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Comparative Study on Seismic Response of Regular and Irregular RC Framed Buildings with HDRB, LRB and FPS Base Isolation Systems

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Abstract: Base isolation is a technique that has been used around the world to protect the buildings from the damaging effect of earthquake. The base isolation system decouple the structures from its foundation and primarily moves the natural frequency of the structure away from the dominant frequency range of the excitation via its low stiffness relative to that upper structure. For this study, considered G+15 storey regular and irregular RC framed building have been analyzed with and without base isolator under seismic zone V with medium soil. The considered base isolation systems are High damping rubber bearing (HDRB), lead Rubber bearing (LRB) and friction pendulum bearing system (FPS) have been used at the foundation level and analysis are carried out using response spectrum method in ETABS 2015 Software. The response of structure such as time period, storey displacement, storey shear, storey acceleration and storey drift are studied and comparison is made between seismic response of Symmetrical and asymmetrical building with and without base isolators. From this study it can be concluded that it is better to provide isolation systems in seismic proven areas rather than providing fixed base and among three isolators used here FPS performs better than HDRB and LRB base isolators.
Keywords: Base isolation, RC framed structure, Response spectrum, ETABS 2015, High damping rubber bearing, Lead rubber bearing, Friction pendulum system, Time period, storey displacement, storey acceleration, Storey shear, Storey drift.

I. INTRODUCTION

A. General

The naturally occurring ground movement which eventually goes on creating disasters such as failure of structure and fatality is known as Earthquake. The energy that is discharged from those seismic activities makes waves, these waves cause ground movement transmitted to the structure via foundation. Depending on the intensity of these vibrations, cracks and settlement is caused to the structure. The maximum point at which the structure can deform and come back to its original shape is called as Elastic limit. If building deforms more than its elastic limit, it forms cracks in the structure. However, ductility will induce some acceptable damage to the structure. If more elasticity is introduced to the structure, it may tend to increase the overall cost and decrease the damage by increasing the strength. Earthquakes are unanticipated phenomena if the structure is located in seismic zones. The structural engineer has to step in so as to save lives and cause minimal damage to the structures in times of earthquake. The recent development for anti-seismic designs is base isolation. Base isolation system is the frequently adopted earthquake resistance system. It reduces the effect of ground motion and thus reduce the effect of earthquake on the structure.

B. Base Isolation

Base isolation has become a traditional concept for structural design of buildings and bridges in high risk areas. By introducing flexible isolation system between the foundation and the structure the system will absorb the shock impact effects of earthquake with the help of its flexibility. This way the seismic energy transmitted to the structure will be reduced to greater extent and the structure will remain stable for a relative period. The different types of isolators are prime factors used to introduce flexibility in the structure. Base isolation increase the flexibility of the structure and hence increases the period of the structure which is due to the isolators. By introducing base isolation in a structure increases the displacement and eventually decreases the acceleration in the structure as the stiffness of the structure also decreases. Generally, the isolation is placed at the base of the structure, Base isolation protects the building components of the superstructure during earthquakes.

C. Types of Base Isolators used

1) *High Damping Rubber Bearing:* HDRB is one type of elastomeric bearing. The HDRB isolators contain layers of rubber and reinforcing steel plates. The bearing is very stiff and strong in the vertical direction, that is vertical stiffness is several hundred times the horizontal stiffness due to the presence of internal steel plate, but flexible in the horizontal direction. HDRB provides damping in the range of 10% to 20%.

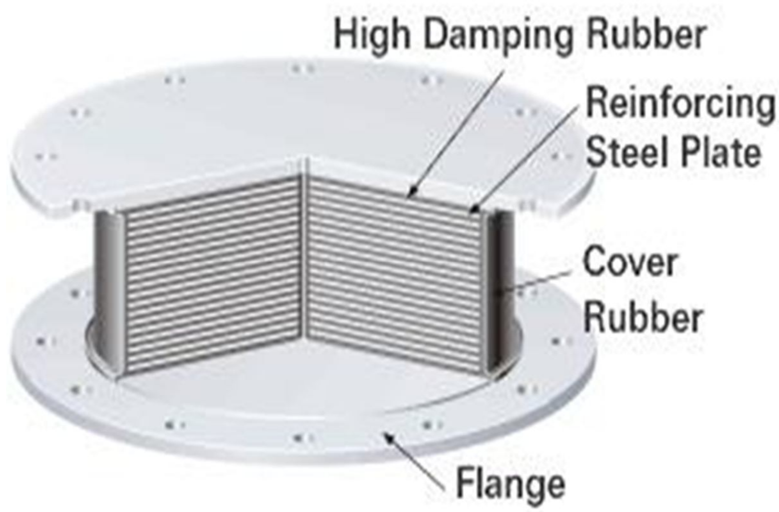

Fig.1: High Damping Rubber Bearing

2) *Lead Rubber Bearing:* Lead Rubber Bearings are rubber bearings made up of alternate layers of steel laminates and hot vulcanized rubber with a cylindrical central lead core. The energy dissipation provided by the lead core, through its yielding, allows to achieve an equivalent viscous damping coefficient up to about 30%. The lead rubber bearings represent best economical solution for the seismic isolation problems because it combines the functions of vertical support, rigidity at service load levels, and of horizontal flexibility at earthquake load. LRB provides the damping in the range of 2-3%.

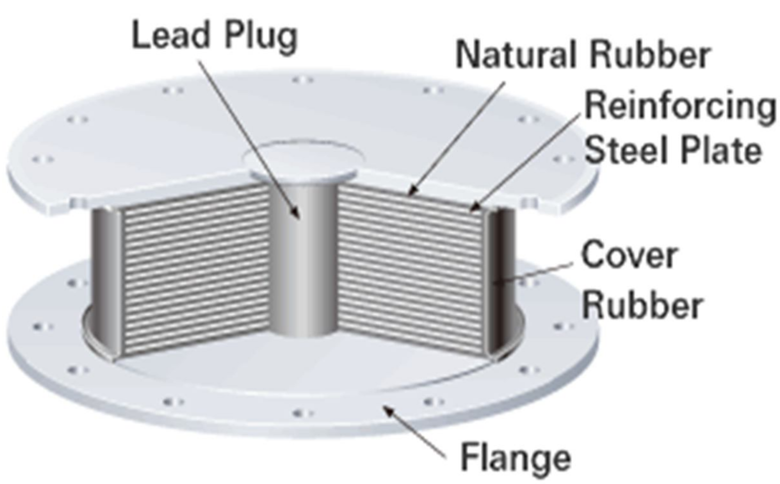

Fig.2: Lead rubber bearing system

3) *Friction Pendulum System:* FPS can be designed to accommodate different magnitudes of displacement simply by adjusting the curvature and diameter of the bearing surface. Friction Pendulum Bearings work on the same principle as a simple pendulum. When activated during an earthquake, the articulated slider moves along the concave surface causing the structure to move in small simple harmonic motions. Similar to a simple pendulum, the bearings increase the structures natural period by causing the building to slide along the concave inner surface of the bearing.

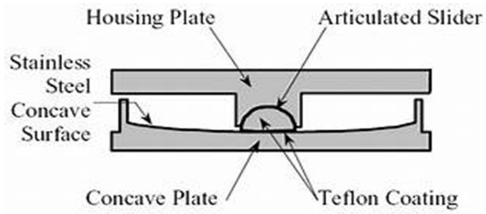

Fig.3: Friction Pendulum system

D. Objectives of the Study

1) Modelling of G+15 storey regular and vertical irregular fixed and base isolated buildings by using ETABS software.
2) To preform seismic analysis on fixed base and base isolated buildings and the effect of earthquake ground motions on these buildings has been studied.
3) To evaluate these modelled by response spectrum analysis and identify the effectiveness of LRB, HDRB and FPS base isolators.
4) To carry out comparison between fixed base and base isolated buildings on the basis of their dynamic properties such as time period, storey displacement, storey acceleration, storey drift, and storey shear.

II. LITERATURE REVIEW

Mital N. Desai and Prof. Roshni John (2015) In this paper, Studied the effect of using three different types of seismic isolators that is Lead rubber bearing, Low damping rubber bearing and friction pendulum isolators, in decreasing the base shear and story shear of structure. They considered 8-storey building, has been analyzed using Response Spectrum Method. The results conclude that the 47% reduction in base shear when isolated with Low damping rubber bearing as compared to the fixed base building. The reduction in base shear are 45% and 38% respectively when isolated with HDRB and LRB as compared to the fixed base.

Jumy Raj and Prof. Basil Sabu (2017) In this work, three different storey such as 8, 10, and 12 storeys are considered for the analysis. The main aim of the present study deals with comparison of seismic response of symmetric and asymmetric building with and without base isolator using SAP 2000. For base isolation, here they provided Friction pendulum systems and assumed the structure is located in California, zone 4 with a soil profile type II with very dense soil and soft rock. Equivalent static analysis and time history analysis are done in this study. The results concluded that friction pendulum system is very significant in order to reduce the seismic response of both symmetric and asymmetric buildings compared to fixed base buildings and control the damages in the building during seismic loading.

Mithun and Dileep Kumar (2017) has briefly described the “Comparative Study on Seismic Response of Irregular Structure with Lead Rubber Bearing and Friction Pendulum Bearing Base Isolation System”. They considered the G+10 irregular building made of three different materials such as RCC, Steel and Composite with (LRB) and (FPB) base isolation system and to compare the seismic response with and without base isolation using Response spectrum method in ETABS-2015 software. The response of the structure such as time period, base shear, story drifts and story displacements are studied and comparison is made. The results concluded that it is better to provide base isolation systems in seismic prone areas rather than providing fixed base and among two isolators used here FPB performs better than LRB for all the structures.

Manoj U. Deosarkar, S. D. Gowardhan (2015) In this journals they studied “Non Linear Dynamic Response of (G+5) storey symmetrical and asymmetrical RC building”. They considered the base isolators are (HDRB), (LRB) and (FPS) for analysis. Time history analysis has been performed on Bhuj earthquake which intensity is 7.7. In the second part of this study seismic response of combined isolation system has presented for symmetric and asymmetric building. Comparing the results of the fixed base and base isolation system with Storey shear, storey drifts, storey acceleration, storey displacement and time period. The results concluded that the reduction of storey shear is more in HDRB. The storey acceleration is reduced in LRB and FPS used in combination not in HDRB. Lateral displacements increases drastically in fixed base building as compare to base isolated building with increases the floor height.

S. M. Dhawade(2014) In this paper, the G+14 storied frame structure is taken to compare the seismic effect of fixed base structure with respect to isolated structure. The analysis of the building is done by using response spectrum method in ETABS software. High Damping Rubber Bearing (HDRB) is used as an isolator and design is done by using UBC- 97. The results concluded that the very less values come for lateral loads by using High Damping Rubber Bearing. It has high flexibility and energy absorbing capacity, so that during an earthquake, when the ground vibrates strongly only moderate motions are induced within the structure itself.

III.METHODOLOGY

A building model of G+15 storey regular and irregular building has been modelled in ETABS software and considered for the present study.

A. Geometrical Modelling

The table 1 shows the details of the model used for the analysis.

Table 1: Building parameters considered for this project work

Building parameter	Details
Number of storey	G+15
Plan dimension in m	20x20m
Height of typical floor	3m
Spacing of frame	5m c/c
Size of column	300X300mm
Size of beam	300X450mm
Slab thickness	150mm
Grade of concrete	M 25
Grade of steel	Fe 500
Type of structure	Special moment resisting frame
Seismic zones	V
soil type	Type II, (Medium soil)
Importance factor	1
Response reduction factor[R]	5
Damping ratio	0.05
Method of analysis	Response spectrum method
Types of isolators used	LRB, HDRB and FPS

B. Description of models

1) Model 1 - G+15 storey regular model with fixed base
2) Model 2 - G+15 storey regular model with HDRB base isolator
3) Model 3 - G+15 storey regular model with LRB base isolator
4) Model 4 - G+15 storey regular model with FPS base isolator
5) Model 5 - G+15 storey vertical irregular model with fixed base
6) Model 6 - G+15 storey vertical irregular model with HDRB base isolator
7) Model 7 - G+15 storey vertical irregular model with LRB base isolator
8) Model 8 - G+15 storey vertical irregular model with FPS base isolator

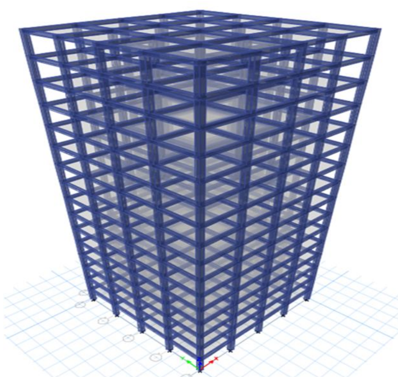

Fig.4: 3D Model of G+15 storey regular model

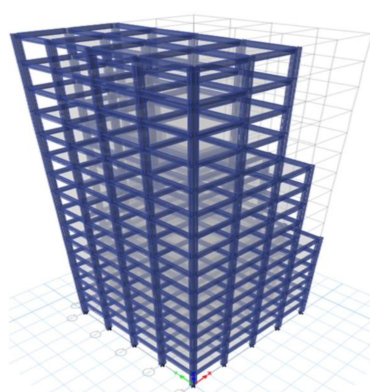

Fig.5: 3D Model of G+15 storey vertical irregular model

C. Modelling of HDRB, LRB and FPS Base Isolators

In this study HDRB, LRB and FPS are designed according to UBC – 97 and IBC – 2000.The maximum vertical reaction is obtained from analysis in ETABS software, using this vertical reaction and total mass of the structure, isolators are designed manually. Properties of HDRB, LRB and FPS isolators are modeled as spring elements in ETABS 2015 and their properties are given as link properties.

Table 2: Link properties of HDRB and LRB base isolators

Parameter	Regular model		Vertical irregular model	
	HDRB	LRB	HDRB	LRB
U1 Linear Effective stiffness kN/m	3448732.4	1121665.6	5839985.4	154677.4
U2 and U3 Linear Effective stiffness kN/m	3577.07	3015.21	3295.20	2777.58
U2 and U3 Non Linear Effective stiffness kN/m	69341.6	13868.3	5765.51	17237.6
Yield force (Fy) kN	433.108	160.095	360.114	139.49
Effective damping (ξ_{eff}) %	20	20	20	20
Post yield stiffness ratio	0.1	0.1	0.1	0.1

Table 3: Link properties of FPS base isolator

Parameter	Regular model	Vertical irregular model
Vertical stiffness of bearing kN/m	39583343.58	39583333.93
Linear effective stiffness kN/m	1666.62	1535.301
Non Linear effective stiffness kN/m	4934.52	4545.695
Effective damping (ξ_{eff}) %	20	20
Friction coefficient, slow	0.03	0.03
Friction coefficient, fast	0.06	0.06
Rate parameter sec/m^2	50	50

IV. RESULTS AND DISCUSSION

The comparison of different parameters like time period, Storey displacement, storey acceleration, storey shear, and storey drift are carried out and tabulated results obtained from response spectrum analysis in ETABS software. Analysis is done for fixed base, HDRB, LRB and FPS base isolated conditions.

A. Time Period

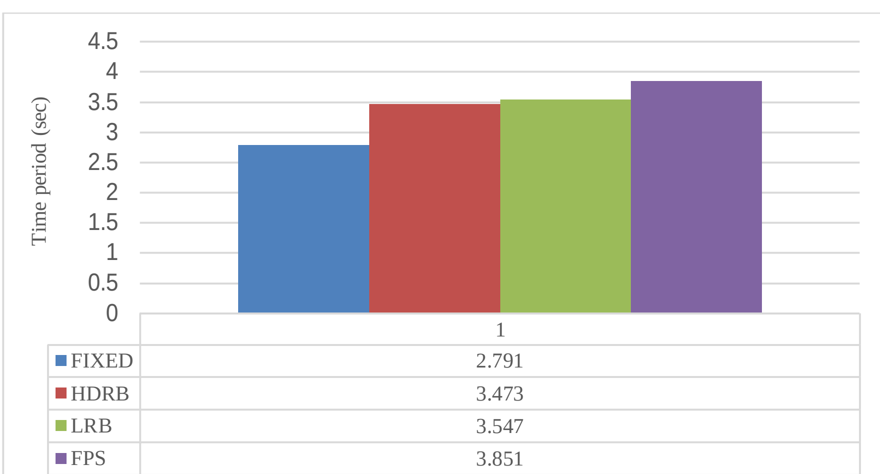

Fig.6: Time period for regular model

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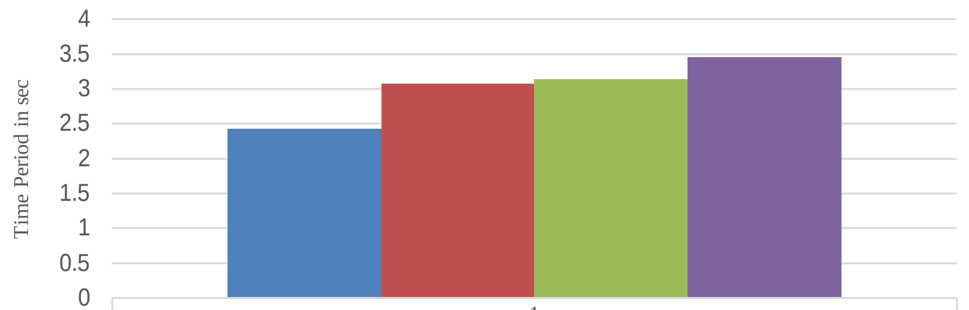

	1
FIXED	2.422
HDRB	3.081
LRB	3.144
FPS	3.452

Fig.7: Time period for vertical irregular model

Figure 6 and 7 shows the time period for fixed base and base isolated symmetric and asymmetric buildings. Time period of base isolated models has been increased compared to fixed base building. In symmetrical model the increased time period of base isolated buildings with respect to fixed base model are (HDRB = 24.435%, LRB = 27.087%, FPS = 37.97%) and for asymmetric model are (HDRB = 27.20%, LRB = 29.81%, FPS = 42.526%) is obtained.

B. Storey Displacement

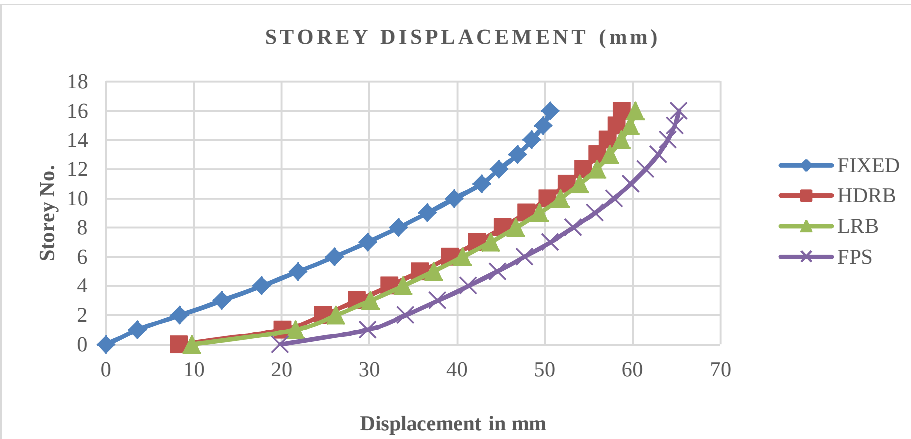

Fig. 8: Storey displacement for regular models

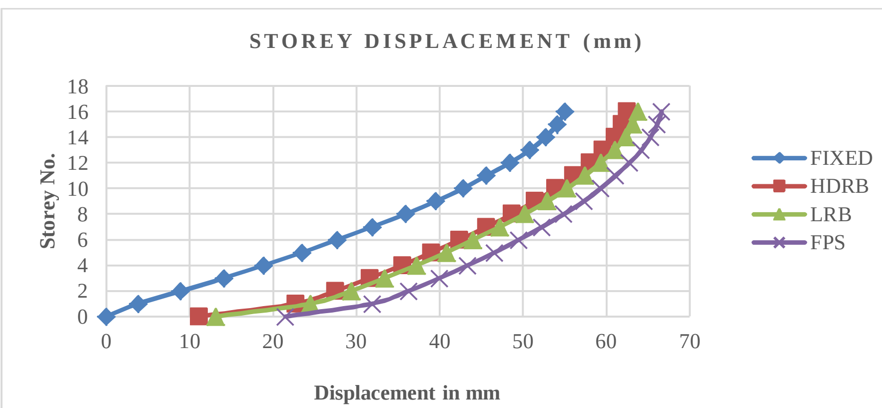

Fig. 9: Storey displacement for vertical irregular models

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Figure 8 and 9 shows the variations of storey displacement for fixed base and base isolated of symmetric and asymmetric buildings. It is observed that, the displacement in case of HDRB, LRB and FPS base isolated models is usually more at the top floor level compared to fixed base building this is due to reduction in stiffness of base isolated models. In symmetrical model the total increase of displacement value for base isolated models compared to fixed base model are (HDRB = 16.205%, LRB = 19.17%, FPS = 29.05%) and for asymmetric model are (HDRB = 13.46%, LRB = 16.918% , FPS = 21.09%) is obtained.

C. Storey Acceleration

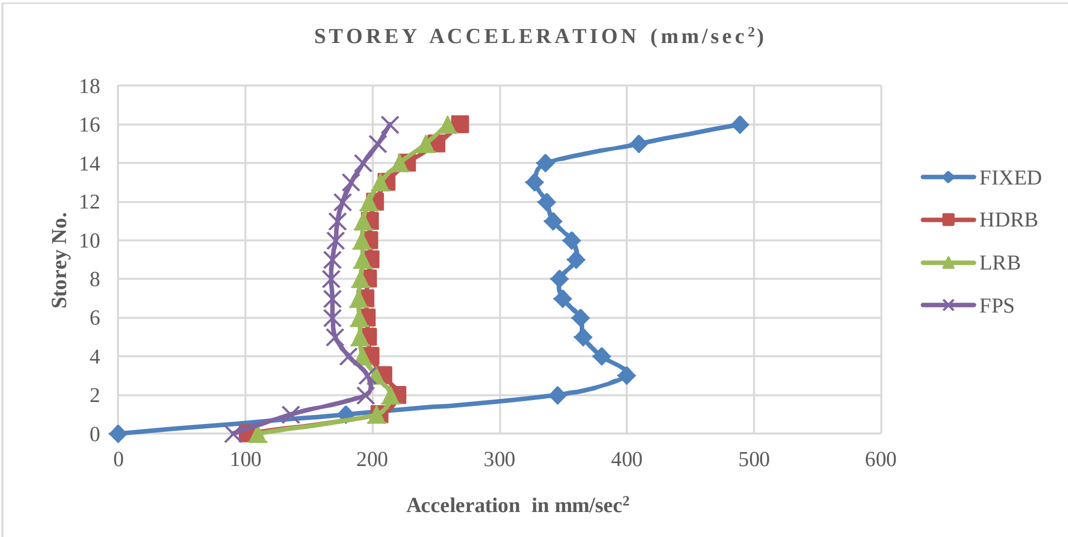

Fig.10: Storey Acceleration for regular models

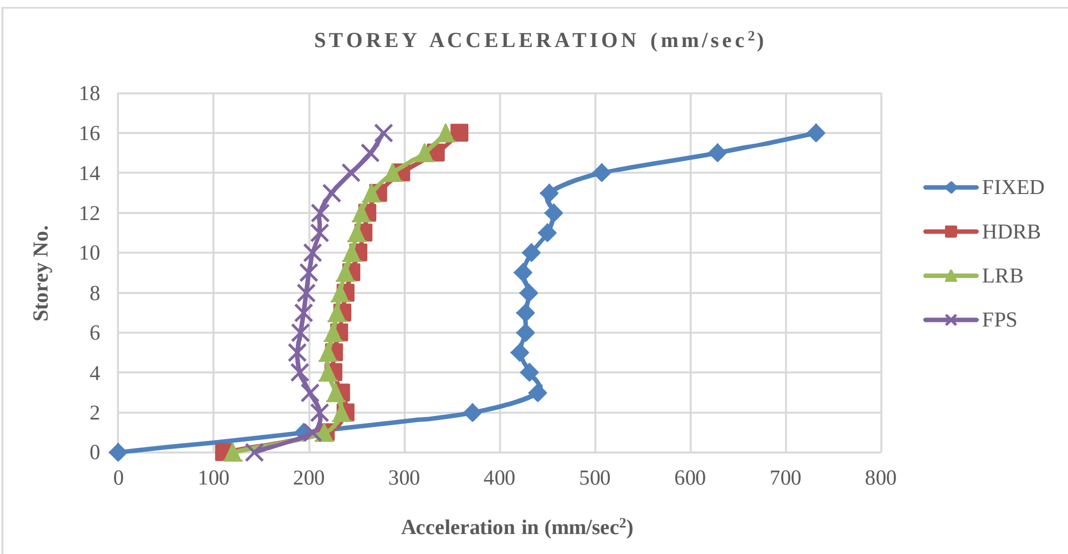

Fig.11: Storey Acceleration for vertical irregular models

Figure 10 and 11 shows the variation of storey acceleration v/s Storey height for fixed base and base isolated of symmetric and asymmetric buildings. In fixed base models figure shows 'S' shaped curve, whose valve is zero at the base and increased towards the top storey but in base isolated models storey acceleration is almost constant. In symmetrical models, the decreases in acceleration value of base isolated models compared to fixed base model are (HDRB = 44.98%, LRB = 47.064%, FPS = 56.31%) is obtained and for asymmetric model are (HDRB = 51.14%, LRB = 53.11%, FPS = 62.02%) is obtained.

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D. Storey Shear

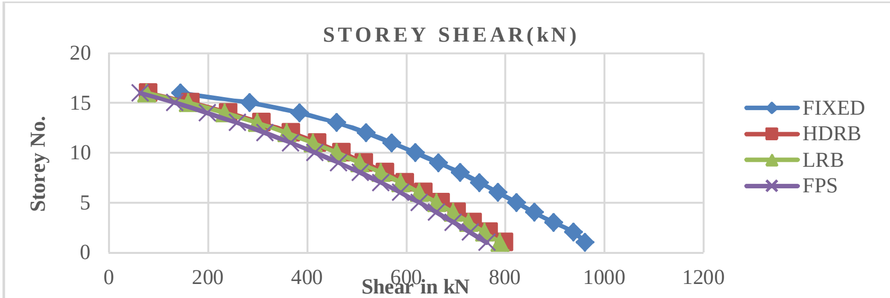

Fig.12: Storey Shear for regular models

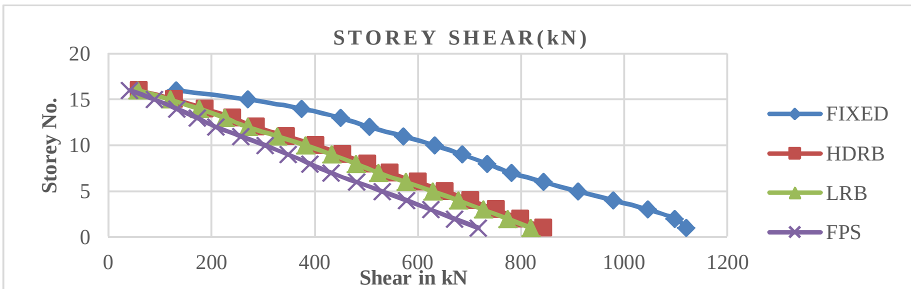

Fig.13: Storey Shear for vertical irregular models

Figure 12 and 13 shows the variation of storey shear with respect to floor level for fixed base and base isolated of symmetric and asymmetric buildings. In symmetrical models, the amount of reduction of storey shear in base isolated buildings compared to fixed base model are (HDRB = 48.97%, LRB = 51.985%, FPS = 63.828%) and for asymmetric model are (HDRB = 55.24%, LRB = 56.85%, FPS = 68.73%) is obtained.

E. Storey Drift

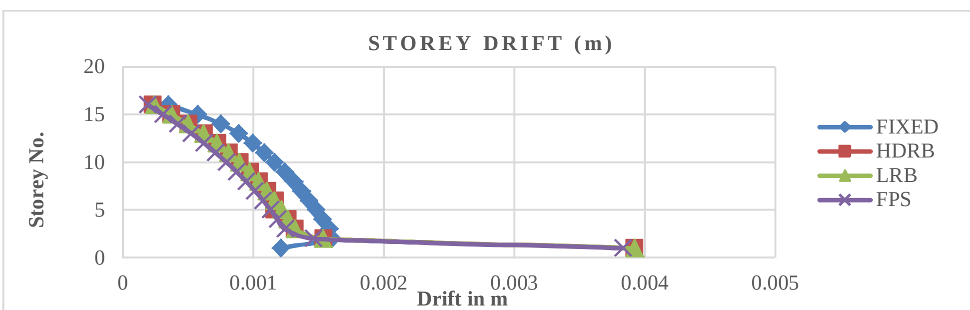

Fig.14: Storey drift for regular models

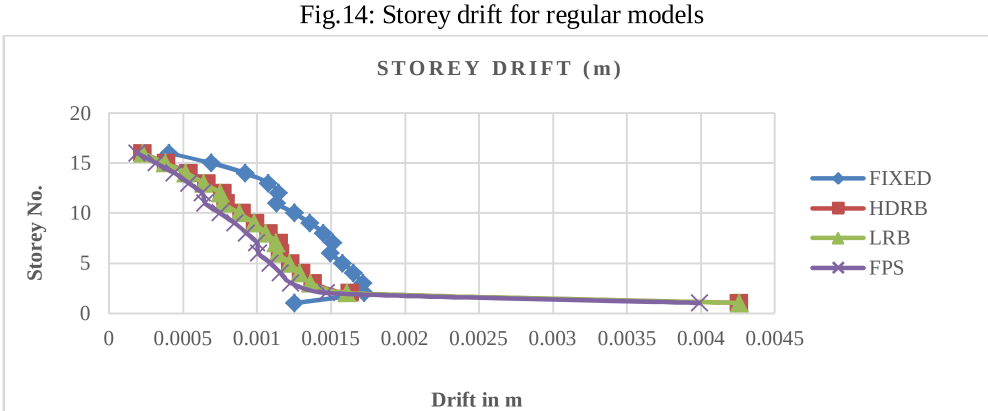

Fig.15: Storey drift for vertical irregular models

Figure 14 and 15 shows the variation of the storey drift with respect to floor level for fixed base and base isolated models. Storey drift of all models are within the permissible limits i,e 0.004 times the storey height as per IS 1893-2002. In symmetrical models, the amount reduction of storey drift in base isolated models compared to fixed base model are (HDRB = 33.11%, LRB = 31.168%, FPS = 44.15%) and for asymmetric model are (HDRB = 43.62%, LRB = 43.62%, FPS = 53.43%) is obtained.

V. CONCLUSIONS

By comparing the dynamic properties of buildings following conclusion are made:

A. Time period increased in all base isolated buildings compared to fixed base buildings due to increased flexibility of base isolated buildings. FPS isolation system provides more time period than HDRB and LRB isolation systems in both symmetric and asymmetric models.

B. In fixed base building have zero displacement at base, where as all base isolated buildings shows increase in amount of lateral displacement at base. Also as the height increases lateral displacement increases drastically in base isolated buildings compared to fixed base building. FPS base isolator gives more displacement compared to LRB and HDRB isolators.

C. Storey acceleration values of base isolated models is less compared to fixed base model. In fixed base building relative difference of storey acceleration is more from bottom to top storey, but in base isolated building the value of storey acceleration is almost constant. FPS base isolator reduces more acceleration compared to HDRB and LRB isolators.

D. In fixed base building storey shear is more at the base and gradually reduces as the height increases, where as in case of base isolated building shear has more reduced from bottom to top floor level compared to fixed base buildings. Out of three isolators FPS base isolator reduces more storey shear compared to HDRB and LRB isolators.

E. In fixed base building storey drift is more at the first floor due to the concentration of mass is more at the bottom of the building and gradually reduced as the height increases, but in base isolated buildings, storey drift is maximum at the ground level, this is due to reduction of stiffness at the base. FPS base isolator reduces more drift compared to HDRB and LRB isolators.

F. Based on the results, it was found that among three isolators, FPS base isolator give better performance compared to HDRB and LRB isolators in both symmetrical and asymmetrical models.

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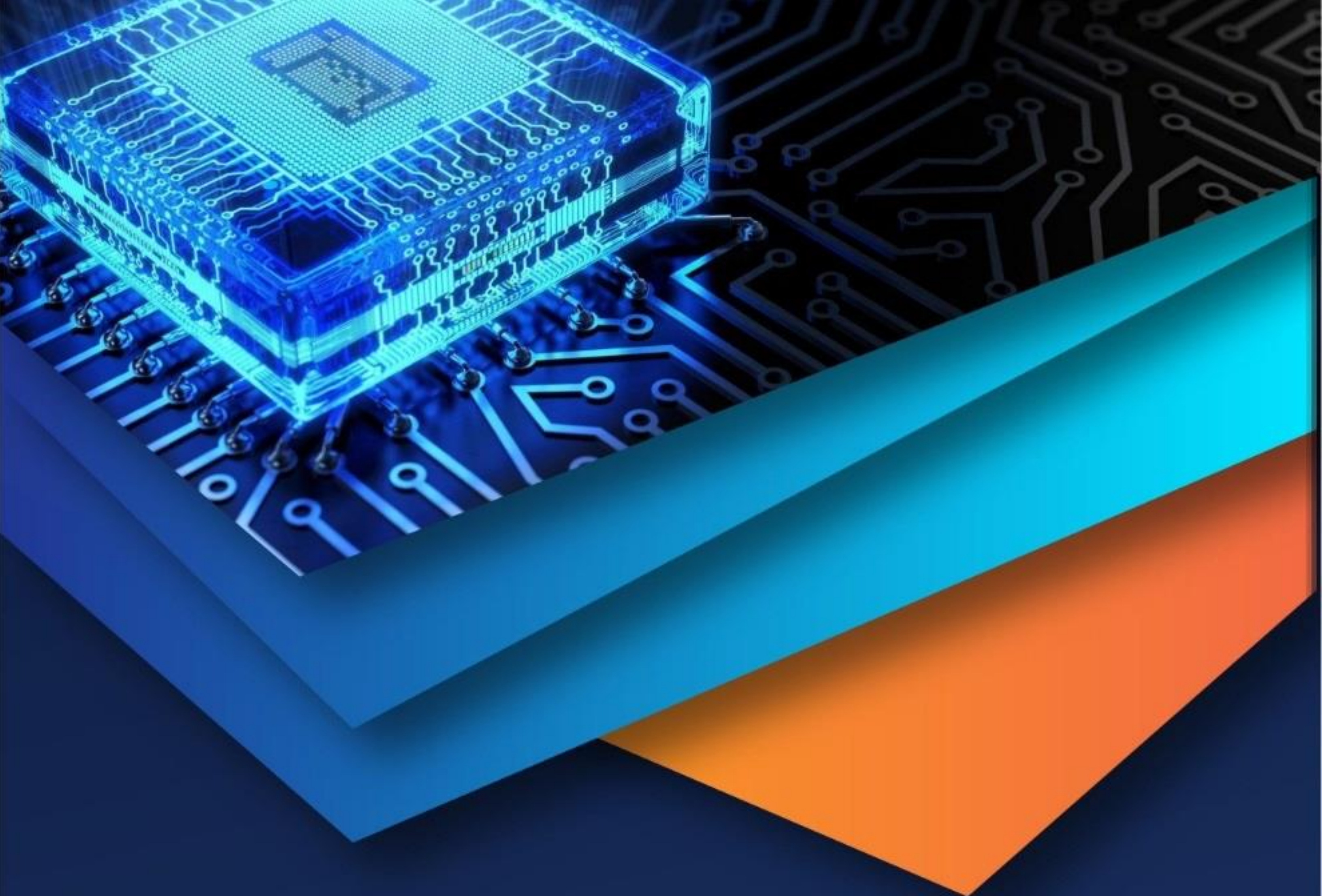

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