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Seismic Base Isolators under Individual and Combined Use in Multi Storied Buildings – A Review

Nithin A V[1], Asha Varma P[2]

[1]PG Student, Department of Civil Engineering, NSS College of Engineering, Palakkad, Kerala, India
[2]Professer, Department of Civil Engineering, NSS College of Engineering, Palakkad, Kerala, India

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Abstract - *Base isolation refers to the principle which introduces flexibility to the supports of the building in the horizontal plane and ensures the period of the buildings outside that of the earthquakes acting on it. These isolators are either installed as a single type or using different isolators on the base of same building. The concept of combined and multiple isolation techniques is not new. The combined isolation is often confused with hybrid isolation where active or semi active isolation systems are used in combination so that effective reduction of seismic response can be carried out in case one of the system fails during the event. The use of one or more passive isolation in combination or the same with a friction slider mechanism is referred as combined base isolation. To avoid the complexity of design and analysis the studies were mostly limited to implementing these systems at the base of the building. The multiple isolation structure has additional isolation devices in stories by inserting isolators in the middle story in addition to the base. In this paper, the suitability of type of base isolators under individual and under combined base isolation and their effectives to reduce inter-story drifts and accelerations of the buildings is studied. A brief idea about base isolation and its different types is needed beforehand.*

Key Words: Base isolation, Lead Rubber Bearings, Friction Pendulum Bearings, Non linear dynamic analysis, Combined base isolation.

1.INTRODUCTION

Base isolation decouples the structure from ground during a seismic event and prevent damages that may occur due to the seismic event. For the past decades, its proven that base isolation is one the effective and popular methods to reduce the seismic response on these types of structures. It is a passive control device which is installed between the foundation and base of the building. The basic principle is either deflection or absorbing the seismic energy. First is achieved by making the building flexible at the base in lateral directions, this increase the fundamental time period of the structure. Also the buildings having longer time periods attract less seismic forces. The nonlinear response of isolators helps in seismic energy absorption. The (internal) force–displacement curve of isolators under sinusoidal excitation exhibits hysteretic behaviour and, therefore, much of the input energy to the isolators is lost in the hysteresis loop. Thus the low lateral stiffness and hysteretic behaviour makes them effective in passive seismic control of seismic response of buildings. These also re-centres the structure when ground motion due to earthquake ceases and should be designed in such a way that necessary rigidity is provided under low service loads. This technique is also used for the seismic retrofit of historic structures, buildings containing motion sensitive equipment, high risk buildings (eg, nuclear power plants), buildings of special importance after earthquakes (hospitals, disaster management centres) etc.

A typical base isolation must satisfy the three basic criteria listed below:

1. Decoupling action between foundation and superstructure with or without flexible mounting.
2. Energy dissipation action
3. Enough rigidity under low in-service loads

2. BASE ISOLATION SYSTEMS

Generally, types of the base isolators can be grouped into (i) Elastomeric bearings, and (ii) Friction sliding bearings and (iii) Roller bearings. The Elastomeric bearings include, laminated lead rubber bearings (LRB), High Damping laminated Rubber Bearing (HDRB) and Low damping laminated rubber bearings. In the friction type, Flat sliding bearings, friction pendulum systems (FPS), Spherical sliding bearing are used. Each isolator differs in their response to an earthquake. Each isolator has its own stiffness and damping characteristics and also each earthquake response varies based on the method of analysis performed. Thus an effective stiffness of base isolation acts in case of combined isolation technique. Most commonly used bearings are Lead Rubber and Friction pendulum bearings. Lead Rubber bearings consist of alternate layers of rubber and steel shims with a central lead core. Fig.1. The elastomeric material provides the horizontal flexibility to the isolator, the lead core provides energy dissipation, while the internal steel shims enhance the vertical load capacity and minimizing lateral buckling. The steel shims also contribute to plastic deformation of the central lead core. The rubber layers deform laterally during an earthquake event of the structure and allows the building

to translate horizontally, and the bearing to absorb energy when the lead core yields.

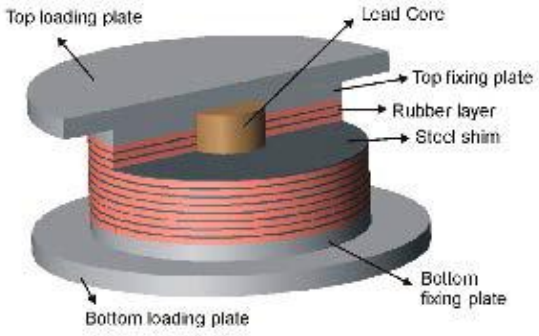

Fig -1: Lead Rubber Bearing isolator components

In Friction pendulum system the movement of the slider generates a dynamic frictional force that provides the required damping to absorb the earthquake energy.Fig.2. Friction at the interface is dependent on the contact between the slider which is teflon-coated and the stainless steel surface and the friction increases with pressure. Values of the friction coefficient ranging between 3% to 10% are considered reasonable for a FPS to be effective. The isolator period is a function of the radius of curvature of the concave surface. The natural period is independent of the mass of the supported structure.

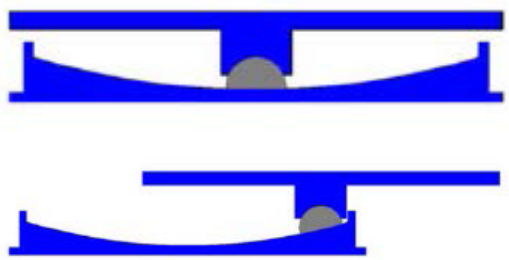

Fig -2: Motion in a FPS (a) initial condition, (b) displaced condition at maximum displacement

3. EFFECTIVENESS OF BASE ISOLATION

Seismic base isolation has been used for reducing the earthquake impact on buildings. But often displacements at base and near ground stories were having a larger value even though base shear and story accelerations are reduced. The effectiveness of this technique depends upon the lengthening time period of building and this results in reduced seismic forces in buildings. The drawbacks of the conventional seismic design used in a fixed structure has paved way for the idea of base isolation but lack of technology in manufacturing and analyzing the isolators prevented their proper usage in buildings for the past 35 years. But now things have changed in the field of dynamic structural analysis by computers, high quality laminated elastomeric bearings and in case of energy dissipating devices, feasibility studies are carried with accuracy and ease. The effectiveness of isolation depends upon the input seismic unit, design parameters like soil type, building type etc and functionality like historical importance, lifeline structures etc. It's a pre requisite building requirement that provides the functionality of the building even in severe earthquake events. Thus preventing the entire building to be in a unusable stage that causes further business crisis and the rebuilding or repairing is costly and time dependent task. The benefits are reduced floor accelerations and inter storey drifts, better protection of buildings and its contents, keeping the structural behaviour elastic or in its range. The major one is increasing the life of the structure as predicted like in countries like Japan there is always uncertainties in the earthquake occurrence and long term benefits are required for the safety of the buildings.

The proper analytical modelling is prerequisite to compute response. The elastomeric type bearings resist the seismic force and the weight of the structure. The natural period depends upon weight of the building that is structural property and the input motion. In sliding type bearings structural response is controlled by the coefficient of friction and by the input motion.

4. LITERATURE REVIEW

Various literature reviewed on base isolation techniques is presented in this section. A number of works have been performed on base isolation using different types of isolators and their combined action. A review of literatures is presented in brief summarizing the work done by different scholars and researchers on the seismic response of multi-story structures using these techniques.

Luis Andrade and **John Tuxworth (2002)** did a design comparison on Lead Rubber bearings and friction pendulum bearings for a five story RC framed building. The response of the fixed-structure and isolated type is compared for dynamic analysis to actual historical records for five significant seismic events, that is, 1940 and 1979 Imperial Valley earthquake, 1989 Loma Prieta Earthquake, 1994 Northridge Earthquake and 1995 Aigion Earthquake. According to design considerations for friction pendulum system, the time period is a function of the radius of curvature (R) of the concave surface and also the natural period is independent of the mass of the supported structure. The principle of Lead Rubber bearings is that the rubber layers deform horizontally during seismic excitation of the structure, allowing the building to translate in that direction, and the bearing to absorb energy when the lead core yields. Here time period depends on the total weight of the building. Both isolators significantly improved the buildings performance during the applied earthquakes. Both the LPB and FP systems reduced the roof level accelerations, however the LPB provided the best reduction in elastic base shear, and inter-storey drift (at first floor). For the adopted bearing characteristics, the FPS provided greatest control of isolator displacement.

Kalantari S. M (2008) studied the effect of using two different types of seismic isolators, that is lead-rubber isolator and friction pendulum isolator, in decreasing the base shear and story shears of structure. Using a nonlinear finite program models with varying height and isolator stiffness properties under earthquake data of Manjil, Naghan, Tabas and Elcentro earthquakes. Increase in time periods of isolators resulted in decrease of base and story shear but it increased displacement of the structure. Results shows that Lead Rubber bearings increases the story displacements in low rise buildings and their effect becomes insignificant when height of building increases. Both the isolators when used in higher stories their displacements where found in comparison to the fixed structure, showing their limitation to long structures. Friction Pendulum bearings showed lesser increase in displacements with respect to fixed structures irrespective of height indicating their displacement reduction property. Decrease in the effective stiffness of isolators resulted in deceased base shear and improved energy dissipation of isolation system.

Torunbalci N and **Ozpalanlar G (2008),** in their paper, as an example, a six storey symmetric structure has been analysed with five seismic protection alternatives such as fixed base, rubber bearings, friction pendulum bearings, additional isolated storey and viscous dampers using SAP 2000. 3-D nonlinear time history method of analysis was performed on RC structural model for fixed base with respect to the isolation and other earthquake protective alternatives. Compared to buildings isolated with viscous damper and additional isolated story, base isolated buildings with rubber bearings and friction pendulum bearings were having reduced base shear and maximum relative drift values with the friction pendulum base isolated building has lowest base shear and relative drift values of them were having lesser difference. The building with friction pendulum bearing has lesser story acceleration compared to other types of isolation systems.

Chandak N. R (2013) also did a comparative study on Reinforced Concrete (RC) building with fixed and isolated base with rubber bearings and friction isolators using response spectrum method using finite element computer program SAP2000. Here both IS code and Euro code are considered for design and their difference is also studied on a symmetric and un-symmetric buildings. Results show Friction pendulum isolators has reduced torque in the response of isolated building when compared to that of the response obtained with rubber bearings. Also base shear and maximum relative drift was found to be lesser in case of friction type isolators under IS code and Euro code with different ground types. IS code depicting higher values of response parameters in all the cases with and without isolation, when compared to that of Euro code. The variation of maximum drift value was reducing with increase in no of stories. IS code gives the maximum and Euro Code gives the minimum displacement values for the buildings with fixed base.

Ashish R. Akhare (2014) compared the effects of High density rubber bearing and friction pendulum system on a regular G+12 storey reinforced concrete hospital building and a non-linear time history analysis was carried out using SAP2000. The results show that base shear is effectively reduced in case of isolated buildings with Friction pendulum system building having the lower value. The storey displacement has no effect on isolator type as their variation shows very little difference. The values of storey displacement, story drift and story accelerations were showing less variation with respect to story height in case of friction pendulum bearing installed buildings than buildings with high damping rubber bearings but these values were comparable at top story of the building.

Alaa Barmo et al (2015) studied about the effect of hybrid isolation technique on the response of a multi storey building under seismic loads. Here Base isolation and seismic dampers can be used to minimize inter-story drifts and floor accelerations using isolation bearings and dampers system at the structural base, or at higher levels of the superstructure. In this research, the response of buildings isolated using isolation systems consisting of Lead-Rubber Bearings, Flat Sliding Bearings, with the addition of Rotation Fiction Damper installed at the base. The results were compared with buildings that have fixed base. The period, displacement and shear force distribution is studied with respect to height of the building. It conducts time history seismic analysis for some varying height buildings, using SAP2000 using an earthquake acceleration-time history for (El- Centro). The results show that the use of combined isolation had a significant impact on reducing displacements and base shear with increasing height of the building. But this isolation technique had a negative impact on the drift, that is the drift increased with the increased flexibility of the building. Also the displacements is increased with the period of the building and with the story height in the base isolated building and with the addition of rotation friction dampers at the base of the structure. This had a significant impact on improving the performance of isolated structure.

Manoj U Deosarkar and **S D Gowardhan (2015),** in their work a G+5 storey symmetrical & asymmetrical RCC building is taken to analyze and design. The main aim of this thesis is to reduce storey shear, storey acceleration and storey drifts due to earthquake excitation, by installing base isolator at the foundation level and also to compare the performances between fixed and isolated base condition of a symmetric and an asymmetric building. The three basic base isolation systems, high damping rubber bearing, lead rubber bearing and friction pendulum system has been used in this work at foundation level for the buildings considered. Time history analysis has been carried out on Bhuj earthquake which is of intensity is 7.7. In the next part of the study seismic response of combined isolation system has been presented for both asymmetric and symmetric buildings. The response of the buildings on the combined isolation system was compared with the buildings mounted on separate base isolation system. It has been confirmed in this study that the use of base isolation system reduces the structural responses under seismic forces. The results of the isolated base condition with

that of fixed base condition has been compared and it has been found that the isolated base system reduces storey shear, storey acceleration and storey drifts also it increases the displacements and time period. The building with High damping rubber bearing and combined isolation system with lead rubber bearing and high damping rubber bearing is having the most reduction in base shear for symmetric and asymmetric plan compared to other models. The storey accelerations are reduced when lead rubber and friction pendulum bearings are used in combination. The variation of floor displacement and story drift is minimum in isolated type buildings with the increase in height. The effective base isolation was observed when friction pendulum bearings were used on outer columns and lead rubber and high damping rubber isolators in inner column.

Zaheer and **Ravichandra.R (2015)** did a comparative study on performance of Multi-Storey Structure using Lead Rubber Bearing and Friction Pendulum Base Isolation Systems on an irregular RC building of G+10 storeys and analysed with and without base isolators using SAP 2000 software. Both Equivalent Static Analysis and Time History Analysis were carried out using El-Centro earthquake. Storey displacements and drifts at earthquake zone V using 15% damping in both isolators and found that Lead Rubber Bearings has lesser displacements and variations with respect to Friction Pendulum System. The base shear was found same of the vertically irregular L shaped building with both isolators. Thus they concluded that Lead Rubber bearings is best suited in this case compared to Friction Pendulum Bearing.

Azin Shakibabarough (2016) studied the feasibility of optimal positions of friction dampers and base isolators (triple pendulum base isolator) on a 2D two bay frame with six stories and Fast non-linear analysis were carried out to find the responses using SAP2000 subjected to El Centro earthquake ground motion. Fixed building, base isolated with isolator and different arrangements of dampers are considered in this study. It is seen that buildings with triple pendulum base isolator has lesser comparable inter story drift with certain configurations of friction damper. The floor displacements were higher in case of base isolated type frame and the frame with base isolators is the best for reducing the bending moment of the frame. Maximum axial force was least for the friction damper placed diagonally on second story of the frame. This configuration of damper location was found to be more effective with respect to inter-story drift, maximum floor joint displacement and maximum axial force.

Donato Cancellara et al (2016) studied the seismic behaviour of an irregular building with two different types of passive base isolation systems in combination with friction slider. Two base isolation systems which are considered are High Damping Rubber Bearing (HDRB) is used along a Friction Slider (FS) and the Lead Rubber Bearing (LRB) with a Friction Slider (FS). The fast nonlinear dynamic analysis algorithm (FNA) is used for the numerical solution of the dynamic response of the structure. A comparative analysis is done to find the effectiveness of the considered base isolation systems when the RC building is subjected to bi-directional ground motions. The time history analysis of the base shear, the peak values of the base shear, the base acceleration, the base displacements of the superstructure and inter-storey drift is done so that a complete assessment can be performed of the seismic behaviour of the base isolated structure. The results show that the LRB isolators show a greater dissipative capacity compared to HDRB isolators but this needs to be controlled as it creates higher inter-story drifts. The studies also show that LRB isolators has more robustness and stability of their hysteretic cycles when compared to the hysteretic cycles of the HDRB isolators.

Sunita Tolani (2016) has done a parametric study on the effectiveness of base isolation technique and its properties on seismic response comparison of a fixed base building with a base isolated building of three storey reinforced concrete building, which is idealized as a shear type building with one degree of freedom in lateral direction at each floor level. The isolation systems considered for this study are Laminated Rubber bearing (LRB), N-Z bearing and Friction Pendulum bearing System (FPS). A non-linear time history analysis was carried using Matlab software on the selected earthquake ground motions, that is, El Centro (1940) Earthquake (N-S component); Kobe (1995) Earthquake; Sylmar (1971) Earthquake. The results show that Lead Rubber Bearing provides maximum reduction in the acceleration on various stories but the isolator displacement values is more for LRB when compared to N-Z system and FPS. On the other hand, the N-Z system and FPS require minimum bearing displacement for reasonable reduction in response. However, the top floor absolute acceleration, inter-story drift and base shear are less for base isolated building compared to fixed base building. In Lead rubber bearings, the increase in time period increases the base displacement but the superstructure acceleration was reduced. Same behaviour was observed in N-Z bearing and increase in the Normalized Yield Strength decreases the bearing displacement but increases the superstructure acceleration. The parameter affecting the FPS is the coefficient of friction and increase in the friction coefficient decreases the displacement of the bearing but increases the storey acceleration. Thus these factors must be properly designed for effective seismic response of the building.

5. CONCLUSIONS

The concept of base isolation is not a recent topic and recent developments in full-scale shake table testing and advancement in accurate software oriented analysis has made this technique more acceptable. This technique ensures a simultaneous reduction acceleration and drift responses of the building even under a large and unpredictable seismic event. However, there are still gaps in the research to be filled like seismic isolation cannot ensure a complete protection of buildings, challenges are still there like how to protect components of buildings subjected to vertical excitation, mitigation of overturning forces in slender structures which causes local uplifts and superstructure yielding in extreme events. This paper attempts to summarize the effectiveness of base isolators

and their suitability in various types of buildings and chosen earthquake parameters. The basic design concepts of most common base isolator, that is, Lead Rubber bearings and Friction Pendulum bearings are briefly discussed. The base shear was effectively reduced by using any types. The variation of the responses with respect to story height was found to be less and stable for friction pendulum type. The displacement values of buildings in the lower stories with rubber bearings isolators were showing much variation while compared to higher stories. Often base isolators with damping properties or combined isolation using base isolators and dampers were found most suitable compared to normal rubber bearings.

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