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Seismic Control Using Base Isolation Strategy

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***Abstract*—** The main idea of the study is the optimum design and the economic evaluation of reinforced (RC) conventional and isolated structures. For the purpose of the study two symmetrical RC structures were studied, designed both with and without seismic isolation, following a performance based concept. The seismic isolation was accomplished by the use of Lead-Rubber Bearings (LRB) and High Damping Rubber Bearings (HDNR).The seismic isolation technique is described, as well as the conditions and the applications of the method worldwide, along with the types of the isolation devices.The modeling, the preliminary design and the final design of the bearings is described.The model of a structure was created in MATLAB and comparison of response of the structure with and without base isolation was done.

***Keywords*—** base isolation, laminated rubber base, passive control

I. Introduction

Natural hazards bring damage to manmade inventions such as habitats and infrastructural facility causing loss to life and property. Earth quakes are one of those hazards with sudden violent movement of earth's surface with the release of large amount of energy. According to revised provision of IS 1893 Part-1(2002), seismic zones of India became more vulnerable and reduced to four zones. An earthquake causes all buildings to be shaken by the ground. Buildings that are shorter and/or stiffer amplify the ground motions and experience accelerations that are much larger than actual ground acceleration. The geometry and stiffness characteristics of the building also cause amplification of the ground motion up through the building. Thus it is important to design structures with seismic resistance. The ductility design was widely followed in building design. High uncertainty of ductility design strategy is primarily due to:

1. The desired strong column weak beam mechanism may not form in reality due to existence of walls.
2. Shear failure of columns due to inappropriate geometrical proportion of short column effect.
3. Construction difficulty in grouting especially at beam column joint due to complexity at steel reinforcement by ductility design.

II. CONCEPT OF BASE ISOLATION

The main types of earth quake protective systems include passive, active and semi-active systems. In passive control systems devices do not additional energy source to operate and are activated by earthquake input. Active control systems require additional power source which has to remain operational during an earth quake and a controller to determine actuator output. Hybrid control systems combine both passive and active control systems. Since a portion of control objective is achieved in passive system, the less active control effect is achieved in hybrid control systems. Seismic isolation may be an effective rehabilitation strategy if the results of seismic evaluation show deficiencies attributable to excessive seismic forces or deformation demands, or if it is desired to protect important contents and nonstructural components from damage. A seismically isolated structure uses seismic isolation devices which increase the period of shaking of a building. They are inserted between the building and ground in order to reduce the amplification of the earthquake motion in the building, thus mitigating the shaking of the building.

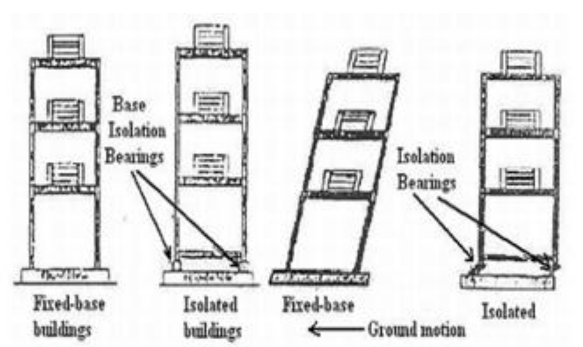

Fig.1 Behavior of building structure with and without base isolation system

Base isolation tries to decouple the structure from the damaging effect of the ground in the event of an earth quake. Base isolation revolves around a few basic concepts:

1. Period shifting of structures
   Base isolator is more flexible device compared to the flexibility of the structure. Thus coupling both an isolator and the super structure together increases the flexibility of the structure. In this way it lengthens the structures natural time period away from the predominant frequency of the ground motion, thus evading disastrous responses due to resonance.
2. Mode of vibration.
   The fundamental mode of vibration is altered from continuous cantilever type to almost rigid structure with deformation concentrated at isolation bases.
3. Damping and cutting load transmission path.
   Damper or energy dissipater is used to absorb energy of force to reduce relative deflection of structure with respect to ground motion.

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4. Minimum rigidity.
   Provide minimum rigidity to low level service load such as wind or minor earth quake loads.

III. TYPES OF BASE ISOLATION DEVICES

The two basic types of isolation bearings are *sliding* and *elastomeric (rubber)* bearings. Typically, isolation systems consist of either elastomeric bearings alone or sliding bearings alone, although in some cases they have been combined.

A. Sliding bearings

Sliding systems are simple in concept and have a theoretical appeal. A layer with a defined coefficient of friction will limit the accelerations to this value and the forces which can be transmitted will also be limited to the coefficient of friction times the weight.

Sliders provide the three requirements of a practical system if the coefficient of friction is high enough to resist movement under service loads. Sliding movement provides the flexibility and the force-displacement trace provides a rectangular shape that is the optimum for equivalent viscous damping. Sliding bearings typically utilize either spherical or flat sliding surfaces.

B. Pure Friction Systems:

It is the earliest and simplest sliding isolation scheme and best represents the principles of sliding isolation systems. The system utilizes a sliding joint to decouple the superstructure from the substructure and operates under the principle of sliding friction. At low lateral service loads, the entire structure acts as a fixed-base system, since lateral forces are too insignificant to overcome the static frictional force and induce horizontal displacement. When the system is subjected to significant lateral seismic forces, the frictional force is overwhelmed and sliding is mobilized. Accelerations in the structure are reduced through the dissipation of energy through friction in the form of Coulomb damping. The lateral force required to overcome the static frictional force is a function of the coefficient of static friction and can be controlled through the selection of material to be employed at the bearing surface. Clear disadvantages of the system include continuous maintenance of the bearings to ensure a constant coefficient of friction and the inability of the system to recenter after an extreme event.

C. Friction Pendulum System bearing (FPS):

It is the most widespread sliding seismic isolation bearing in use within the United States. FPS uses geometry and gravity to achieve the desired seismic isolation results. The FPS concept is based on an innovative way of achieving a pendulum motion. It combines the concept of sliding isolation systems with the action of a pendulum. The superstructure is isolated from the substructure via a bearing that is comprised of an articulated slider resting on top of a convex bearing surface with a low coefficient of friction, usually made of chrome or stainless steel. When lateral seismic forces overcome static friction the articulated slider is displaced along the convex spherical bearing surface. If friction between the articulator and the bearing surface is neglected, the system behaves as a simple pendulum. The restoring force that recenters the friction pendulum systems provided by the change in direction of the frictional and normal forces as the articulator slides up the wall of the curved bearing surface. Coulomb damping generated through sliding friction provides constant energy dissipation in the bearing. The effective stiffness and usually made of chrome or stainless steel. When lateral seismic forces overcome static friction the articulated slider is displaced along the convex spherical bearing surface. If friction between the articulator and the bearing surface is neglected, the system behaves as a simple pendulum. The restoring force that recenters the friction pendulum systems provided by the change in direction of the frictional and normal forces as the articulator slides up the wall of the curved bearing surface. Coulomb damping generated through sliding friction provides constant energy dissipation in the bearing. The effective stiffness and subsequent shifted period of the isolation system, based on dynamics of a pendulum, is dependent upon the radius of curvature of the convex bearing surface

D. Sliding Isolation Pendulum Bearings (SIP):

SIP bearings can be compared to a spherical bearing that can move in all directions. The horizontal displacements caused by seismic events are accommodated by the sliding movement and in the same time the energy that is introduced is converted either into heat or into potential energy. It also provides recentering to the superstructure by means of its dead weight into the central position of the curved sliding surface. Therefore, SIP-bearings combine the four main requirements of the seismic isolation: Vertical load transmission, horizontal displacement, energy dissipation and recentering.

Elastomeric bearings consist of a series of alternating rubber and steel layers. The rubber provides lateral flexibility while the steel provides vertical stiffness. In addition, rubber cover is provided on the top, bottom, and sides of the bearing to protect the steel plates. In some cases, a lead cylinder is installed in the center of the bearing to provide high initial stiffness and a mechanism for energy dissipation. Natural rubber bearings were first used for the earthquake protection of buildings in 1969 for the Pestalozzi School in Skopje. Characteristic of isolation systems of this kind, the horizontal motion is strongly coupled to a rocking motion, so that purely horizontal ground motion induces vertical accelerations in the rocking mode.

E. Low-Damping Natural or Synthetic Rubber Bearings:

The isolators have two thick steel endplates and many thin steel shims. The rubber is vulcanized and bonded to the steel. The steel shims prevent bulging of the rubber and provide a high vertical stiffness but have no effect on the horizontal stiffness, which is controlled by the low shear modulus of the elastomer. The material behavior in shear is quite linear up to shear strains above 100%, with the damping in the range of 2-

3% of critical.

F. High-Damping Natural Rubber Bearings (HDNR):

In order to eliminate the need of supplementary damping elements, it was developed a natural rubber compound with enough inherent damping. The damping's shear modulus is 0.35-1.4 MPa, its maximum shear strain is 200 to 350%, while the damping values range between 7-14% of the critical. The dynamic properties of high damping rubber bearings tend to be strongly sensitive to loading conditions. For example, high damping rubber bearings are subjected to scragging. Scragging is a change in behavior (reduction in stiffness and damping) during the initial cycles of motion with the behavior stabilizing as the number of cycles increases. The behavior under unscragged (virgin) conditions can be appreciably different from that under scragged (subjected to strain history) conditions. Over time (hours or days), the initial bearing properties are recoverable.

G. Lead-Rubber Bearings (LRB):

This kind of seismic isolator was invented in 1975 in New Zealand by Bill Robinson and is used extensively in New Zealand, Japan and the United States. Their structure is similar to low-damping rubber bearings, but they contain a central lead plug which increases the initial stiffness of the bearing, as it provides wind loading restraint, and increases the energy dissipation capacity of the bearing. After the lead yields, it dissipates energy as it is cycled. Fatigue of the lead is not a concern, since lead recrystallizes at normal temperatures.

IV. STEP-BY-STEP PROCEDURE FOR THE DESIGN OF ISOLATED STRUCTURES

Step 1: Establish seismic zone factor Z.
Step 2: Establish site soil profile category.
Step 3: Calculate Maximum Capable Earthquake (MCE).
Step 4: Determine seismic coefficients according to the seismic zone factor and the site soil profile.
Step 5: Determine seismic coefficients according to the soil profile type determined in step 2.
Step6: Determine structural system reduction factor R_I corresponding to the structural system used above the isolation interface
Step 7: Select the type of isolation bearings and the damping coefficients β_D and β_M (for LRB 15% - 35% and for HDNR 10%-20%).
Step 8: Select a desired isolated period of vibration T_D. Decide on an initial estimate for the isolated system fundamental period of vibration at the design basis displacement level, between 2.0 and 3.0 sec.
Step 9: Estimate the effective stiffness of the isolation system for the isolated period established in step 9.
Step10: Estimate the minimum design displacement D_D, by the equation and calculate the initial estimate of the minimum design displacement D_D.
Check: *If this value is larger than what is acceptable for the project, go back to step 8 and start with a smaller estimate of the vibration period.*
Step 11: Establish the minimum design lateral forces V_b and V_s, to estimate the minimum design lateral forces for the isolation systems and structural system at or below the isolation interface (V_b) and structural elements above the isolation interface (V_s), respectively.
Check: *If the values of either V_b or V_s are larger than what is acceptable for the project, go back to step 8 and start with a larger estimate of the vibration period.*
Step12: Perform a preliminary design of the structural elements of the superstructure. With V_s estimated in step 11, static lateral forces at each level of the building are calculated. These lateral forces are used for preliminary stress sizing of superstructure elements based on drift limits ($0.010/R_I$ - static force procedure, $0.015/R_I$ - response spectrum analysis, $0.020/R_I$ - time history analysis).
Check: *If the period of the fixed-base superstructure as designed is significantly different from that assumed in calculating the limitations on V_s in step 11, go to step 11 and verify the adequacy of V_s as assumed.*
Step 13: Perform a preliminary design of isolator units and their distribution. Using the preliminary displacement, stiffness, force and damping properties established in the previous steps, design the isolator units to resist the gravity load, lateral load and displacement requirements.

Final Design Steps

Step 14: Construct mathematical model of the isolated structure. Incorporate the force-displacement characteristics of the isolation bearings obtained from step 13 in the models.
Step 15: Select an appropriate lateral response procedure.
Step 16: Finalize the target values of design displacements and isolated periods. Iteratively finalize the values of design displacement D_D' and maximum displacement D_M' for the project. $D_M' > D_D' > D_D$, where D_D was calculated in step 10. Establish the isolated period at design displacement and maximum displacement levels, T_D and T_M.
Step17: Finalize the target values of effective stiffness, as follows:

$$\mathbf{K_{D\,max} = K_{D\,min} = \frac{DBE\ base\ shear}{D_D}}$$

$$\mathbf{K_{M\,max} = K_{M\,min} = \frac{MCE\ base\ shear}{D_M}}$$

Step18: Verify the effective period suggested by the mathematical model. Verify the effective periods T_D and T_M as determined by the mathematical model against those calculated by minimum values.
Step 19: Verify the damping level suggested by the Eq. (2.12), (2.13)
Step 20: Verify design displacements and forces against code minimum values. Also verify reported base shears

against code minimum values.

Step 21: Verification of performance as suggested by the prototype bearing test results. Upon the availability of prototype bearing test results, revise the mathematical model constructed in step 14 to reflect the lower bound and upper bound bearing properties suggested by the prototype test results.

Step22: Verification of performance as suggested by the production bearing test results. Upon the availability of production bearing test results, revise the mathematical model constructed in step 14 to reflect the lower bound and upper bound bearing properties suggested by the production test results and actual distribution of individual isolators

V. RESPONSE OF STRUCTURE WITH AND WITHOUT ISOLATOR

A model of structure was made in MATLAB and response of structure with and without using base isolating device was compared. It was found that the ground acceleration was comparatively reduced for the structure using base isolator.

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