mounting plate. (Steel mounting plate and top mounting plate)

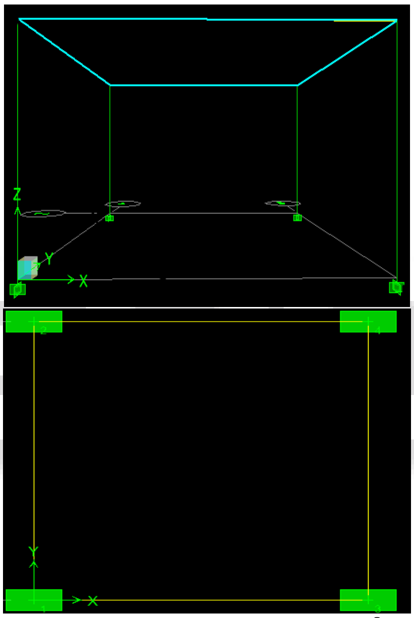
C. *Description and modeling of building*

1) *Building Data*

Number of Building= 12

a) Building 1 (Without base isolator)

Number of Storey = 1
Storey Height
Bottom storey =3.1m
Link element =0.4m
Number of lines in a Bay
Number of lines along, X = 2
Number of lines along, Y = 2
Storey width
Along, X = 6m
Along, Y = 6m
Structural Elements Dimension
Beam size = 0.45m x 0.6m
Column size = 0.45m x 1m
Slab thickness = 0.15m
Load data



Live load on the beam =4 kN/m^2

Fig. 5.1: Plan view and elevation view of building 1 without base isolation

b) Building 2(With base isolator)

Number of Stories = 1
Storey Height
Bottom storey =3.1m
Link element =0.4m
Number of lines in a Bay
Number of lines along, X = 2
Number of lines along, Y = 2
Storey width
Along, X = 6m
Along, Y = 6m
Structural Elements Dimension
Beam size = 0.45m x 0.6m
Column size = 0.45m x 1m
Slab thickness = 0.15m
Load data
Live load on the beam = 4 KN/m^2
Isolator characteristic

LINEAR Properties
Effective stiffness = 418.05 KN/m
Effective damping = 0
NON-LINEAR Properties
Effective stiffness = 4745.78 KN/m
Yield strength =10.2 KN
Post yield stiffness ratio = 0.07

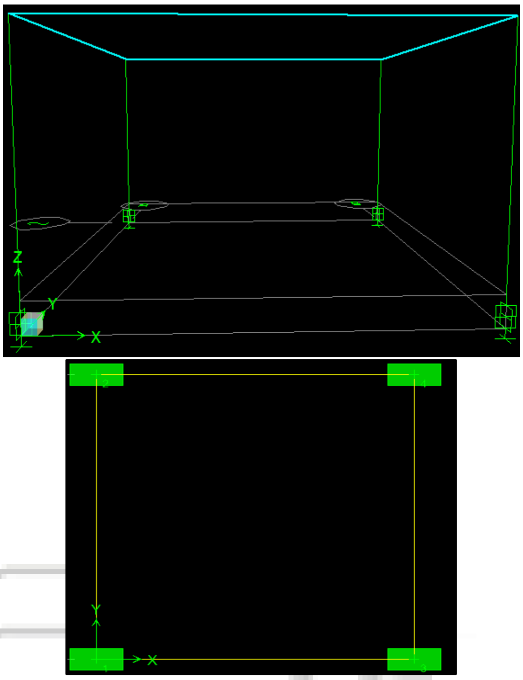
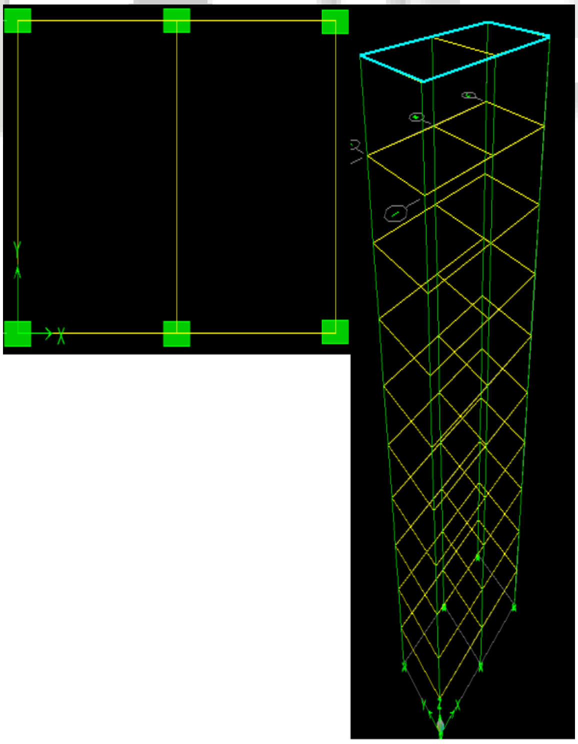


Fig. 5.2: Plan view and elevation view of building 2 with base isolation



Data
Live load on the beam = 4kN/m^2
Isolator characteristic
LINEAR Properties
Effective stiffness = 418.05 KN/m
Effective damping = 0

NON-LINEAR Properties
Effective stiffness = 4745.78 KN/m
Yield strength =10.2 KN
Post yield stiffness ratio = 0.07

D. Material properties

1) Concrete

Compressive strength of concrete, f_{ck} = 25000 kN/m^2
Density (weight per unit volume) = 25 kN/m^3
Mass per unit volume = (25 / 9.81) = 2.55 Kg/m3
Modulus of Elasticity of concrete, E_f = $(5000\sqrt{f_{ck}})$ = 25X10^{6}kN/m^2
Poison's Ratio = 0.2

2) Steel

Yield Strength of Steel, F_y= 415000 kN/m^2
Poisson's Ratio, μ = 0.15

E. ETAB Procedure for modeling

1) Structural Analysis Programs.

The physical structural members in a ETABS model are represented by objects. Using the graphical user interface, "draw" the geometry of an object, then "as-sign" properties and loads to the object to completely de fine the model of the physical member.

The following object types are available, listed in order of geometrical dimension:

– Point objects of two types:
- Joint objects: These are automatically created at the corners or ends of all other types of objects below, and they can be explicitly added to model supports or other localized behavior.
- Grounded (one-joint) support objects: Used to model special support behavior such as isolators, dampers, gaps, multi linear springs, and more.

– Line objects of several types
- Frame objects: Used to model beams, columns, braces, and trusses; they may be straight or curved
- Cable objects: Used to model flexible cables
- Tendon objects: Used to prestressing tendons in side other objects
- Connecting (two-joint) link objects: Used to model special member behavior such as isolators, dampers, gaps, multi linear springs, and more. Un-like frame, cable, and tendon objects, connecting link objects can have zero length. These are not covered in this manual.

– Area objects: Used to model walls, floors, and other thin-walled members, as well as two-dimensional sol ids (plane stress, plane strain, and axisymmetric solids). Only shell-type area objects are covered in this manual.

– Solid objects: Used to model three-dimensional sol ids. These are not covered in this manual.

a) Coordinate Systems

Each structure may use many different co-ordinate systems to de scribe the location of points and the directions of loads, displacement, internal forces, and stresses. Understanding these different co-ordinate systems is crucial to being able to properly define the model and interpret the results. The global coordinate system is a three-dimensional, right- handed, rectangular coordinate system. The three axes, de noted X, Y, and Z, are mutually perpendicular and satisfy the right- hand rule. The location and orientation of the global system are arbitrary.

b) Upward and Horizontal Directions

ETABS always assumes that Z is the vertical axis, with +Z being upward. Local coordinate systems for joints, elements, and ground-acceleration loading are defined with respect to this upward direction. Self-weight loading always acts down-ward, in the –Z direction.

The X-Y plane is horizontal. The primary horizontal direction is +X. Angles in the horizontal plane is measured from the positive half of the X axis, with positive angles appearing counter- clockwise when you are looking down at the X-Y plane.

c) Section Properties

A frame section is a set of material and geometric properties that describe the cross-section of one or more frame elements. Sections are defined independently of the frame elements, and are assigned to the elements. The Frame element activates all six degrees of freedom at both of its connected joints.

A Shell Section is a set of material and geometric properties that describe the cross- section of one or more Shell elements. Sections are de fined independently of the Shell elements, and are assigned to the area objects.

Section Type

When defining an area section, you have a choice of three basic element types:

– Shell– the subject of this chapter, with translational and rotational degrees of freedom, capable of supporting forces and moments
– Plane (stress or strain) – a two-dimensional solid, with translational degrees of freedom, capable of supporting forces but not moments. This element is not covered in this manual.
– A solid–axisymmetric solid, with translational degrees of freedom, capable of supporting forces but not moments. This element is not covered in this manual.

For shell sections, you may choose one of the following sub-types of behavior:

– Membrane – pure membrane behavior; only the in-plane forces and the normal (drilling) moment can be sup ported
– Plate – pure plate behavior; only the bending moments and the transverse force can be supported
– Shell – full shell behavior, a combination of membrane and plate behavior; all forces and moments can be supported
– It is generally recommended that you use the full shell behavior unless the entire structure is planar and is adequately restrained.

d) Thickness Formulation

Two thickness formulations are available, which determine whether or not transverse shearing deformations are included in the plate- bending behavior of a plate or shell element:

– The thick-plate (Mindlin/Reissner) formulation, which includes the effects of transverse shear deformation
– The thin-plate (Kirchhoff) formulation, which neglects transverse shearing deformation.

e) Material Properties

The material properties for the Section are specified by reference to a previously defined material. The material properties used by the Section are:

– The modulus of elasticity, for axial stiffness and bending stiffness;
– The shear modulus, for torsional stiffness and transverse shear stiffness; this is computed from and the Poisson's ratio.
– The mass density (per unit of volume), m, for computing element mass.
– The weight density (per unit of volume), w, for computing Self-Weight Load.
– The design-type indicator indicates whether elements using this section should be designed as steel, concrete, aluminum, cold-formed steel, or none (no design).

f) Mass

In a dynamic analysis, the mass of the structure is used to compute inertial forces. The mass contributed by the Shell element is lumped at the element joints. No inertial effects are considered within the element itself.

The total mass of the element is equal to the integral over the plane of the element of the mass density, m, multiplied by the thickness. The total mass is apportioned to the joints in a manner that is proportional to the diagonal terms of the consistent mass matrix. The total mass is applied to each of the three translational degrees of freedom: UX, UY, and UZ. No mass moments of inertia are computed for the rotational degrees of freedom.

g) Self-Weight Load

Self- Weight Load can be applied in any Load Pattern to activate the self- weight of all elements in the model. For a Shell element, the self- weight is a force that is uniformly distributed over the plane of the element. The magnitude of the self- weight is equal to the weight density, w, multiplied by the thickness. Self- weight always acts down ward, in the global Z direction. The self- weight may be scaled by a single factor that applies to the whole structure.

h) Loads

Loads represent actions upon the structure, such as force, pressure, support displacement, thermal effects, ground acceleration, and others. You may define named Load Patterns containing any mixture of loads on the objects. The program automatically computes built-in ground acceleration loads.

In order to calculate any response of the structure due to the Load Patterns, must define and run Load Cases which specify how the Load Patterns are to be applied (e.g., statically, dynamically, etc.) and how the structure is to be analyzed (e.g., linearly, nonlinearly, etc.) The same Load Pat tern can be applied differently in different Load Cases.

By default, the program creates a linear static Load Case corresponding to each Load Pattern that you define.

i) Load Patterns

Define as many named Load Pat terns as you like. Typically you would have separate Load Patterns for dead load, live load, wind load, snow load, thermal load, and so on. Loads that need to vary independently, either for design purposes or because of how they are applied to the structure, should be de fined as separate Load Patterns.

After defining a Load Pattern name, you must as sign specific load values to the objects as part of that Load Pattern. Each Load Pattern may include:

- Self-Weight Loads on Frame and/or Shell elements
- Concentrated and Distributed Span Loads on Frame elements
- Uniform Loads on Shell elements
- Force and/or Ground Displacement Loads on Joints

Each object can be subjected to multiple Load Patterns.

j) Diaphragm Constraint

A diaphragm constraint causes all of its constrained joints to move together as a planar diaphragm that is rigid against membrane deformation. Effectively, all constrained joints are connected to each other by links that are rigid in the plane, but do not affect out- of- plane (plate) deformation. This constraint can be used to:

- Model concrete floors (or concrete- filled decks) in building structures, which typically have very high in-plane stiffness.
- Model diaphragms in bridge super structures

The use of the diaphragm constraint for building structures eliminates the numerical- accuracy problems created when the large in-plane stiffness of a floor diaphragm is modeled with membrane elements. It is also very useful in the lateral (horizontal) dynamic analysis of buildings, as it results in a significant reduction in the size of the Eigen value problem to be solved

2) Computer Modeling of Isolator System

Modeling of isolation systems by computer originally evolved from SDOF models that simply assumed the rigid structure above the isolator system and only accounted for the nonlinearity of the isolator units. However, with the improvement of computational technologies and the decrease in computer processing time, isolation system have enabled to be incorporated into computer program for two or three dimensional structural analyses. In the meantime, the invention of high speed personal computer and price reduction of computer hardware have resulted in developing powerful computer programs to analyze and design complicated, building structures with consideration of the isolation system.

Along with other popular computer programs, sap 2000 and ETABS have recognized as reliable programs to analyze and design seismically isolated structures. Both programs have capabilities to perform equivalent static analysis, response spectrum analysis, linear response historey analysis and nonlinear response historey analysis, but each program also has its own unique characteristic: ETABS mainly emphasizes the analysis and design of building structures with isolation systems. The operating the other since the assignment of isolator properties is basically the same both programs, this section only introduces how to model isolator properties using ETABS.

There are two types of link elements that are built into ETABS: ISOLATOR1 is usually used to model elastomeric type bearing and ISOLATOR2 is considered for friction pendulum bearing. For ISOLATOR 1, effective stiffness, K_{eff} and effective damping, $_{eff}$, of a bearing along two principal directions of the superstructure shall be the input for response spectrum analysis and linear response historey analysis. The K_{eff} and $_{eff}$ are derived at the design displacement, DD, or the maximum displacement, DM, However, DD and DM from ETABS results are usually not the same values as used to determine K_{eff} and $_{eff}$ initially. Iteration procedures are normally performed to adjust DD and DM unit the ETABS results are satisfactorily close to assumed values for determination of K_{eff} and $_{eff}$. In addition, attention should be paid to the input effective damping, eff. During linear analysis such as response spectrum analysis, the total damping factor of the structural system consists of two portion: one is additionally specified to the structure above the isolation system, and the other is automatically converted by ETABS from the effective damping, $_{eff}$. Of such ISOLATOR1 assigned in the structural model.

Elastomeric type bearing have a higher vertical stiffness in compression than tension. However, ISOLATOR1 only assumes the same magnitude of vertical stiffness in tension is modeled, the same as in compression, the overturning or uplift force in the bearing becomes abnormally higher and, reality the bearing does not have the capacity to resist such high tensile force. Consequently, the analytical results in accurately reflect the actual performance of the seismically isolated structure. The modeling of different tensile and compressive stiffness in the vertical direction can be achieved by adding a gap element to ISOLATOR1. The gap element has only vertical stiffness in compression but does not resist tensile force. Therefore, use the tensile stiffness, Kten, in ISOLATOR1 and assign the stiffness, Kcom – Kten, to the gap element in the vertical direction, Kcom is the bearing's compressive stiffness. Once the bearing is compressive the vertical deformation is assumed to be u, the sum of the compressive force ISOLATOR1 and the gap element is Ken u + $(K_{com} - K_{en})$u = K_{com}u, which means that the compressive stiffness of the bearing is properly assigned by combining two elements at the same location.

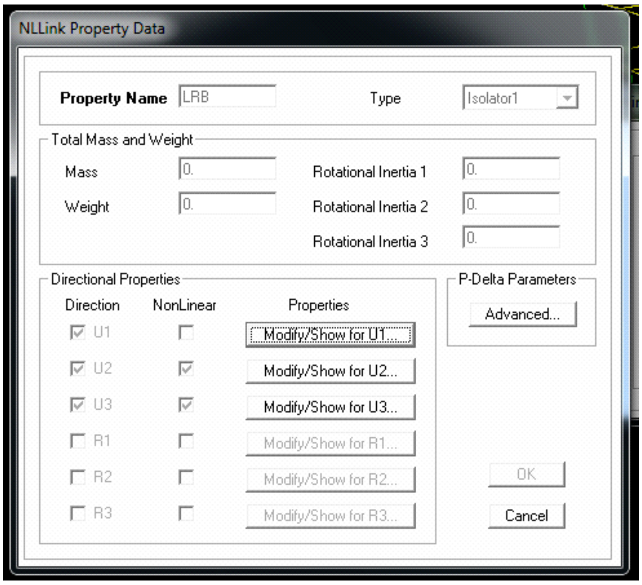


Fig. 5.12: Link property in ETABS.

F. Modal Analysis

Modal analysis calculates vibration modes for the structure based on the stiffness's of the elements and the masses present. Those modes can be used to investigate the behavior of a structure, and are required as a basis for subsequent response spectrum and time historey analyses.

Two types of modal analysis are available: eigenvector analysis and Ritz-vector analysis. Only one type can be used in a single analysis case.

1) Mass Source

To calculate modes of vibration, a model must contain mass. Mass may be determined and assigned in ETABS using any of the following approaches:

- ETABS determines the building mass on the basis of object self-masses (defined in the properties assignment) and any additional masses that the user specifies. This is the default approach.
- ETABS determines the mass from a load case that the user specifies. ETABS determines the mass on the basis of self-masses, any additional masses the user assigns, and any load case that the user specifies, which is a combination of the first two approaches.

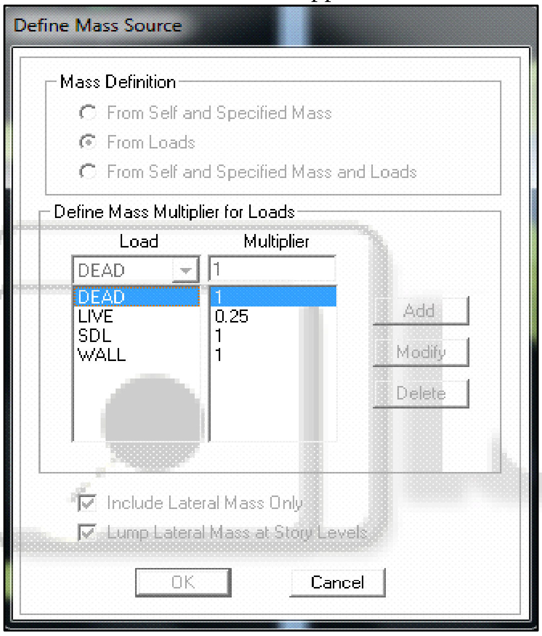


Fig. 5.13: Define mas source in ETABS.

Typically, masses are defined in all six degrees of freedom. However, ETABS has an option that allows only assigned translational mass in the global X and Y axes directions and assigned rotational mass moments of inertia about the global Z axis to be considered in the analysis. This option is useful when vertical dynamics are not to be considered in a model. In addition, an option exists for all lateral masses that do not occur at a storey level to be lumped together at the storey level above and the storey level below the mass location. That approach is used primarily to eliminate the unintended dynamic out-of-plane behavior of walls spanning be-tween storey levels.

2) Time history Analysis

For time history analyses, earthquake ground acceleration in each direction is given as a digitized response spectrum curve of pseudo-spectral acceleration response versus period of the structure. This approach seeks to determine the likely maximum response rather than the full time history.

ETABS performs response spectrum analysis using mode superposition, and eigenvector or Ritz vectors may be used. Ritz vectors are typically recommended because they give more accurate results for the same number of modes.

Even though input response spectrum curves may be specified in three directions, only a single, positive result is produced for each response quantity. The response quantities may be displacements, forces, or stresses. Each computed result represents a statistical measure of the likely maximum magnitude for that response quantity. Although all results are reported as positive, actual response can be expected to vary within a range from this positive value to its corresponding negative value.

VI. RESULT AND DISCUSSION

Using ETABS software with & without base isolated symmetric building are analyzed.

A. Lateral displacement

Storey Level	Without base isolation 1B1S(mm)	With base isolation 1B1S(mm)
0	0	29.5
1	0.116	59.11

Table 1: Lateral displacement symmetrical building 1 & 2 without & with base isolation.

Storey Level	Without base isolation 1B5S (mm)	With base isolation 1B5S (mm)
0	0	47.6
1	1.30	101.1
2	4	163.8
3	6.8	239
4	9.2	316.1
5	11	394

Table 2: Lateral displacement symmetrical building 3 & 4 without& with base isolation.

Storey level	Without base isolation 2B1S(mm)	With base isolation 2B1S (mm)
0	0	50.1
1	0.1	69.4

Storey	Without base isolation 1B10S (mm)	With base isolation 1B10S (mm)
0	0	42.1
1	3.3	36.2
2	10.3	34.3
3	18.8	49.4
4	27.7	64.6
5	36.4	79.9
6	44.3	95.2
7	51.3	110.7
8	57.2	126.2
9	61.9	141.8
10	65.6	157.5

Table 3: Lateral displacement symmetrical building 5 & 6 without & with base isolation.

Storey level	Without base isolation 2B5S (mm)	With base isolation 2B5S (mm)
0	0	59.9
1	1.4	86.1
2	3.9	113.9
3	6.6	148.1
4	8.8	192.7

5	10.4	240.4

Table 4: Lateral displacement symmetrical building 7&8 without & with base isolation.

Storey level	Without base isolation 2B10S (mm)	With base isolation 2B10S(mm)
0	0	39.6
1	3.3	43.3
2	10.3	56.1
3	18.7	79.1
4	27.5	102.1
5	36.4	125.1
6	44.9	148.3
7	52.5	171.4
8	59.1	194.7
9	64.6	218
10	69.3	241.4

Table 5: Lateral displacement symmetrical building 9&10 without & with base isolation.

Storey level	Without base isolation 1B1S	With base isolation 1B1S
0	0	0
1	0.000036	0.009563

Table 6: Lateral displacement symmetrical building11&12 without & with base isolation.

Figure 6.1: Lateral displacement vs floor level for building 1 BAY

Figure 6.2: Lateral displacement vs floor level for building 2 BAY

The lateral displacements vs floor level graph of various building without & with base isolated building as shown in Figure 6.1&6.2.From Figure 6.1&6.2 it observed lateral displacement is more in base isolated building as compared to fixed base building. From analytical study, it is observed that for all soil condition fixed base building have zero displacement at base of building whereas, In case of all soil condition model of base isolated building appreciable amount of lateral displacements was observed at base. Also it has been observed that as floor height increases, lateral displacements increases drastically in fixed base building. Increased flexibility of the system led to increase of the total displacements due to the elasticity of the existing isolation. Displacements of the system are concentrated at the isolation plane level

B. Storey Drift

Storey level	without base isolation 2B1S	with base isolation 2B1S
0	0	0
1	0.000037	0.006336

Table 7: Storey drift symmetrical building 1&2 without & with base isolation.

Storey level	Without base isolation 1B10S	With base isolation 1B10S
0	0	0.005245
1	0.001054	0.005346
2	0.002258	0.005383
3	0.002755	0.005419
4	0.002889	0.00545
5	0.002815	0.005474
6	0.002605	0.00549
7	0.00231	0.005498
8	0.001966	0.005498
9	0.001597	0.005492
10	0.001265	0.005482

Table 8: Storey drift symmetrical building 3 & 4 without & with base isolation.

Storey level	Without base isolation 2B5S	With base isolation 2B5S
0	0	0
1	0.000438	0.015792
2	0.000836	0.015817
3	0.000865	0.015850
4	0.000713	0.015849
5	0.000508	0.015815

Table 9: Storey drift symmetrical building 5&6 without & with base isolation.

Storey level	Without base isolation 2B10S	With base isolation 2B10S
0	0	0
`	0.001498	0.007825
2	0.003111	0.007845
3	0.003707	0.00787
4	0.003811	0.007891
5	0.003645	0.007906
6	0.003777	0.007914
7	0.004031	0.007916
8	0.004185	0.00791
9	0.004259	0.0079
10	0.004283	0.007887

Table 10: Storey drift symmetrical building 7&8 without & with base isolation.

Type of Structure	Without base isolation 1B1S (KN/mm)	With base isolation 1B1S (KN/mm)	Without base isolation 1B5S (KN/mm)	With base isolation 1B5S (KN/mm)	Without base isolation 1B10S (KN/mm)	With base isolation 1B5S (KN/mm)
Base shear	0.010	0.004	0.061	0.007	0.056	0.014

Table 11: Storey drift symmetrical building 9&10 without & with base isolation.

soil condition of fixed base and base isolate dbuilding 1 BAY.

Figure 6.4: Floor level v/sstorey drifts graph for various soil condition of fixed base and base isolatedbuilding 2 BAY.

The floor level v/sstorey drifts graph of various soil condition models of fixed and base isolated symmetric buildingas shown in Figure 6.3&6.4.

From Figure 6.3&6.4, it is observed that the base isolated building storey drifts are significantly reduced in comparison with the corresponding fixed base models for various soil condition and both fixed base and base isolated building, as storey drift increases with decrease in stiffness of soil.

In case of base isolated building, storey drift is more at the base for all soil condition than compared to fixed base building. As storey height increases, the storey drifts of base isolated building drastically decreases as compared to fixed base building. Implementation of the isolation system resulted into the reduction of the storey drift to negligible level, so that they practically not exist. This reduction enables the structure to behave as almost ideally stiff.

C. Base shear

Type of structure	Without base isolation 2B1S (KN/mm)	With base isolation 2B1S (KN/mm)	Without base isolation 2B5S (KN/mm)	With base isolation 2B5S (KN/mm)	Without base isolation 2B10S (KN/mm)	With base isolation 2B10S (KN/mm)
Base shear	0.016	0.010	0.131	0.063	0.122	0.078

Table 13:Maximum base shear for fixed base and base isolated building1 BAY.

Type of structure	1B1S	1B5S	1B10S
without base isolation	11.03	1.91	0.9
with base isolation	0.73	0.13	0.05

Table 14:Maximum base shear for fixed base and base isolated building 2 BAY

Figure 6.5: Maximum base shear graph fixed base and base isolated building 1 BAY.
Figure 6.6: Maximum base sheargraphof fixed base and base isolated building 2 BAY.

The maximum base shear graph of fixed and base isolated building as shown in Figure 6.5&6.6.

Type of structure	2B1S	2B5S	2B10S
without base isolation	9.67401	1.76798	0.24286
with base isolation	0.63812	0.11547	0.04428

Table 15: Natural time frequency for fixed base and base isolated building1 BAY.

Figure 6.6: Variation of natural frequency graph of fixed base and base isolated building 1 BAY.
Figure 6.7: Variation of natural frequency graph of fixed base and base isolated building 2 BAY.

VII. Conclusion

Following conclusions can be made from the analysis

- From analytical results, it is observed that base isolation reduces the seismic response of all soil condition in comparison to fixed base building and control the damages in building during strong ground motion.
- From the comparison between the base isolated and fixed base building, it has been observed that maximum shear force, bending moment, storey, acceleration, base shear decreases whereas generally increases lateral displacements were observed for base isolated building.
- Increase of displacements: Increased flexibility of the system led to increase of the total displacements due to the elasticity of the existing isolation. Displacements of the system are concentrated at the isolation plane level.
- Reduction of storey drifts: Implementation of the isolation system resulted into the reduction of the storey drifts to negligible level, so it can be said that they practically do not exist. This reduction enables the structure to have as almost ideally stiff. In this way the damage risk of the structural and non-structural-elements is minimized.
- Reduction of base-shear: Reduction of the base-shear force is evident in the model with implemented seismic isolation.
- Reduction of storey acceleration: Analysis of base isolated model shown significant reduction of the storey accelerations.
- Increase of natural period: As result of the increased flexibility of the system, natural period of the structure increased from T= 1.48 to T= 2.16sec.
- Energy dissipation mechanism: Contrasting the classical structure where the energy dissipation mechanism is based on the plastic deformation at certain points of the structure, in the seismically isolated structure energy dissipation mechanism is concentrated at the isolation level enabling simple design, control and eventual repair.
- Lateral displacement and storey drifts observed more in asymmetric building model of fixed base and base isolated building as compared with symmetricbuilding model of fixed and base isolated building.
- Storey drift, storey acceleration, base shear, maximum shear force and maximum bending moment gradually increase with decreases of soil stiffness.

VIII. Future Scope in Work

The vibration control technology is developing and its application is spreading in various fields of engineering structures. Factories, hospitals and residential houses will be protected from environmental vibration. It is evident that this technology will be progressed and become more important in the coming century.

In the present study response spectrum analysis of fixed base and base isolated building using ETABS software is done. The symmetric and asymmetric fixed base and base isolated building are compared for parameters such as maximum shear force, torsion, bending moment, lateral displacement, storey drift, storey acceleration and base shear was carried out to determine the behavior of the structure under dynamic loading. Effectiveness of base isolation was studied by considering bilinear model of the LRB and modeling the same and superstructurebyETABS.

The future scope of the present study can be extending as follows:

- Study on these buildings can be performed using real time earthquake data by performing a time history analysis.
- Study on these buildings with the effect of brick in fill can be performed.

