Seismic Analysis of Multi Storey RC Buildings supported on Single and Combined Base Isolation Systems

Nithin A V, Jayalekshmi R

Abstract— Base Isolation is an earthquake mitigation technique where seismic demand on the building is reduced rather than increasing the earthquake resistance capacity of the building. Base isolated buildings has less base shear and displays less story drifts compared to fixed base buildings. Due to the effectiveness of base isolation techniques, it is more widely used for new structures and also for retrofitting the existing structures. The objective of the study is to compare the behaviour of the buildings with lead rubber bearing (LRB) and friction pendulum bearing (FPB) under individual and combined use for both regular and irregular plans. The parameters like base shear, storey displacements, inter-storey drifts and storey rotations are studied under EL Centro, Loma and Northridge earthquakes. The design of the isolators is first studied and the variation of effective damping is investigated for different isolation systems. The seismic responses are evaluated by performing nonlinear time analysis on a twelve storey reinforced concrete building. From the results, combined isolation type where Friction Pendulum Bearings are provided on the exterior and Lead Rubber Bearings on the interior, are found to be the most effective in reducing the response compared to Lead Rubber bearing only model. The Friction Pendulum Bearing models had the lowest base shear and inter-storey drift values. The Lead Rubber Bearing type models were found most effective in reducing the storey rotations of building irregular in plan.

Index Terms— Base isolation, Lead Rubber Bearing, Friction Pendulum Bearings, Non Linear Time History Analysis, Base Shear, Displacement, Storey Drift, Storey Rotations.

1 Introduction

THE study of earthquake impact on the structures and its mitigation is very essential. Due to earthquake, unwanted responses in the form of displacement are induced in the structures. The unpredictable behaviour of earthquake makes us to implement early precautions while designing and construction of a building in a seismic prone area. The traditional method of designing earthquake resistant structures is not cost effective as it is based on making building stiff and strong so as to absorb all the lateral forces caused due to earthquake ground motion.

The base isolation techniques help to reduce the responses caused due to seismic events by decoupling the base from the superstructure. It makes the building more flexible. Due to the low horizontal stiffness of the isolators, large displacement values are induced on the base, causing impounding effects on adjacent buildings, connecting pipes etc. It is necessary to limit both the acceleration response and large displacement of the structure in an effective manner. 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. This helps in reducing floor accelerations and inter-story drift demands on the structure above the isolation system and results in negligible structural and non-structural damage. This makes the superstructure to act elastic almost. The buildings having longer time periods attract less seismic forces. The nonlinear response of isolators helps in seismic energy absorption.

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. This idea reduces the pressure on building a structure more earthquake resistant by reducing the seismic demand acting over them. 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 used in so that effective reduction of seismic response can be carried out in case one of the system fails during the event.

This paper presents a comparative study of the variation of the seismic behaviours of a Reinforced Concrete building with different types of seismic isolation systems. The responses like base shear, story displacement, inter-story drifts and story rotations of the buildings are investigated for understanding the behaviour of base isolated systems on a multi-storied building. The common types of base isolators, the Lead Rubber Bearing (LRB) and Friction Pendulum Bearing (FPB) are

- *Nithin A V is currently pursuing master of technology degree program in Structural Engineering at NSS College of Engineering, Palakkad, APJ Abdul Kalam Technological University, Kerala, India E-mail: nithinav2312@mail.com*
- *Dr Jayalekshmi R is Professor at NSS College of Engineering, Palakkad, APJ Abdul Kalam Technological University, Kerala, India E-mail: jayalekshmisankar@gmail.com*

ISSN 2229-5518

used for understanding this variation on a multi-storey building. The analysis is carried out using non-linear time history analysis in finite element software SAP2000. The effect is studied on both regular and irregular plans

2 BASE ISOLATION SYSTEMS

Most commonly used bearings are Lead Rubber Bearings (LRB) and Friction pendulum bearings (FPB). Both types of isolators have inherent damping effects. They shift the buildings fundamental frequency beyond the range of earthquake excitation. Both types are defined by stiffness, displacements and yield strength characteristics.

The LRB is an elastomeric bearings consisting of a series of alternating rubber and steel layers. The rubber provides lateral flexibility while the steel provides vertical stiffness. The lead core provides damping effects to the isolator. The nonlinear behaviour of a LRB isolator can be effectively idealized in terms of a bilinear force-deflection curve, with constant values throughout multiple cycles of loading

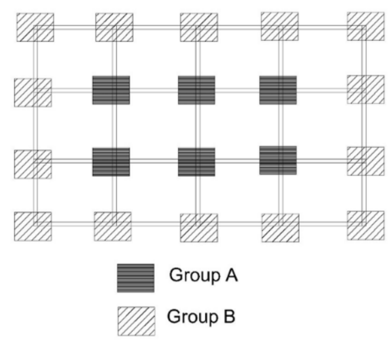
A FPB is comprised of a stainless-steel concave surface, an articulated sliding element, and cover plate. The slider is finished with a self-lubricating composite liner (e.g. Teflon). Movement of the slider generates a dynamic frictional force that provides the required damping to absorb the earthquake energy. When the slider moves over the spherical surface, the supported mass will be lifted and the movement will provide the restoring force to the system. Friction at the interface is dependent on the contact between the Teflon-coated slider and the stainless-steel surface.

3 DESCRIPTION OF THE MODEL AND ISOLATOR DETAILS

The building is assumed to be in Zone V and medium soil condition is considered. The properties of the considered building configurations in the present study are given in Table 1. The isolator arrangement is shown in Figure 1 and Figure 2.

TABLE 1 STRUCTURAL PROPERTIES AND LOADS

Plan dimension	20 x 12 m
Spacing between frames	5m along X direction and 4 m along Y direction
No of storey's	12
Storey height	3.2m
Building frame system	Special Moment Resisting Frame
Foundation type	Fixed and Isolated
Damping ratio	5%
Concrete Grade	M40
Steel Grade	Fe 415
Beam Size	300mm x 500 mm
Column size	450 mm x 450 mm
Slab Size	150 mm
Wall thickness Exterior	230 mm
Wall thickness Interior	150 mm
Live Loads	3 kN/m2
Floor Finish	1 kN/m2



The target period (T) was taken as 2.5 sec and effective damping (βeff) of 10% has been adopted for the design of the isolators. C_{vd} and B_D are taken as 0.4 and 1.2 in the design of isolators. Two types of bearings i.e. Type A and B were manually designed as per the axial loads and properties. Table 2 and 3 shows the isolator link properties for regular and irregular building. IBC 2000 [32] and design handbook [29] has been used to design of both isolators. 1.5 times Dead load and live load is taken for calculating axial load.

FIGURE 1 ISOLATOR ARRANGEMENT IN REGULAR BUILDING

FIGURE 2 ISOLATOR ARRANGEMENT IN IRREGULAR BUILDING

TABLE 2 HYSTERETIC PROPERTIES OF THE LRB AND FPB SYSTEM FOR REGULAR BUILDINGS

Parameters	Group A	Group B	Type of Isolator
Axial load(kN)	4690	3890	LRB & FPB
Effective Stiffness (kN/m)	3016.78	2502.19	LRB
	3591.4	2978.8	FPB
Post elastic stiffness (kN/m)	2782.79	2308.11	LRB
	3025.8	2509.67	FPB
Initial Stiffness (kN/m)	27827.9	23081.1	LRB
	1092316	905993.5	FPB
Yield Strength(kN)	49.14	40.76	LRB & FPB
Yield Displacement(m)	0.002	0.002	LRB
	0.0001	0.0001	FPS

TABLE 3 HYSTERETIC PROPERTIES OF THE LRB AND FPB SYSTEM FOR IRREGULAR BUILDINGS

Parameters	Group A	Group B	Type of Isolator
Axial load (kN)	4786	3940	LRB & FPB
Effective Stiffness (kN/m)	3078.53	2534.35	LRB
	3664.925	3017.09	FPB
Post elastic stiffness (kN/m)	2782.79	2308.11	LRB
	3087.74	2541.935	FPB
Initial Stiffness (kN/m)	27827.9	23081.1	LRB
	1114675	917638.7	FPB
Yield Strength (kN)	49.14	40.76	LRB & FPB
Yield Displacement(m)	0.002	0.002	LRB
	0.0001	0.0001	FPS

The SAP2000 models are shown in Figure 3 and 4

4 MODEL ANALYSIS

Following two models are considered in all the three types of earthquake loads, El Centro, Loma and Northridge. Table 4 shows the earthquakes selected

TABLE 4 SELECTED EARTHQUAKES FOR MODELLING

Event	Year	Station	PGA
Imperial Valley	1979	El Centro Array # 1	0.3746 g
Loma Prieta	1989	Gilroy Array #2	0.3529 g
Northridge	1994	Canyon Country	0.4355 g

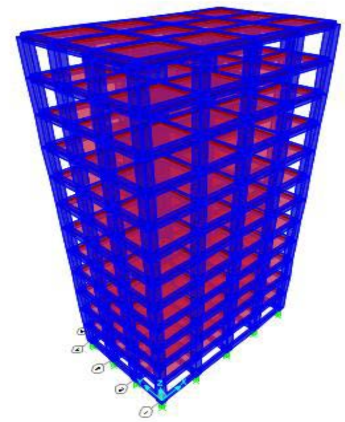
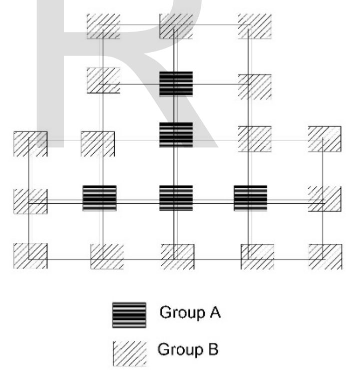


FIG. 3 SAP2000 MODEL OF REGULAR BUILDING



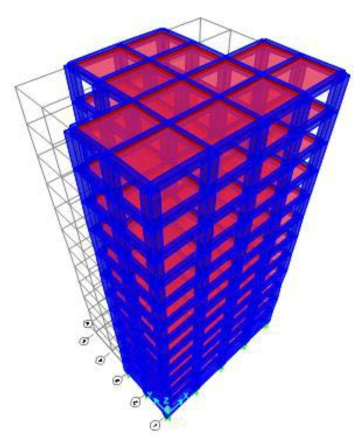


FIG. 4 SAP2000 MODEL OF IRREGULAR BUILDING

The model types taken for study are shown in Table 5. Group A are provided for the internal and Group B for External Column bases.

TABLE 5 MODEL TYPES CONSIDERED FOR STUDY

BASE CONDITIONS	MODEL TYPE	
	Regular	Irregular
FIXED BASE	1A	2A
LRB ISOLATION SYSTEM	1B	2B
FPB BASE ISOLATION	1C	2C
LRB (internal columns) + FPB BASE ISOLATION(external columns)	1D	2D
FPB (internal columns) + LRB BASE ISOLATION(external columns)	1E	2E

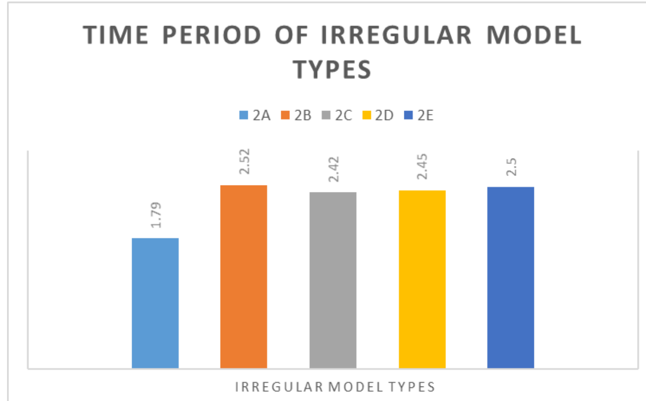


FIG 6 TIME PERIOD (S) OF IRREGULAR BUILDING

5 RESULTS AND DISCUSSION

The parameters studied are time period, base shear, storey displacement, storey-drift for regular and irregular buildings and storey rotation for irregular buildings along the building height.

5.1 BASE ISOLATION EFFECTS ON REGULAR AND IRREGULAR BUILDINGS UNDER INDIVIDUAL AND COMBINED USE OF LRB AND FPB

5.1.1 Variation of Time Period and Base Shear

Time Period was effectively increased for Regular and Irregular Building (Figure 5 ad 6). Base shear was greatly reduced by using base isolation techniques. (Figures 7 and 8) both in regular and irregular buildings. Combined Isolation models, MODEL 1D and MODEL 2D were more effective in reducing base shear. MODEL 1C and 2C has the least base shear values of all the earthquake excitations applied.

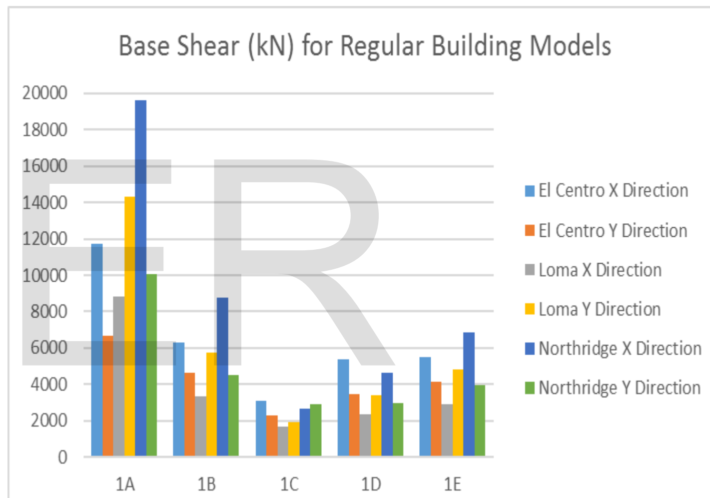


FIG.7 BASE SHEAR –REGULAR BUILDING

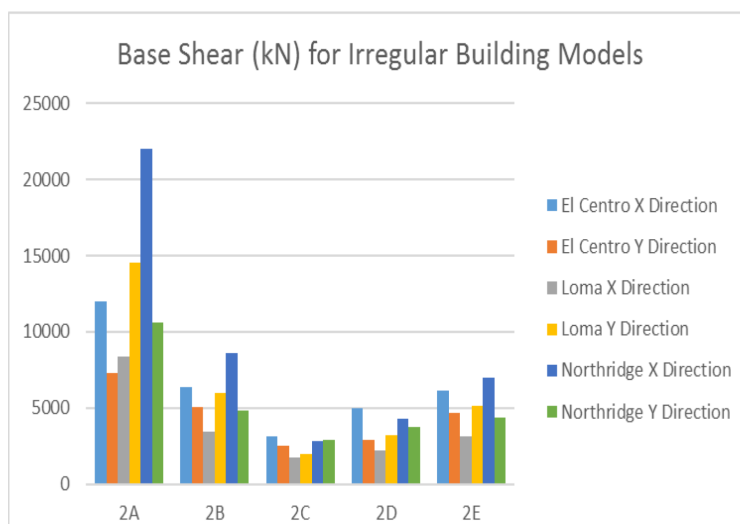


FIG.8 BASE SHEAR –IRREGULAR BUILDING

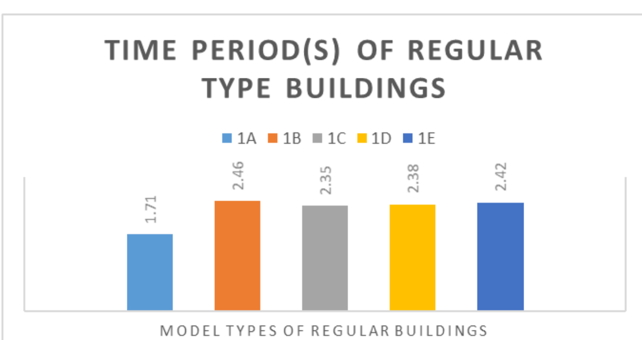


FIG 5 TIME PERIOD (S) OF REGULAR BUILDINGS

5.1.2 Variation of Storey displacement and Storey Drift

The displacements were reduced for base isolated buildings. For regular buildings Maximum displacement along both is taken and plotted. Figures 9,10 and 11 shows the variation for each model case for regular building. Figures 12,13 and 14 shows the variation of storey drift for regular buildings.

For Irregular buildings, both U1 and U2 directions are taken for the study. Figures 15, 17 and 19 shows the variation of storey displacement along U1 direction. Figures 16,18 and 20 shows the same along U2 direction. Figures 21, 23 and 25 shows the variation of inter-storey displacement along U1 direction. Figures 22,24 and 26 shows the same along U2 direction. Due to Irregularity, drift values along U1 and U2 showed slightly different patterns for Lead Rubber Bearing models.

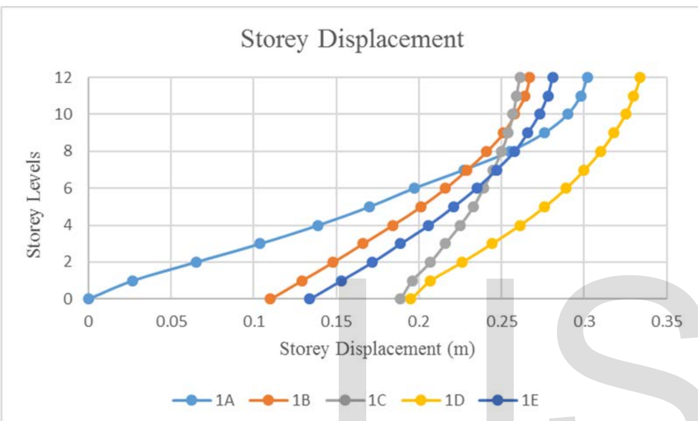


FIG 9 VARIATION OF STORY DISPLACEMENT (M)ALONG HEIGHT FOR EL CENTRO FOR REGULAR BUILDING

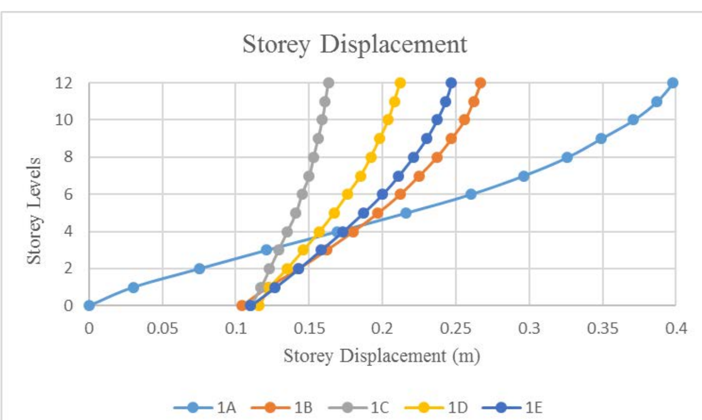


FIG 10 VARIATION OF STORY DISPLACEMENT (M)ALONG HEIGHT FOR LOMA FOR REGULAR BUILDING

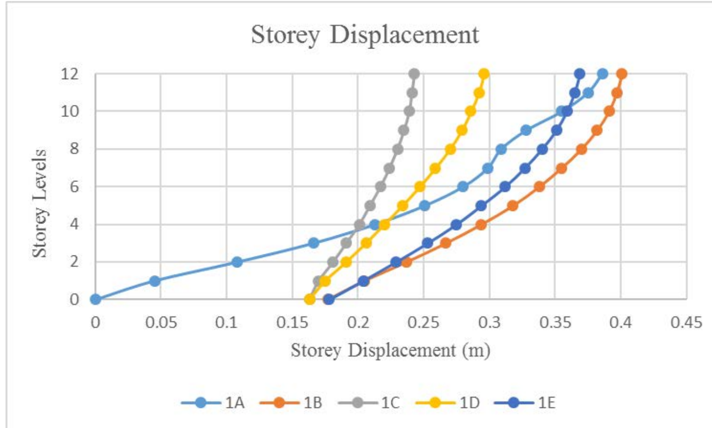


FIG 11 VARIATION OF STORY DISPLACEMENT (M)ALONG HEIGHT FOR NORTHRIDGE FOR REGULAR BUILDING

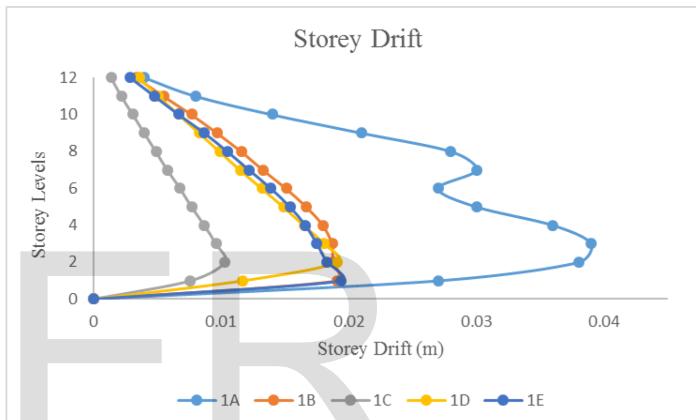


FIG 12 VARIATION OF STORY DRIFT (M)ALONG HEIGHT FOR EL CENTRO FOR REGULAR BUILDING

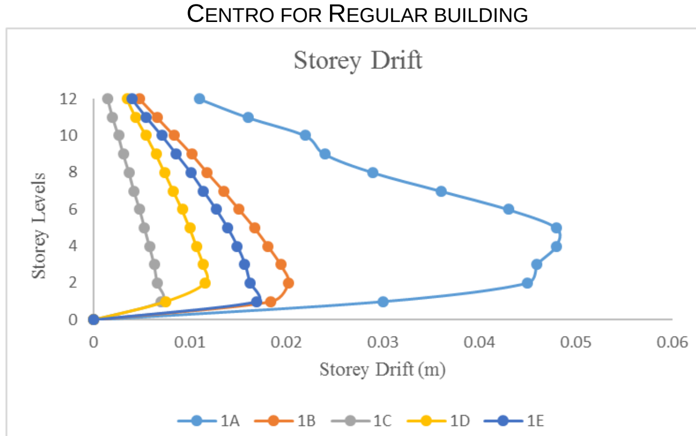


FIG 13 VARIATION OF STORY DRIFT (M)ALONG HEIGHT FOR LOMA FOR REGULAR BUILDING

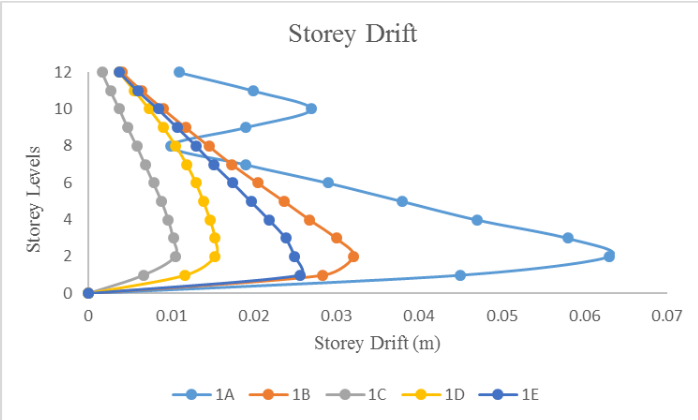


FIG 14 VARIATION OF STORY DRIFT (M)ALONG HEIGHT FOR NORTHRIDGE FOR REGULAR BUILDING

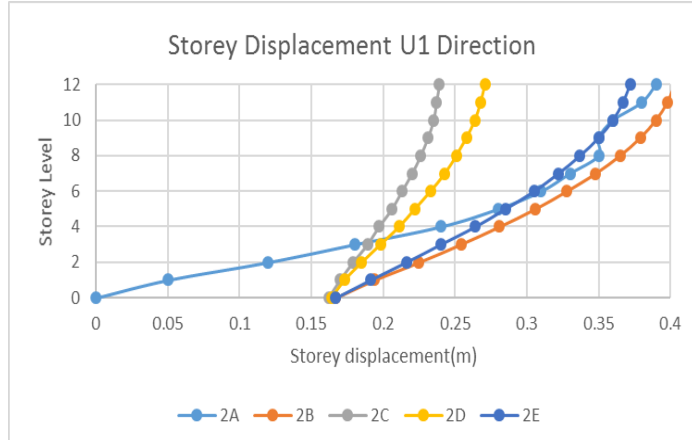


FIG 17 VARIATION OF STORY DISPLACEMENT (M)ALONG HEIGHT FOR LOMA FOR IRREGULAR BUILDING

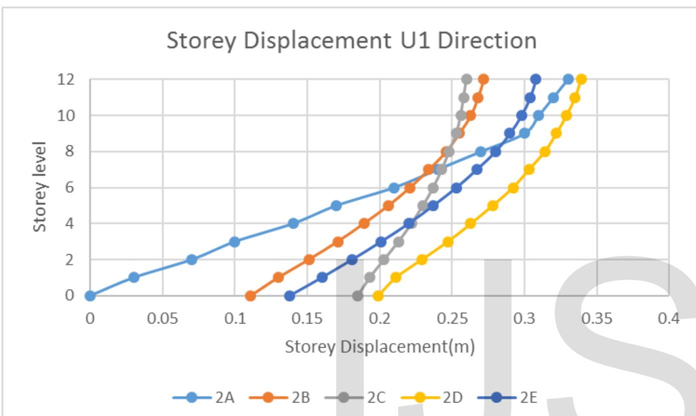


FIG 15 VARIATION OF STORY DISPLACEMENT (M)ALONG HEIGHT FOR EL CENTRO FOR IRREGULAR BUILDING

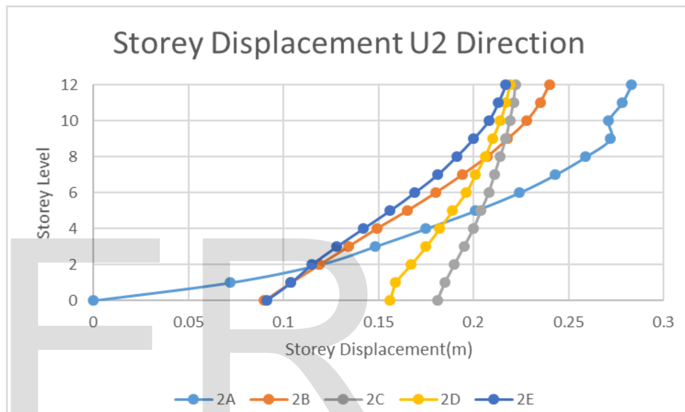


FIG 18 VARIATION OF STORY DISPLACEMENT (M)ALONG HEIGHT FOR LOMA FOR IRREGULAR BUILDING

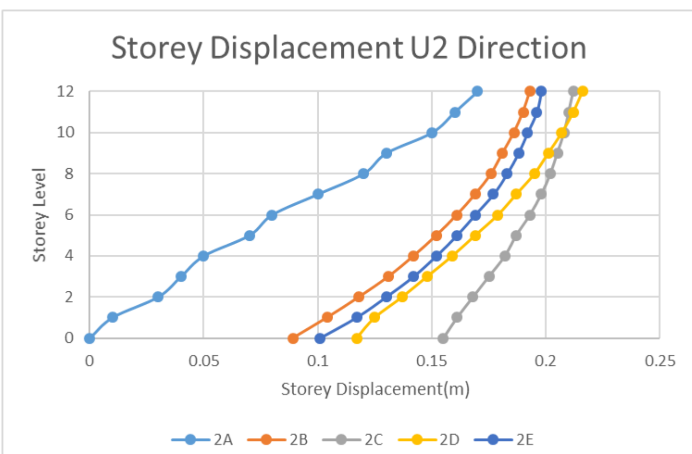


FIG 16 VARIATION OF STORY DISPLACEMENT (M)ALONG HEIGHT FOR EL CENTRO FOR IRREGULAR BUILDING

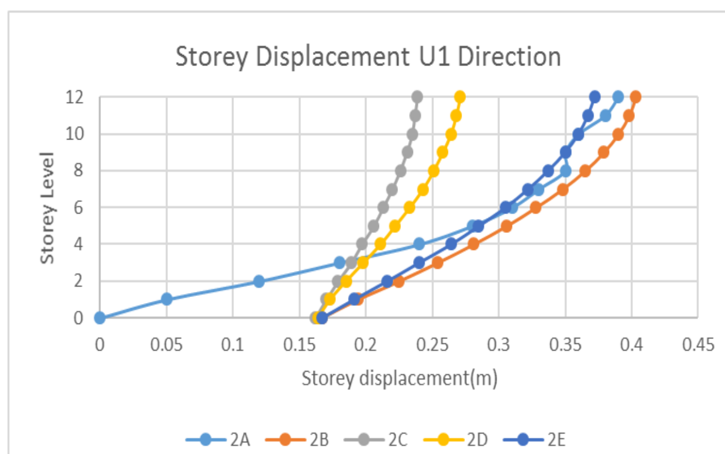


FIG 19 VARIATION OF STORY DISPLACEMENT (M)ALONG HEIGHT FOR NORTHRIDGE FOR IRREGULAR BUILDING

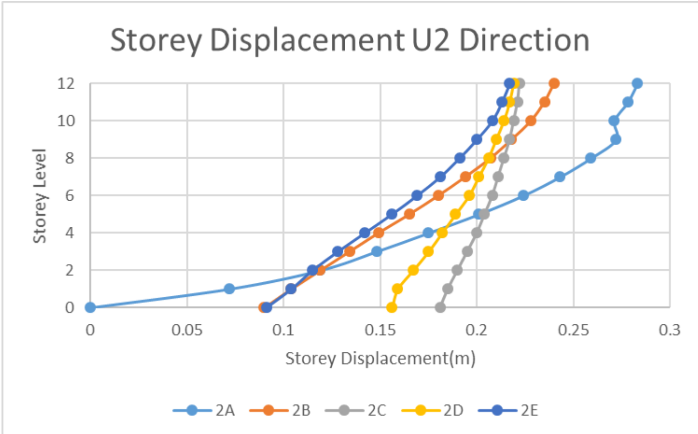


FIG 20 VARIATION OF STORY DISPLACEMENT (M)ALONG HEIGHT FOR NORTHRIDGE FOR IRREGULAR BUILDING

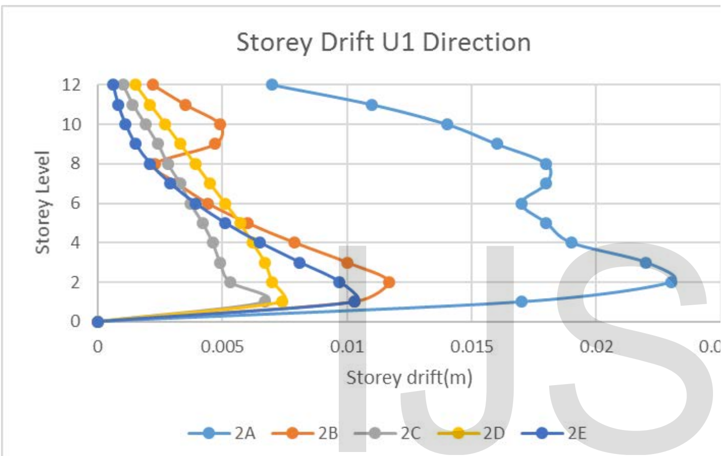


FIG 21 VARIATION OF STOREY DRIFT (M)ALONG HEIGHT FOR EL CENTRO FOR IRREGULAR BUILDING

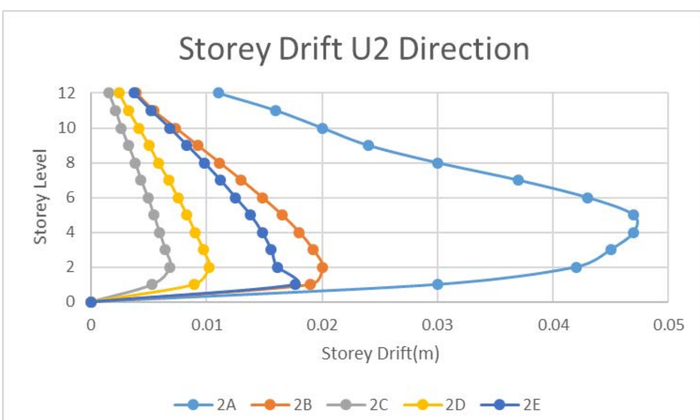


FIG 22 VARIATION OF STOREY DRIFT (M)ALONG HEIGHT FOR EL CENTRO FOR IRREGULAR BUILDING

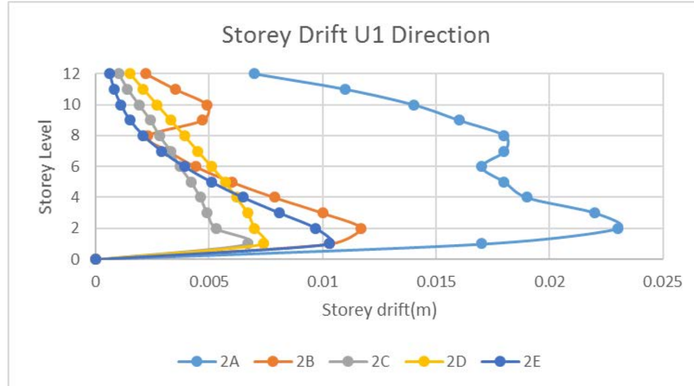


FIG 23 VARIATION OF STOREY DRIFT (M)ALONG HEIGHT FOR LOMA FOR IRREGULAR BUILDING

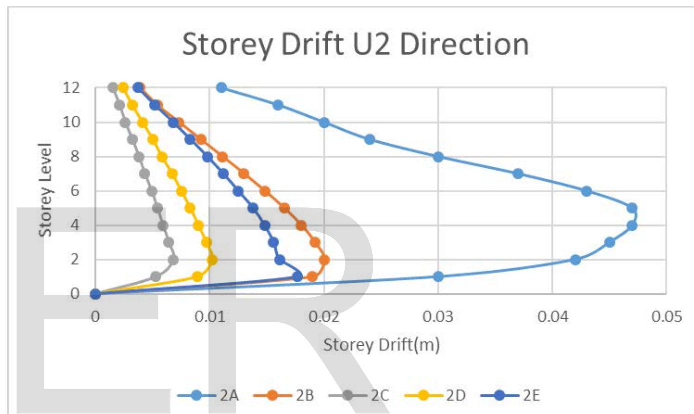


FIG 24 VARIATION OF STOREY DRIFT (M)ALONG HEIGHT FOR LOMA FOR IRREGULAR BUILDING

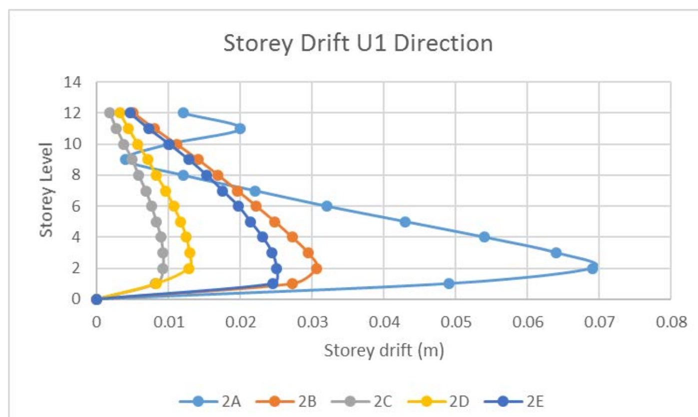


FIG 25 VARIATION OF STOREY DRIFT (M)ALONG HEIGHT FOR NORTHRIDGE FOR IRREGULAR BUILDING

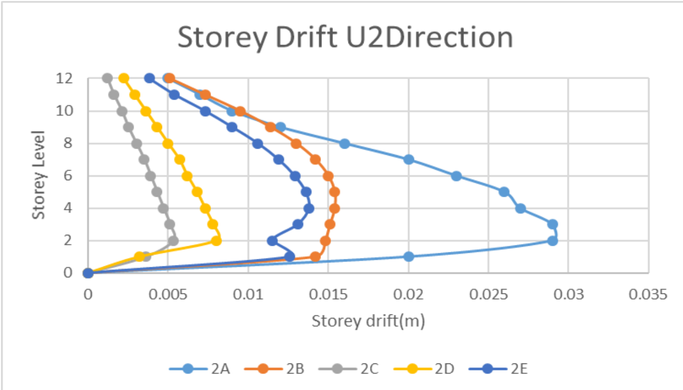


FIG 26 VARIATION OF STOREY DRIFT (M)ALONG HEIGHT FOR NORTHRIDGE FOR IRREGULAR BUILDING

5.1.3 VARIATION OF STOREY ROTATION

The variation of storey rotation is studied for Irregular buildings for El Centro, Loma and Northridge. The variations are shown in Figures 27, 28 and 29.

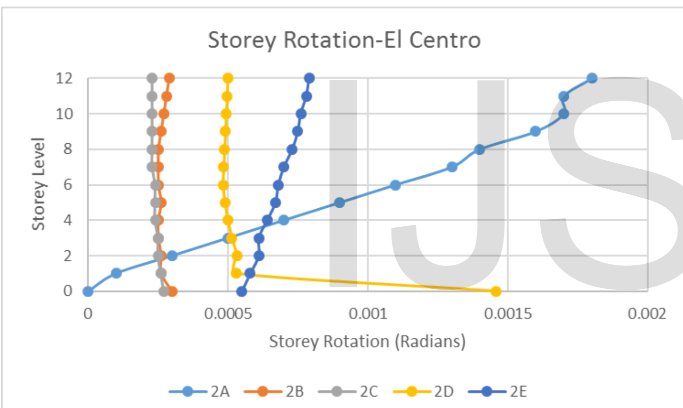


FIG 27 VARIATION OF STOREY ROTATION FOR EL CENTRO

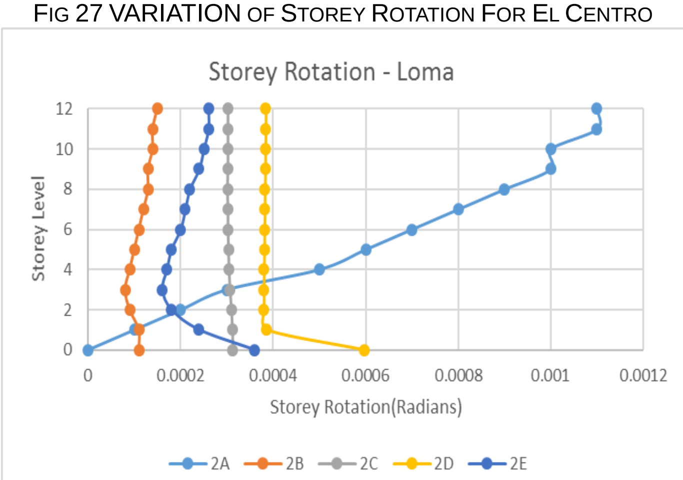


FIG 28 VARIATION OF STOREY ROTATION FOR LOMA

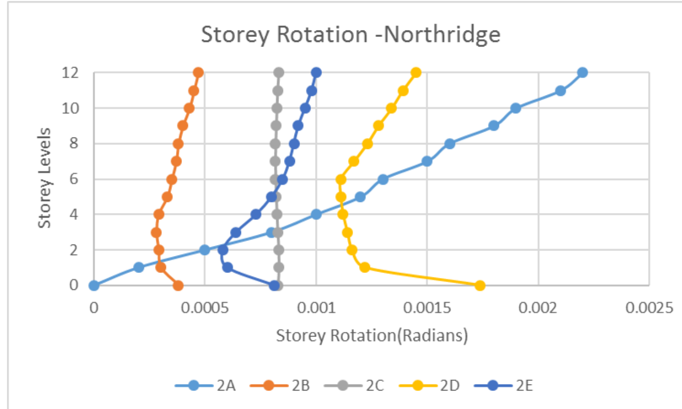


FIG 29 VARIATION OF STOREY ROTATION FOR NORTHRIDGE

6 CONCLUSION

All the base isolated models were effective in minimising the structural responses during the earthquake accelerogram data that was applied to the building model. the conclusions obtained from the results are:

- All the base isolated models showed reduced base shear compared to fixed base building.
- The Friction Pendulum Bearing (MODEL 1C & 2C) was found to be more effective in reducing base shear compared to other models and Lead Rubber Bearings(LRB) based isolation systems in regular and irregular cases.
- The variation of story drift along various floors became very less while using the Lead Rubber Bearing and Friction Pendulum Bearing systems.
- The implementation of Lead Rubber Bearings on the interior and the Friction Pendulum Bearings on the exterior column shows greater reduction in the parameters taken for study, i.e., storey drift and displacement. The story drift was found to be less than that in Lead Rubber Bearing Model.
- The variation of base shear and story drifts were similar in regular and irregular buildings in most of the considered earthquake cases.
- Friction Pendulum Bearing Model, MODEL 1C has the least values storey drifts for regular and irregular cases.
- Maximum drift values were observed at the floor level for isolated building cases.
- Replacing the FRB on the external columns on a LRB model was found to disadvantageous as the parameters showed less variation in this case when compared Friction Pendulum Bearings only models
- It was also found that the magnitude story rotation at top storey was effectively reduced by the isolation systems. The effect was most reduced for LRB based models, i.e., MODEL 2B and 2E. Combined Isolation in MODEL 1D showed high rotations at isolator level

compared to MODEL 1C, Friction Pendulum Bearing model.

ACKNOWLEDGMENT

I express my deep and sincere gratitude to my guide Dr Jayalekshmi R, Professor, Department of Civil Engineering, NSS College of Engineering for the very kind co-operation and sincere guidance for the successful completion of my project report

REFERENCES

[1] Alaa Barmo et al (2016), "The Behaviour of Multi-Story Buildings Seismically Isolated System Hybrid Isolation (Friction, Rubber and with the Addition of Rotational Friction Dampers)," Open Journal of Earthquake Research, 4, 1-13.

[2] Alfonso Vulcano et al (2014), "Non-linear Seismic Response of RC Framed Structures Retrofitted by Different Isolation Systems", Second European Conference on Earthquake Enginnering and Seismology,25-29

[3] Arathy S and Manju P.M (2016), "Analysis of friction pendulum bearing isolated structure", IRJET, Vol 03, Issue 08, 317-322.

[4] Arati Pokhrel et al (2016)," Comparative Studies of Base Isolation Systems featured with Lead Rubber Bearings and Friction Pendulum Bearings", Applied Mechanics and Materials, 846, 114-119

[5] Ashish R. Akhare, Tejas R. Wankhade (2014), "Seismic Performance of RC Structure Using Different Base Isolator," IJESRT, vol. 3, Issue-5, 724-729

[6] Azin Shakibabarough et al (2016), "Effects of Damper Locations and Base Isolators on Seismic Response of a Building Frame," International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering Vol:10, No:6, 710-715.

[7] Cancellara D, De Angelis F (2016).," Assessment and dynamic nonlinear analysis of different base isolation systems for a multi-storey RC building irregular in plan". Comput Struct

[8] Chandak N. R. (2013), "Effect of Base Isolation on the Response of Reinforced Concrete Building", Journal of Civil Engineering Research ,3(4), 135-142

[9] Dia Eddin Nassani, Mustafa Wassef Abdulmajeed (2015) "Seismic Base Isolation in Reinforced Concrete Structures," International Journal of Research Studies in Science, Engineering and Technology, Volume 2, Issue 2,1-13.

[10] Darshale S.D and N.L Shelke (2016), "Seismic Response Control of Vertically Irregular R.C.C. Structure using Base Isolation", International Journal of Engineering Research, 5,2, 683-689.

[11] Fanel Scheaua (2011), "Seismic Base Isolation of Structures Using Friction Pendulum Bearings", The Annals of "Dunarea De Jos" University of Galati, 61-64.

[12] Gordon P. Warn, and Keri L. Ryan (2012), "A Review of Seismic Isolation for Buildings: Historical Development and Research Needs," Buildings 2012, 2, 300-325

[13] John Stanton and Charles Roeder (1991), "Advantages and Limitations of Seismic Isolation", Earthquake Spectra, Vol. 7, No. 2, pp-301-324, 1991

[14] Kadlag V A et al (2016), "Combined Base Isolation for Asymmetric Buildings", 5th International Conference on Recent Trends in Engineering, Science & Management, 1037- 1046

[15] Kalantari S.M et al (2008) "Investigation of Base-Isolator Type Selection on Seismic Behaviour of Structures Including Story Drifts and Plastic Hinge Formation," The 14 th World Conference on Earthquake Engineering, 12-17

[16] Khloud El-Bayoumi et al (2015), "Dynamic Analysis of High Rise Seismically Isolated Buildings", American Journal of Civil Engineering, Vol. 3, No. 2, 43-50

[17] Luis Andrade and John Tuxworth, "Seismic Protection of Structures with Modern Base Isolation Technologies," Green Leaf Engineers.

[18] Manoj U Deosarkar and Gowardhan S D (2015), "Non Linear Dynamic Response of Combined Isolation System on Symmetric and Asymmetric Buildings," IJIFR, Vol 3, Issue -3,1021-1035.

[19] Mohammed Ghouse et al (2016), "A Comparative Study on RC Frame Structure Considering Lead Rubber Bearing and Triple Friction Pendulum Bearing", International Journal of Innovative Research in Science, Engineering and Technology, Vol 05, Issue 08, 14907-14918.

[20] Naveen K et al (2015)," Base Isolation of Mass Irregular RC Multi-Storey Building", IRJET, 2,7, 903-906.

[21] Sameer S. Shaikh and P.B. Murnal (2015), "Base Isolation at Different Levels in Building", Journal of Civil Engineering and Environmental Technology, Volume 2, Number 10, 54-58.

[22] Shirule Pravin Ashok et al (2012), "Response Spectrum Analysis of Multi Storeyed Base-Isolated Building", IJCSEIERD, Vol 2, Issue 3, 66-75.

[23] Sunita Tolani and Dr. Ajay Sharma (2016), "Effectiveness of Base Isolation Technique and Influence of Isolator Characteristics on Response of a Base Isolated Building," AJER, vol. 5, Issue-5, 198-209.

[24] Tao Liu et al (2014)," Simplified Linear Static Analysis for Base-Isolated Buildings with Friction Pendulum Systems", Structural Engineering International, 4, 490-502.

[25] Torunbalci N and. Ozpalanlar G (2008), "Earthquake Response Analysis of Mid-Story Buildings Isolated with Various Seismic Isolation Techniques," The 14 th World Conference on Earthquake Engineering ,12-17

[26] Tessy Thomas and Alice Mathai (2016), "Study of base isolation using friction pendulum bearing system", IOSR Journal of Mechanical and Civil Engineering, 19-23.

[27] Vinodkumar Parma and G.S Hiremath (2015), "Effect of Base Isolation in Multi storied RC Irregular Building using Time History Analysis", IJRET,4,2, 289-292.

[28] Zaheer Ul Hassan Samdani et al (2015) "Comparative Study on Performance of Multi-Storey Structure Rubber Bearing and Friction Pendulum Base Isolation Systems," IJARET, vol. 2, Issue-2,150-154

[29] Farzad Naeim and James M. Kelly, Design of Seismic Isolated Structures from Theory to Practice, John Wiley& Sons Inc, 1999.

[30] Shome, N and Cornell, C.A (1999), "Probabilistic Seismic Demand Analysis of Nonlinear Structures", Reliability of Marine Structures Program Technical Report

[31] IS 1893 (Part 1): 2002, Criteria for Earthquake Resistant Design of Structures, Part 1 General Provisions and Buildings.

[32] International Building Code 2000

[33] Uniform Building Code 1997, Volume 2