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Parametric Study of Different Types of Base Isolation Techniques

G.S. Manjunath[1], K.G. Guptha[2] and Rashmi Guptha[3]

[1,3]Civil Engineering Gogte Institute of Technology Belgaum, Karnataka
[2]Civil Engineering Goa College of Engineering Farmagudi,Ponda-Goa
E-mail: [1]gsmanjunath@git.edu, [2]kgg@gec.ac.in, [3]rashgit@gmail.com

Abstract—*Earthquakes are natural calamities that are characterised of releasing large amount of energy in the form of vibrations that damage structures. Base Isolation techniques help in decoupling the structure from its foundation thereby improving its performance. Study involves analysis of G+3; G+10 and G+20 building models, studied for their base fixed and for their base isolated, using MIDAS Gen analysis software.*

Base isolation is achieved by two types of isolators namely lead rubber bearing and friction pendulum bearing. All the models were analysed with equivalent static analysis procedure, response spectrum analysis and time history analysis. Building modelled with Lead rubber bearings were further analysed considering hard soil, medium soil and soft soil. The effect of all the considered parameters is assessed with respect to variations in base shear, storey displacement, storey drift, period of the structure and its frequency. It was observed that isolating a structure lengthened its period and improved its performance by reducing the inter-storey drifts and base shear. Parametric study gives an overall idea of the effect of all the considered parameters on response of the structure and an idea as to whether the parameter has to be considered or can it be safely neglected based on the importance of the work, its priority, budget of the project and the given time frame for its completion. Review of literature indicates work in this field is still gray and scanty. This study definitely will contribute useful information to the literature.

The study can further be extended to considering the modelling of soil to study soil structure interaction, study the behaviour of the models under blast loading, studying the effect of considering dampers together with base isolation and combining the desirable characteristics of each type of isolation technique to form a new isolation technique having all the desired characteristics.

Keywords*: lead rubber bearings; friction pendulum bearings; time history; inter-storey drifts; inter-storey displacements; base shear.*

1. INTRODUCTION

Base isolation is a powerful technique that has been developed and being extensively adopted especially in severe seismic zones to protect structures against harmful damaging effects of ground shaking. Action of base isolators is analogous to the action of suspension springs provided in a car. Ultimate aim of isolators lies in absorbing and reducing the transmission of ground vibrations to the superstructure above during an earthquake. This technique can be very well adopted to a medium rise to a high-rise structure made of brick, stone or reinforced cement concrete (RCC) and retrofitting measures can include the efficient use of this technique to a structure that is already existing.

1.1 Elastomeric Bearings

Elastomeric bearings are the most preferred type of isolators which find their application in wide spectrum of Civil Engineering structures. The desirable engineering characteristics of elastomeric bearings include: high vertical load carrying capacity, rotational capacity, translational movement in any horizontal direction and minimum effects of seating distortions or span deformations apart from being economical. The bearing consists of alternate layers of steel shims and rubber which may be natural or neoprene rubber bonded together to form a single integrated unit. This unit as a whole decouples the superstructure from the horizontal component of earthquake ground motion thus introducing a flexible layer between the structure and its foundation. The bearing has high vertical stiffness, which is slightly improved by introducing a lead plug at the central axis. Vertical stiffness ensures that there are no settlements or sandwiching of the layers due to weight of the superstructure. Horizontal flexibility allows small lateral movement thus reducing the effects of destructive horizontal vibrations.

1.2 Friction Pendulum Bearing

Friction pendulum bearings work on the principle of a simple pendulum. It essentially consists of a slider that moves along a concave surface when subjected to lateral vibrations during the event of an earthquake. The dimensions of the isolator are fixed up based on the size of structure being supported, type of soil in the locality, load capacity requirements and earthquake displacement capacity. When the structure is subjected to lateral vibrations, the sliding arrangement provided helps in absorbing the energy which is spent in the work done to overcome the friction and slide along the concave inner surface. This indirectly reduces the acceleration imparted to the structure as the period of the isolated structure gets lengthened. This type of isolator has the capacity to re-center itself and the structure even after it undergoes any displacement from its equilibrium position due to gravity force and the concave inner surface.

2. MODELLING

The multi storey structure being considered for carrying out the proposed parametric study was modelled as a bare frame with only beams and columns having a plan area of 560 square meters consisting of four bays of 5m each in horizontal x direction and four bays each of 7m in vertical y direction when viewed from plan. Numbers of floors were varied for G+3, G+10 and G+20. The connections between beams and columns were considered to be rigid. Tables 1 to 4 present modelling details considered for analysis in MIDAS Gen. Figures 1 and 2 depict the chosen time history and plan of the building models respectively.

Table 1: Material Properties as Defined in MIDAS Gen

Sl.No.	Parameter	Value
1	Grade of concrete	M30 for 3 storeys M40for 10 and 20 storeys
2	Design Code	IS(RC) 456:2000
3	Modulus of elasticity	2.7386e+007 KN/m^2
4	Poisson's ratio	0.2
5	Thermal Coefficient	5.5556e-006 per deg F
6.	Weight Density	23.6KN/m^3
7	Damping ratio	0.05
8	Type of infill	FRI bricks
9	Modulus of elasticity	1.4000e+007 KN/m^2
10	Poisson's ratio	0.213
11	Thermal Coefficient	8.6360e-008 per deg F
12	Weight Density	17.61 KN/m^3
13	Thickness of masonry infill	230mm

Table 2: Parameters for Carrying-out Seismic Analysis

Sl.No.	Parameter	Value
1	IS Code adopted for design	IS 1893(2002)
2	Seismic zone	III
3	Zone factor	0.16
4	Type of soil	Hard rock
5	Importance Factor	1
6	Percentage Damping	5%
7	Fundamental period in x direction	0.3897 sec
8	Fundamental period in y direction	0.3897 sec
9	Response Reduction Factor	5

Table 3: Loads Defined and Modelled for the Structure in the Software

Sl.No.	Type of load	Magnitude of load
1	Self weight	Assigned in negative z direction
2	Wall load on floor beams	(0.23×17.61×2.6×1.5) 15.75KN/m
3	Wall load on roof beams due to parapet 1m high	(1×0.23×17.61×1.5) 6.08 KN/m
4	Wall load on roof beams during earthquake analysis	(0.23×17.61×1.5×1.3) 8 KN/m
5	Live load of floor	(3×1.5) 4.5 KN/m^2
6	Floor finish of floor	1.5 KN/m^2
7	Load due to slab	(0.1×23.6×1.5) 3.54 KN/m^2
8	Live load on roof during earthquake analysis	0 KN/m^2
9	Dead load of roof	(2×1.5) 3KN/m^2
10	Percentage of live load considered during earthquake analysis	25%
11	Type of eigen value analysis adopted	Lanczos with 12 iterations
12	Time history	El centro
13	Type of time history analysis	Linear
14	Analysis method	Modal
15	Type of time history	Transient
16	Damping method	Modal
17	Time function data type	Normalized acceleration

Table 4: Details of Design of Lead Rubber Bearing Isolator

Sl.No.	Soil type	Sa/g	K_h(KN/m)	K_v(KN/m)	Infill	Load	Floors
1	Hard	0.5	377	172862.7	Present	1546.3	3
2	Medium	0.68	525	310245	Present	1546.3	3
3	Soft	0.835	647	310245	Present	1546.3	3
4	Hard	0.5	332	138340	Absent	1371.5	3
5	Medium	0.68	463	249527	Absent	1371.5	3
6	Soft	0.835	570	353729	Absent	1371.5	3
7	Hard	0.5	1003	888494	Present	3957.9	10
8	Medium	0.68	1386	1452572	Present	3957.9	10
9	Soft	0.835	1703	1958260	Present	3957.9	10
10	Hard	0.5	1047	951213	Absent	4116.2	10
11	Medium	0.68	1442	1539896	Absent	4116.2	10
12	Soft	0.835	1777	2081468	Absent	4116.2	10
13	Hard	0.5	1982	2423763	Present	7684.2	20
14	Medium	0.68	2727	3732197	Present	7684.2	20
15	Soft	0.835	3356	4882090	Present	7684.2	20
16	Hard	0.5	1887	2264633	Absent	7309.5	20
17	Medium	0.68	2591	3487492	Absent	7309.5	20
18	Soft	0.835	3184	4563091	Absent	7309.5	20

Table5: Details of Design of Friction Pendulum Bearing Isolator

Sr. No.	Max.vertical reaction	Radius of curvature	Coeff. of friction	V_{bmax}	K_v	K_h	Floors	In fill
1	25948.12	2.235	0.1	0.15	28908.64	23126.915	3	Present
2	21052.9	2.235	0.1	0.15	23454.91	18763.927	3	Absent
3	33786.06	3.048	0.1	0.15	66435.48	53148.382	10	Present
4	65774.06	3.048	0.1	0.15	65428.79	52343.031	10	Absent
5	124558.83	3.962	0.1	0.15	114477.59	91582.074	20	Present
6	120426.35	3.962	0.1	0.15	110679.58	88543.661	20	Absent

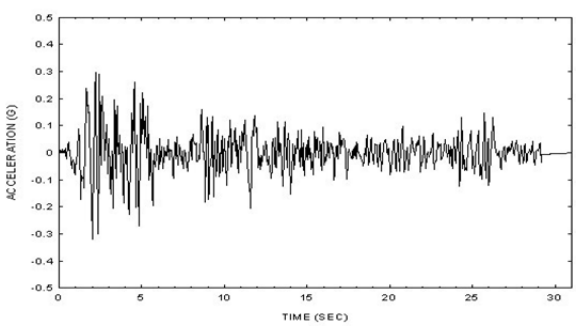


Fig. 1: Time History of May 18, 1940 El Centro Earthquake

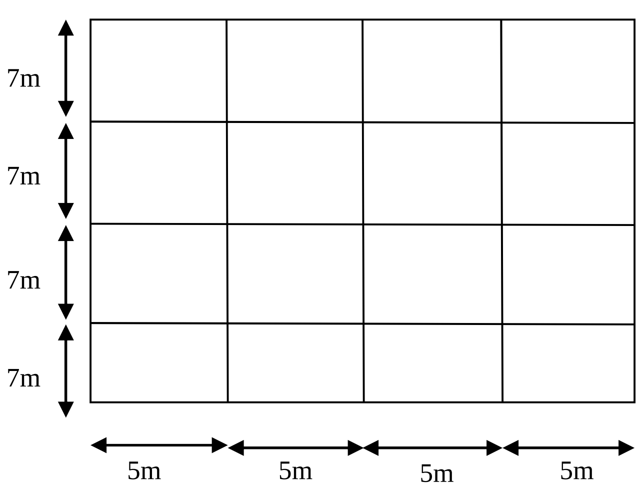


Figure02: Typical Plan of G+3, G+10 and G+20 Building Models

3. RESULTS

All the models (G+3, G+10 and G+20) were modeled with a storey height of 3m with 100 mm thick slab. The basement is planned for parking and the residential occupation is from the ground floor. The model is modelled with basement at -3.0m and ground floor at 0.0m level. The analysis is done considering the frames to be SMRF (Special Moment Resisting Frames) with a reduction factor of 5 which is planned purely for residential purpose. The effect of wind was considered in case of ten and twenty floors models only.

These models were considered to have three cases of support conditions namely:

1. **Fixed base**: Restrained against displacement and rotation.
2. **Base isolated with lead rubber bearings**: Allowing lateral displacement with sufficient vertical stiffness (The bearing being designed based on the maximum value of support reaction under service loads). Lead rubber bearings are considered for the following soil type :
   a. LRBH :Lead Rubber Bearing for Hard soils
   b. LRBM : Lead Rubber Bearing for Medium soils
   c. LRBS : Lead Rubber Bearing for Soft soils
3. **Base isolated with friction pendulum bearings**: Allowing lateral displacement within the concave spherical plate with designed radius and co-efficient of friction. The horizontal and vertical stiffness of the bearings were designed based on the total load of superstructure and substructure.

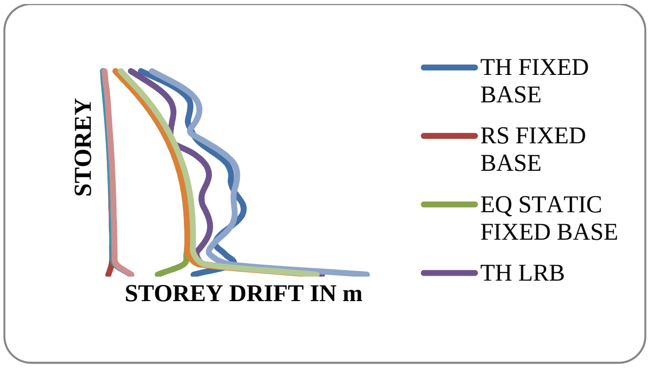
The storey drift, its displacement, natural period and base shear of the models were calculated using the following procedures:

1. Equivalent Static Force Procedure (Static analysis procedure)
2. Response Spectrum Analysis and (Dynamic analysis procedure)
3. Time History Analysis(Dynamic analysis procedure)

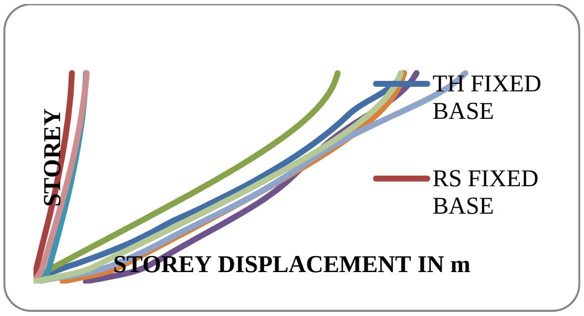
Considering critical combinations of the parameters, the effect and the interrelationship existing between:

1. Storey v/s storey drift (for type of isolation)
2. Storey v/s storey displacement (for type of isolation)
3. Variation of base shear(for type of isolation)
4. Period v/s mode number (for type of isolation)
5. Frequency v/s mode number(for type of isolation)

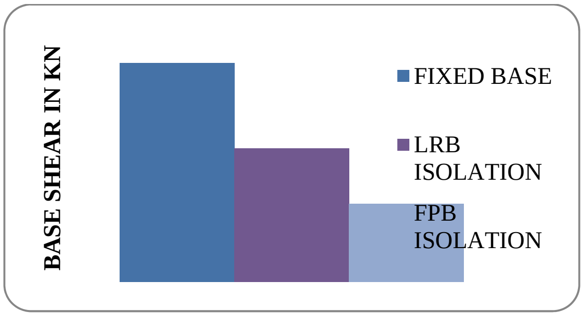
are evaluated and discussed.



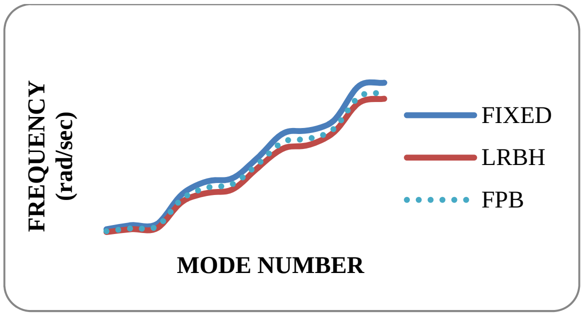
Graph 01: Variation of Storey Drift for Different Types of Isolation techniques and Analysis Procedures.



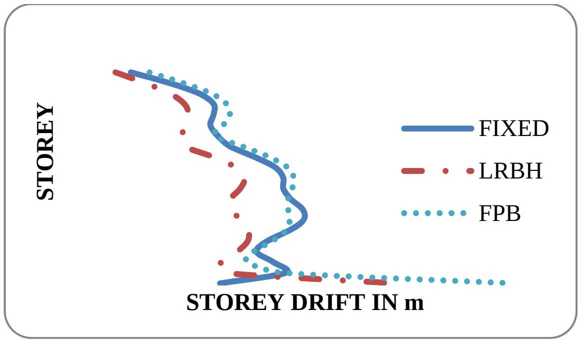
Graph 02: Variation of Storey Displacement for Different Types of Isolation techniques and Analysis Procedures.



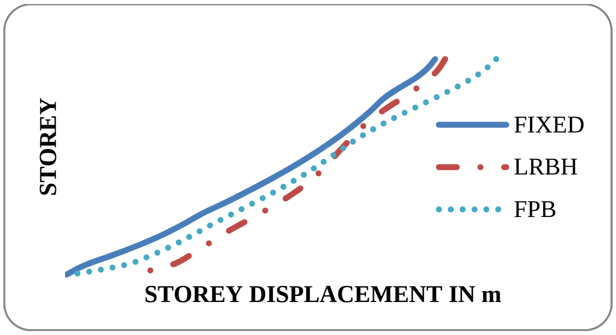
Graph 03: Variation of Base Shear for Different Types of Isolation techniques.



Graph 04: Variation of Frequency of the Structure for Different Types of Isolation techniques



Graph 05: Variation of Storey Drift Under Time History Analysis for Different Types of Isolation techniques



Graph 06: Variation of Storey Displacement Under Time History Analysis for Different Types of Isolation Techniques

Graphs 1,2,3 and 4 show the inter storey drifts, displacements, base shear and frequency of the structure respectively for a twenty storeyed RCC building considering different methods of analysis and different types of isolators. Graphs 5 and 6 show variation of inter storey drift and displacement for twenty storeyed RCC building considering different types of isolation technique but for time history of 1940 El Centro Earthquake.

Isolation of the base of structure improves its performance by increasing its period. An increase in period refers to a corresponding decrease in the frequency of the structure since these two parameters are inversely proportional. This fact is well depicted in graph 4.Since the fixed base has least period, it has maximum frequency followed by FPB and LRB types of isolation.

Isolating a structure also results in reducing the base shear to which the structure would be subjected to otherwise. Isolators at the base tend to absorb the seismic vibrations which allows its lateral deformation. Thus the absorbed energy is used up in allowing the isolator to deform laterally. Only small amount of vibrations are transferred to the structure. This behaviour of the isolator reduces the base shear remarkably which is very well depicted in graph 3. Vibrations go unabsorbed in fixed base case due to which it is subjected to maximum base shear.

LRB and FPB isolated cases absorb the seismic energy thus the structure is subjected to lower base shears.

Introduction of isolators to decouple the base and the superstructure results in increasing the inter-storey displacements relative to the fixed base case on account of imparting flexibility to the structure as depicted in graph 2 irrespective of the method used for analysis. Inter-storey displacements are maximum at the base (relative to the fixed base case) for isolated cases due to the lateral deformation of isolators. Also since the fixed base case has least flexibility and zero displacements at the base, graph 2 and 6 shows the variation to begin from the origin while for isolated cases the variation begins for some finite amount of displacement accounting for deformation of the isolator. Further analysis shows that LRB in smaller displacements than FPB type of isolation.

Graph 1 depicts the variation of inter-storey drift for different types of isolation cases. Graphs 1 and 5 shows drifts to be greater for isolated cases at the base and reduce considerably at the top storeys relative to the fixed base case. A larger drift at the base is due to lateral deformation of the isolator. In general LRB isolation has relatively lower drifts as compared to FPB isolation at the base and also has performed better than FPB (by having drifts lesser than fixed base case).

The results of time history analysis and equivalent static force method of analysis are more or less in good agreement with each other. However this statement is true when the necessary magnification or scaling up of the shear is not done (as in the present study). In the considered case response spectrum results are more reliable than other two methods. Though time history analysis gives more realistic results, in the present study El Centro earthquake has been considered and an earthquake similar to that of El Centro occurring in India is quite bleak. However, the reason for selecting El Centro time history is just to carry out the parametric study, which can be taken up for any other time history.

Table 6: Comparative Results of Considered parameters for Different Types of Analysis Procedures and Type of Isolation

Parameter	Response Spectrum Analysis			Equivalent Static Force Method			Time History Analysis		
	FIXED	LRB	FPB	FIXED	LRB	FPB	FIXED	LRB	FPB
Displacement	0.037	0.0491	0.0513	0.169	0.2071	0.375	0.3588	0.3708	0.418
Peak Drift	0.0025	0.0064	0.0065	0.01	0.0222	0.04	0.0298	0.0411	0.0557
Period	6.5332	7.7568	7.352	6.5332	7.5	7.352	7.124	8.185	8.0198
Frequency	1.3847	1.2089	1.2318	0.9617	0.8377	0.8546	0.882	0.7676	0.7835

On the other hand, results by response spectrum analysis are always more reliable for distribution of storey forces and storey shears than equivalent static force method of analysis. This is due to the fact that in response spectrum analysis, eigen value problem is solved to obtain period while equivalent static force method calculates period of the structure based on codal formula considering height and type of frame.

4. DISCUSSIONS

1. Choice of selecting a particular type of isolation depends on assessing its overall performance in terms of drifts, displacements, shear and period. Engineer has to bear in mind all the physical and financial constraints together with its performance before selecting the type of isolation technique.
2. Base shear reduced considerably when the base is isolated using friction pendulum bearing and analysed using time history analysis but the reduction in base shear was relatively lesser when analysed with equivalent static force procedure.
3. From the study it was observed that the storey drift was relatively greater for isolated structure at the base but as the number of storeys increased the storey drifts in isolated buildings reduced in comparison with fixed base structure
4. Introduction of base isolation reduced the inter storey drift but increased the storey displacement relative to fixed base structure due to the elasticity imparted by the isolation system
5. Introduction of isolation increased the flexibility of the structure as a whole thus increasing the period of the structure and making it less susceptible to attract greater magnitude of lateral forces.

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