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Analysis of Reinforced Concrete and Steel Multi Storey-ed Structures with Lead Rubber Bearing and Friction Pendulum Systems

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Base Isolation is one of the most common methods adopted to protect the building against seismic forces. The base isolated structures have very less base shear, displacement and storey drift compared to the fixed base buildings. The present work investigates the nonlinear dynamic analysis of RC and Steel multi-storeyed structures with Lead Rubber Bearing and Friction Pendulum Systems. The main objective is to compare the behavior of the structures with base isolation and fixed base buildings by using SAP2000. The dynamic response of the structures have been estimated by means of Non-linear Analysis based on the El-Centro earthquake ground motions. The Time History Analysis was used for analysing the buildings and the results were taken in the form of displacements and inter-storey drifts. The result shows that as the storey height increases, the inter-storey drift decreases by using the base isolation systems.

Keywords: Base Isolators, Lead Rubber Bearing, Friction Pendulum System, Fixed Base, Time History Analysis, interstorey drifts, storey displacements..

1. Introduction

Earthquake is one of the major natural disasters of the world. Earthquake causes movement of tectonic plates that creates the seismic waves due to the sudden release of energy. In order to resist the seismic waves, earthquake resistant techniques are adopted. In recent years, base isolation techniques have been applied to the buildings and the bridges in the seismic areas to resist the seismic forces. For the structures located in the seismic zones, earthquake load is considered to be one of the main factors for the design of the structures under seismic loading. The seismic design is adopted to resist the seismic forces from low to moderate levels of earthquake without structural damage. Thedynamic characteristics of the ground motions are Peak Ground Acceleration (PGA), time duration and frequency of the ground motion. Hence, the base isolation techniques have been adopted to reduce the peak acceleration, base shear and inter-storey drifts. The base isolation technique is used to decouple the superstructure from the foundation in order to prevent the structure from earthquake ground motions. The base isolation system increases the flexibility and stiffness of the structure and resists the structure from damage. The base isolator absorbs the energy dissipation of the structure and reduces the amount of lateral force transferred to the superstructure.

A.B.M. Saiful Islam, et.al, [10], investigated the nonlinear seismic response of a ten- storeyed building isolated by the Lead Rubber Bearing (LRB) and Friction Pendulum System (FPS) under Natore Earthquake record. The most effective choice between High Damping Rubber Bearing (HDRB) and Lead Rubber Bearing (LRB) is based on the reduction of the floor displacements and amplification of the rigid body displacements.

Donato Cancerllara, et.al, [3], investigated the seismic behavior of multi–storey reinforced concrete building with two base isolation systems. The two base isolation systems considered were High Damping Rubber Bearing (HDRB) and Lead Rubber Bearing (LRB) and the friction isolators are used in parallel with LRB and HDRB. The result shows that LRB isolators had greater dissipation capacity than HDRB isolators.

2. TYPES OF BASE ISOLATION SYSTEMS

The most commonly used base isolation systems safety of the building components, by reducing the seismic design forces. Eight storeyed RC and steel structures were modelled and analysed for both fixed base and base isolated structures by using SAP2000 [5]. The comparative results between the fixed base and base isolated structures were studied for an 8-storeyed building. The El-Centro earthquake ground motion record is taken for the non-linear analysis.

CONCEPT OF BASE ISOLATION

The main concept of base isolation technique is to decouple the structure from its foundation and by increasing the strength of the structure [9]. If the foundation is rigidly attached to the building, then the earthquake forces will be directly transferred, without any change in the frequency to the rest of the building. By providing a base isolation system between the substructure and superstructure, the ground motions that is transferred to the building is minimized by the action of installation of isolators. The isolators increase the building stiffness and flexibility. This concept increases the building safety and reduces the lateral design forces acting on the building [11]. Fig. 1 illustrates the concept of base isolation technique.

- Elastomeric Bearing
- Sliding Bearing

A. Elastomeric Bearing

An elastomeric bearing consists of a number of rubber layers and steel layers bonded together in alternate layers, to produce a vertically stiff isolator. The alternating steel layers act to restrain the rubber layers from bulging laterally [4]. This bearing can produce flexibility and is capable of withstanding the vertical loads with very small deformation. The lead core is inserted in the elastomeric bearing to increase the damping capacity and lateral stiffness of the building as shown in Fig. 2. The elastomeric bearing may be classified as:

- High Damping Rubber Bearing
- Lead Rubber Bearing
- Natural and Synthetic rubber Bearing

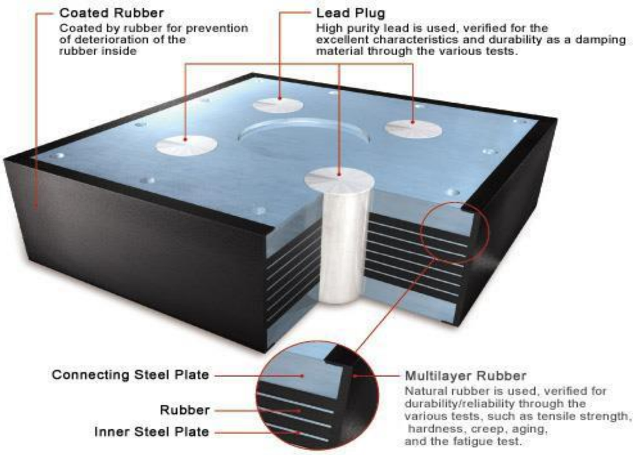


Fig. 2. Elastomeric Lead Rubber Bearing

B. Sliding Bearing

Sliding bearings are also known as plain bearing which are introduced to resist the earthquake forces through the frictional interfaces. This type of system possess only bearing surface and has no rolling materials. This kind of bearing has no re-centering capacities, except the Friction Pendulum Bearings (FPB) which has a curved sliding surface and can provide the structures with restoring capacities by the forces of gravity [1]. Fig. 3 shows the FPS isolator, which combines both sliding action and restoring action.

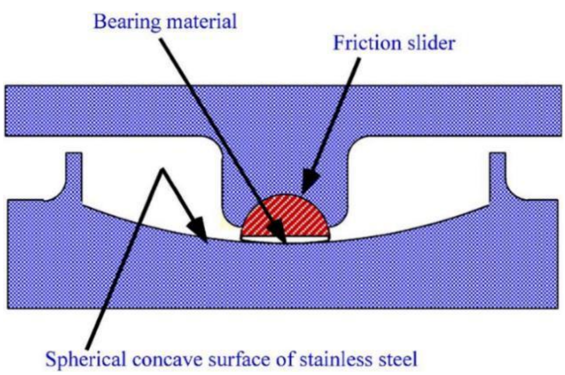


Fig 3. Friction Pendulum System

The other types of sliding bearing are:-

- Pure Friction System
- Resilient Friction Base Isolation System

SELECTION OF ISOLATORS

The various parameters considered in the choice of selection of an isolation system depends on the following:

- Deformability under frequent quasi-static load
- Yield force and displacement
- Self-centering capacity after deformation
- The vertical stiffness

MODELLING DETAILS

In the present study, an 8-storeyed reinforced concrete and steel multistoried building having symmetrical geometry is considered. The building is located at Bhuj, Gujarat with seismic zone-V having medium stiff soil and the response reduction factor is taken as 5 and importance factor as 1. It is an I-shaped building with each bay having 5 m length in x-direction and 4 m length in y-directions. The height of each storey is 3m for all the floors. Figures 4 and 5 shows the plan and 3D view of the RC and steel building.

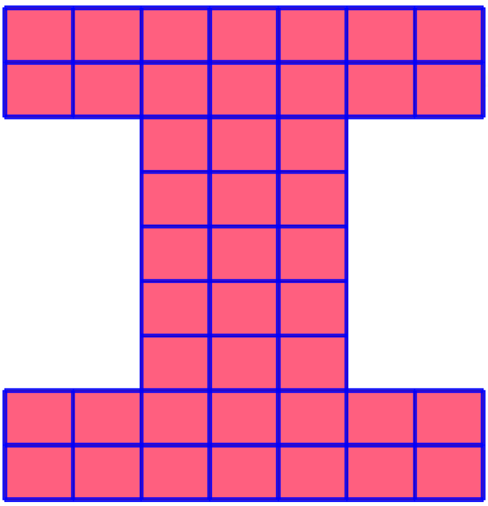


Fig. 4. RC and Steel Building Plan

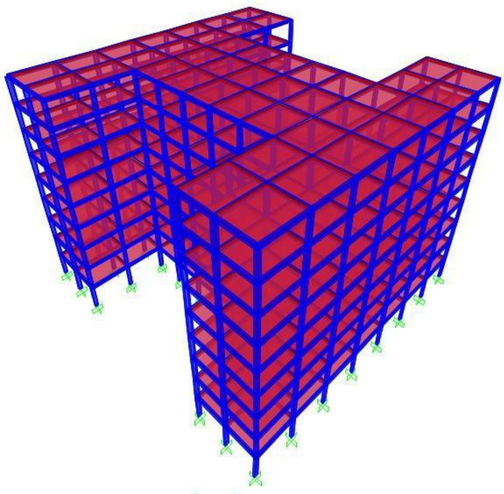


Fig 5. 3D View of the RC and Steel Building

The modeling and analysis of RC and Steel buildings for the two cases were initiated. The first case is fixed base and the second case is base isolated [12]. In this study, the base isolators used are Lead Rubber Bearing (LRB) [7] and Friction Pendulum System (FPS). The base isolators are designed as per IBC 2018 [13]. Figures 6 and 7 shows the elevation of RC and steel building with beam and column sectional properties. The dimensions of beam, column and mechanical properties for RC and steel members are shown in table 1.

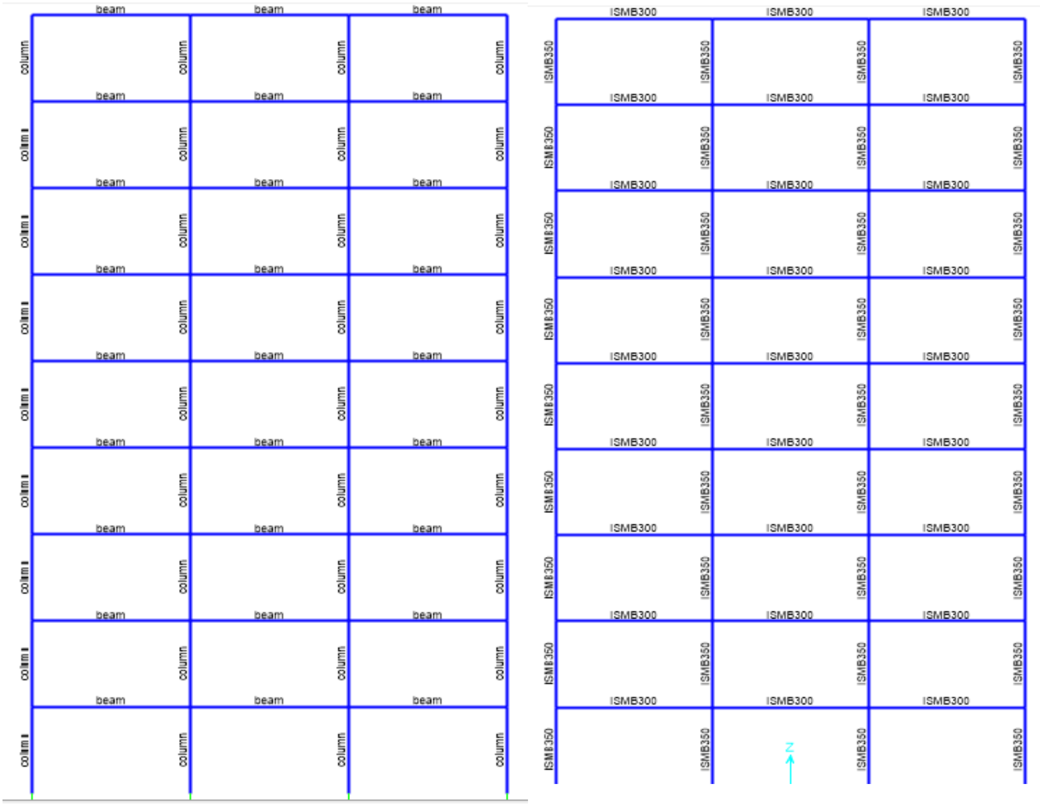


Fig. 6 Elevation of RC Building

TABLE I. BEAM AND COLUMN SIZE AND MATERIAL PROPERTIES FOR RC AND STEEL MEMBERS

Type of Structure	Beam Size	Column Size	Material Properties
8 Storeyed RC Structure	0.23 m x 0.381 m	0.23 m x 0.4572 m	• M30 • Fe415
8 Storeyed Steel Structure	ISMB 300	ISMB 350	• M30 • Fe315

NON-LINEAR TIME HISTORY ANALYSIS

The Non-Linear Dynamic Analysis [2] has been carried out for the El-Centro bi-directional earthquake records. The Direct Integration method was used to solve the dynamic equations The Newmark time integration method was used for solving step by step numerical equations and the number of output time steps is taken as 500 and output time step is taken as 0.02.

The thickness of the slab is taken as 0.15 m. The boundary condition of the building is taken as fixed support. The live load is applied as 3 kN/m2 for all the floors. The earthquake loads and load combinations are defined as per IS 1893 – 2016 [16]. El-Centro time history records were used for this

3. PROPERTIES OF ISOLATORS

The base isolators LRB and FPS are designed according to the IBC2018. The properties of LRB and FPS are calculated manually. The properties of Lead Rubber Bearing and Friction Pendulum System are entered in the link support properties as the base isolators in the SAP2000[15] as shown in the tables II and III.

TABLE II. PROPERTIES OF LEAD RUBBER BEARING FOR BOTH RC AND STEEL BUILDINGS

Properties of Lead Rubber Bearing		
Propertie ofIsolator	RC Building	Steel Building
Effective Stiffness, kN/m	642.003	568.7054
Stiffness,kN/m	3396.196	3901.319
Yield Strength ,kN	60.47	39.683
Post Yield Strength , Ratio	0.1	0.1
Effective Damping, kNs/m	37480.13	14571.12
Distance from end j	0.017807	0.010172

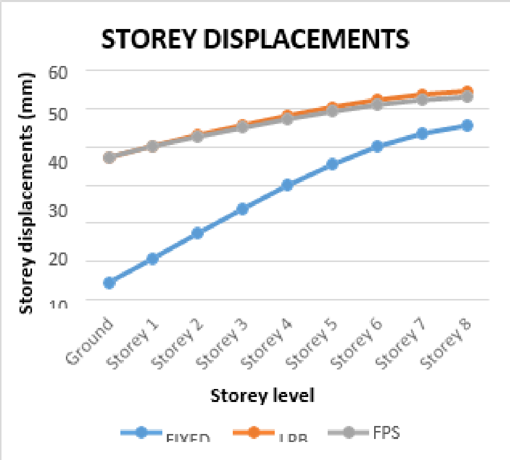
Table III. PROPERTIES OF FRICTION PENDULUM SYSTEM FOR BOTH RC AND STEEL BUILDINGS

Properties of Friction Pendulum System		
Properties ofIsolator	RC Building	Steel Building
Effective Stiffness, kN/m	561.5983	438.3497
Stiffness,kN/m	21496.58	16782.91
Radius of Isolator,m	2.24	2.24
Effective Damping, kNs/m	53721.52	29142.25
Friction Coefficient, Slow	0.02	0.02
Friction Coefficient, Fast	0.04	0.04

4. RESULTS AND DISCUSSION

In this study, SAP2000 [14] is used to model and analyse the 8 storeyed RC and steel structure for both fixed base and base isolation using non-linear time history analysis and the results were compared and discussed for bi- direction earthquake ground motion records. In order to evaluate the performance and effectiveness of the base isolation, the non-linear dynamic analysis has been performed and the results are assessed with fixed base buildings.

A. Storey Displacement



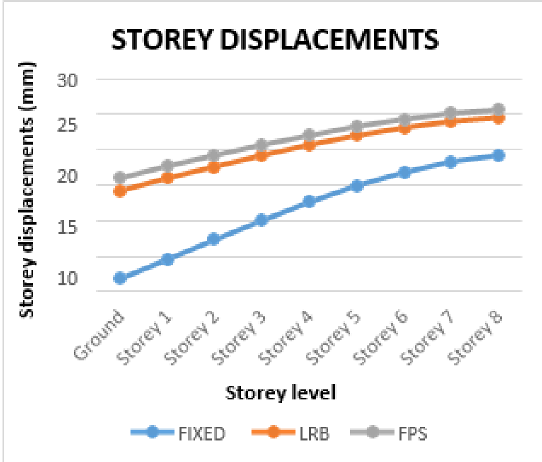


Fig 8. Storey Displacement of RC Building   Fig 9. Storey Displacement of Steel Building

From the figures 8 and 9, it is observed that for both the multistoreyed RC and steel structures, the storey displacement is increased in the base isolated (LRB and FPS) structures when compared to the fixed base structures. In the RC structure, LRB had a greater storey displacement when compared to the fixed base structure. For the steel structure, FPS had a greater storey displacement when compared to fixed base structure. By using base isolators, the relative displacement of the structural element (beam and column) and the internal force gets reduced.

B. Storey Drift

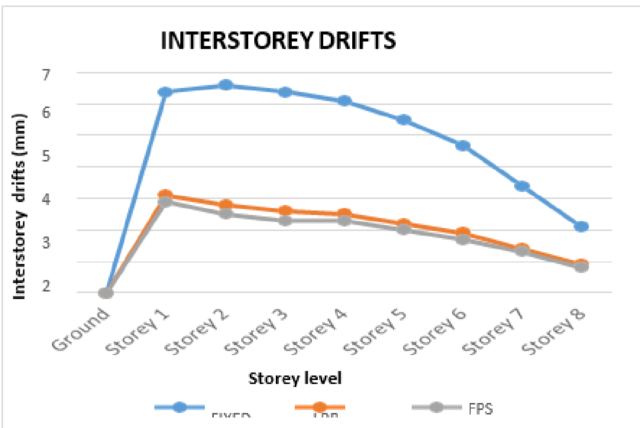


Fig 10. Interstorey Drift of RC Building

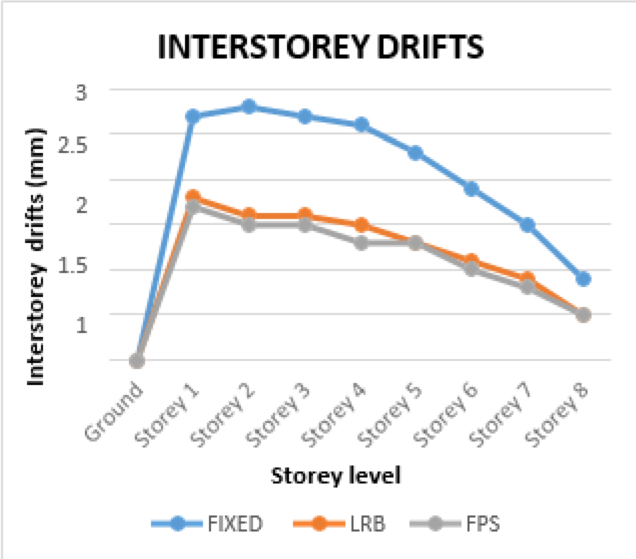


Fig 11. Interstorey Drift of Steel Building

From the figures 10 and 11, it is observed that for both the multistoreyed RC and steel structures, the interstorey drift is decreased in the base isolated (LRB and FPS) structures when compared to the fixed base structures. In the RC structure, FPS has reduced a greater percentage of interstorey drift when compared to the fixed base structure by 61.78%. For the steel structure, FPS has reduced a greater percentage of interstorey drift when compared to fixed base structure by 44.98%.

5. CONCLUSIONS

Form the analysis, it is observed that the base isolation is substantial in reducing the seismic response when compared to the fixed building. From the results, the performance of LRB and FPS was studied. By comparing the results of fixed base structure and base isolated structures, the following conclusions are made:-

- Fixed base building has zero displacement at the base, whereas the base isolated buildings have a significant amount of lateral displacement at the base of the building, for both RC and steel structures.
- It was identified that, as the height of the floor increases, the lateral displacement increases tremendously in the fixed base building relative to the base isolated building. Due to this reduced lateral displacement in the base isolated structure, the building is protected from structural and non- structural damage.
- As the height of the floor increases, the interstorey drifts in the base isolated structure decreases considerably compared to the fixed base building.
- Base isolation is very effective in reducing the cost of the building and cost effective in reducing the weight of the building.

- FPS showed overall good performance when compared to LRB for both RC and steel structures.
- Hence the performance of the isolators differ from the type of structure, height of the structure and regularity of the building.

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