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Correlation Analysis on Seismic Response of Base-Isolated Multi-Storey Structures

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Abstract: In recent times with the increased use of multi-storey structures in India and around the world, the analysis of such buildings is of considerable significance. The base-isolation techniques prove to be very effective in enhancing the structural safety and integrity against severe earthquakes. During an earthquake the principal attack on a structure is by transient horizontal forces. The earthquake resistance of the structure depends on a combination of elastic strength, inelastic deformability and damping capacity of the structure. The geometrical parameters of the structure also have a major influence on the seismic response of both fixed base and base-isolated structures. In this paper a series of 3-dimensional dynamic response spectrum analyses are carried out in ETABS to investigate in detail the geometrical parametric responses of structures with and without base-isolation, when subjected to dynamic loading. The first phase of the study addresses the effect of each parameter such as bay width, number of bays, number of stories and story height of the structure subjected to earthquake forces. To have better interpretation of dynamic behavior, the study then focuses on deriving a correlation of these parameters with the response of the structure.

Keywords: *Base isolation, Friction pendulum bearing, Response spectrum analysis, Correlation*

1. Introduction

A large number of reinforced concrete multi-storied frame buildings got heavily damaged and many of them collapsed in past earthquakes leading to enormous loss of life and property. This has compelled the engineers and scientists to think of innovative techniques and methods to save the buildings and structures from the destructive forces of earthquake.

Conventional seismic design attempts to make buildings that do not collapse under strong earthquake shaking, but may sustain damage to non-structural elements and to some structural members in the building. This may render the building non-functional after the earthquake, which may be problematic in some structures, like hospitals, which need to remain functional in the aftermath of the earthquake. Special techniques are required to design buildings such that they remain practically undamaged even in a severe earthquake.

Significant damage in building under strong ground shaking can be avoided by altering the building's characteristics through external intervention such that even in strong ground shaking the demand is less than the design strength of building and its components. Seismic isolation and energy dissipating systems are some of the design strategies applied to increase the earthquake resistance of the structures.

1.1 Base Isolation

Base isolation (BI) is a mechanism that provides earthquake resistance to the structure. The fundamental principle of base isolation is to modify the response of the building so that the ground can move below the building without transmitting these motions into the building [Kelly (9)]. Base isolation can't claim to make a building "earthquake proof", but it reduces considerably the forces and inter-storey drifts within a building and so limits damage [Charleson & Allaf (3)].

The BI systems decouples the building from the horizontal ground motion induced by earthquake, and offer a very stiff vertical components to the base level of the superstructure in connection to substructure (foundation). Base isolation systems significantly reduce inter-story drifts, seismic forces and inelastic deformations in structural elements, preventing damages that may be caused to a building during an earthquake. This issue is especially relevant for public structures because of their high importance [Ribakov and Iskhakov (12)]. Base isolation shifts the fundamental lateral period and dissipates the energy in damping. The reduction in the accelerations protects the non-structural elements from the acceleration originated damages. Also, an acceleration value being low is very important especially for the protection of the valuable and sensitive content of the structure [Torunbalci & Ozpalanlar (14)].

Seismic isolation systems for building structures are designed to preserve structural integrity and to prevent the damage by reducing the earthquake-induced forces and deformations in the super-structure. The compliant elastomeric bearings and frictional sliding mechanisms installed in the foundations of seismically isolated structures protect the structures from strong earthquakes through a reduction of stiffness and an increase in damping Kelly [8].

On the other hand, the flexibility of the super-structure in a base isolated building is generally less than the non-isolated building which can cause the reduction of construction costs [Monfared et. al, (10)]. Analytically it has been shown by Kabeer & Kumar [7] that isolators can bring about 20% savings in the reinforcement used due to base isolation of structures. Since the building does not undergo any deformation but only gets displaced.

In recent years, this relatively new technology has emerged as a practical and economic alternative to conventional seismic strengthening. This concept has received increasing academic and professional attention and is being applied to a wide range of civil engineering structures. To date, there are several hundred buildings in Japan, New Zealand, United States, and very few in India which use seismic isolation principles and technology for their seismic design.

The present paper evaluates the effectiveness of base isolation for a simple building conducted using response spectrum method in ETABS. Response spectrum analysis is a linear dynamic statistical analysis method which measures the contribution from each natural mode of vibration to indicate the likely maximum seismic response of an essentially elastic structure. Response spectrum analysis provides insight in to dynamic behavior by measuring pseudo-spectral acceleration, velocity or displacement as a function of structural period for a given time history and level of damping.

There are four aspects of buildings that architects and design engineers work with, to create earthquake-resistant design of a building, namely seismic structural configuration, lateral stiffness, lateral strength and ductility. Lateral stiffness, lateral strength and ductility of buildings can be ensured by strictly following seismic design codes. But, good seismic structural configuration can be ensured by following coherent architectural features that result in good structural behavior. Seismic structural configuration entails three main aspects, namely - (a) geometry, shape and size of the building, (b) location and size of structural elements, and (c) location and size of significant non-structural elements [Murthy et. al, (11)].

Earthquake response calculation, parametric analysis and seismic parameter optimization of base-isolated structures are some critical issues for seismic design of base-isolated structures [Huang, Ren & Mao (4)]. Configuration of building is critical for its good seismic performance. The geometrical parameters of the structure have a major influence on the seismic response of both fixed base and base-isolated structures. Present study conducted addresses the effect of dimensions of the structure under the action of earthquake forces. Correlation coefficients are used in deriving the statistical relationship between the variables. On the basis of such analysis multiple linear regression equations are formulated, which will be useful to predict the response of a structure.

1.2 Correlation

When there is more than one independent variable, the collection of all pair-wise correlations are sufficiently represented in a correlation form. In statistics, dependence is any statistical relationship between two random variables or two sets of data. The magnitude of correlation coefficient is a statistical measure of the degree of linear interrelationship between two random variables [Ang & Tang (1)]. These are useful in indicating a predictive relationship that can be exploited in practice.

The most familiar measure of dependence between two quantities is the Pearson product-moment correlation coefficient, or "Pearson's correlation coefficient", commonly called simply "the correlation coefficient". It is obtained by dividing the covariance of the two variables by the product of their standard deviations. If we have a series of n measurements of X and Y written as x_i and y_i where i =1, 2, .., n, then the sample correlation coefficient can be used to estimate the population Pearson correlation r between X and Y. The sample correlation coefficient is written as

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{(n-1)s_x s_y} = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2 \sum_{i=1}^{n}(y_i-\bar{y})^2}}, \quad (1)$$

where, x and y are the sample means of *X* and *Y*, and s_x and s_y are the sample standard deviations of *X* and *Y*.

The correlation coefficient is +1 in the case of a perfect direct (increasing) linear relationship (correlation), −1 in the case of a perfect decreasing (inverse) linear relationship (anti-correlation). Values between −1 and 1 in all other cases indicate the degree of linear dependence between the variables. As it approaches zero there is less of a relationship (closer to uncorrelated). The closer the coefficient is to either −1 or 1, the stronger the correlation between the variables. If the variables are independent, correlation coefficient becomes 0.

2. Methodology

This paper discusses the effectiveness of base isolation for simple multi-storey buildings without any irregularity in mass or stiffness. The structures are analyzed using response spectrum method as per IS 1893:2002 in ETABS software. To investigate the effect of geometrical parameters on the dynamic response of buildings, the behavior of a set of prototypical structures is studied. The dynamic response parameters such as base shear, time period, storey displacement and storey drift are evaluated.

The first phase of the study addresses the effect of each parameter such as bay width, number of bays, number of stories and storey height of the structure subjected to earthquake forces on the dynamic response. To have better interpretation, the study then focuses on deriving a correlation of these parameters with the response of the structure.

3. Parametric study

Building configuration is critical for good seismic performance of structures. A parametric study is conducted to check the geometrical adequacy of both fixed base and base isolated structures under dynamic response. A typical structure considered in the study is of 4x4bay with 5 m bay width, 12 stories with a story height of 3m as shown in fig-1. To address the effect of geometrical dimensions on the seismic performance of the structure, parameters such as bay width, no of bays, no of stories and story height are varied. A number of models are analyzed by varying the above mentioned parameters with values ranging in both lower and upper limits of the typical model as shown in table-1. Bay width is varied between 3m and 7m, number of bays between 2x2 to 6x6, number of stories from 4 to 20 and story heights of 2.5m, 3m and 3.5m. During the course of analysis while varying a particular parameter, all other input quantities are kept constant as in typical case. In total 15 models are considered for the comparative study.

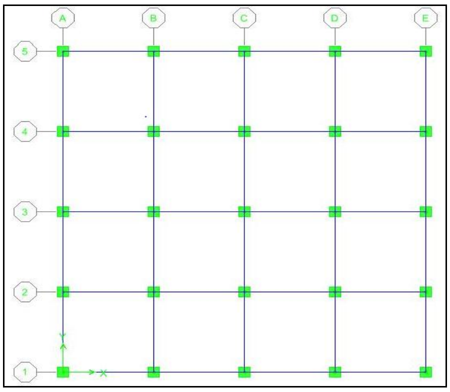
Table-1: *Parameters considered for comparative study*

Parameters	**Cases considered**	**Typical case (Mean)**
Bay width	3m, 4m, 5m, 6m, 7m	5m
No. of Bays	2x2, 3x3, 4x4, 5x5, 6x6	4x4
No. of stories	4, 8, 12, 16, 20	12
Story height	2.5m, 3m, 3.5m	3m

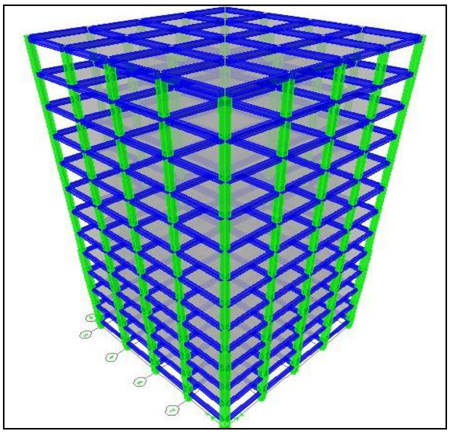
3.1 Building details

The structures for the parametric study are considered to be located in seismic zone –V on a site with medium soil as per IS 1893-2002. Table-2 summarizes the building configuration and loadings considered for the present study. Plinth level is at a height of 1.5m from the foundation level. A slab thickness of 150mm is considered.

Building is assumed to be used for commercial purpose; hence a live load of 3.5kN/m^2 is applied. The cumulative loading due to ceiling plaster, mortar and flooring material is taken under a single case of floor finishes with a value of 1.5kN/m^2. All beams carry wall loads and parapet wall loads are applied on exterior roof beams.



(a) *Plan view*



(b) *3D view*

Fig-1: *Views of typical building model*

Table-2*: Building details for typical structure*

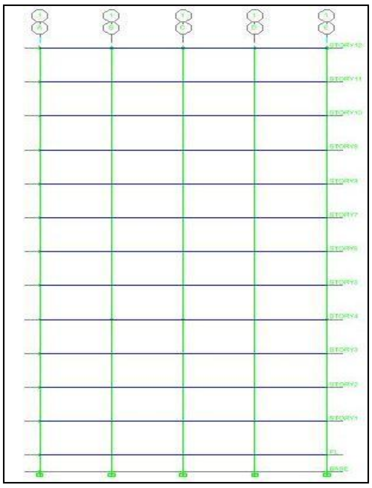
Grade of concrete & steel	M25 & Fe415
Plinth height above foundation	1.5m
Slab thickness	150mm
Wall thickness	Exterior walls – 230mm Interior walls – 150mm
Beam dimensions	300x450mm 7m bay width case (only) - 350x500mm
Column dimensions	top 8 stories - 450x450mm, 8 to 16 stories from top - 600x600mm, after 16 stories from top - 750x750mm
Parapet wall height	1m
Density of masonry	20kN/m^3
Live load on floors	3.5kN/m^2
Load due to floor finishes	1.5kN/m^2

4. Modelling in etabs

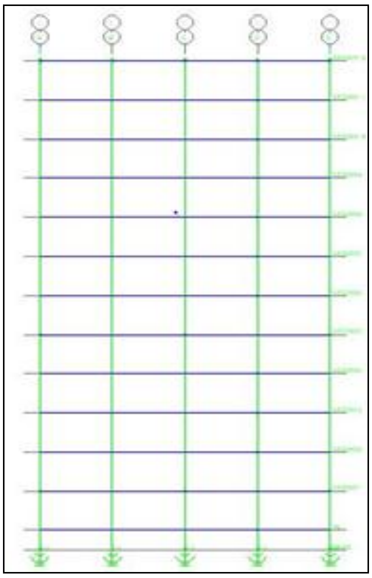
The buildings are modeled as three-dimensional frame structure in ETABS computer software. The structural material is assumed to be isotropic and homogeneous. The floors/slabs are modeled as membrane elements and the joint between building elements has been considered as rigid diaphragms. To evaluate the seismic response of the building, elastic analyses were performed by the response spectrum method. In the present work friction pendulum isolator is considered for the analysis of base isolated structures. This has been modeled as Isolator2 using link element in ETABS as shown in fig-2.Table-3 gives the input parameters considered for Friction pendulum base isolator.

***Table-3**: Properties of Base Isolator – FP*

Linear Stiffness (U1)	35E6 kN/m
Non-linear Stiffness (U1)	35E6 kN/m
Linear Stiffness (U2 & U3)	1750 kN/m
Non-linear Stiffness (U2 & U3)	35E3 kN/m
Friction coefficient – slow (U2 & U3)	0.03
Friction coefficient – fast (U2 & U3)	0.05
Rate parameter (U2 & U3)	40
Radius of sliding surface (U2 & U3)	2.23



***(a)** with fixed base*



***(b)** with base isolation (Link element)*

***Fig-2:** Elevation view of typical model*

5. Results and Discussions

Similar to the analysis carried out by Thakare & Jaiswal [13], using the stiffness and damping of base isolation, building is analyzed using response spectrum analysis. The dynamic response of base isolated structure is first compared with that of fixed base. This is followed by discussion on effect of each of the variable parameter on the overall dynamic behavior of the structure. Based on the analysis in ETABS, seismic response of the building such as modal time period, storey shear, storey displacement and story drift are evaluated for all the cases considered under parametric study and presented in fig-3 to 18.

5.1 Effect of Base isolation on dynamic response

To understand the behavior of base isolated structure in comparison to a fixed base structure, friction pendulum type of base isolators are being provided beneath all the columns. With the addition of isolator the building becomes flexible and this improves the structural seismic response compared to fixed base as seen in table-4.

***Table-4:** Comparison of parameters in fixed base and base isolated models*

Parameter	Fixed Base Model	Base isolated Model
Mode time period (s)	2.20	3.45
Base shear (kN)	851.89	605.09
Base displacement (mm)	0	25.28
Max displacement (mm)	27.29	36.84
Max drift (mm)	5.02	3.55

From the basic concept of base isolation system, the natural period of the fixed base (FB) building is lengthened by 37%, making it flexible. Base isolation (BI) systems significantly reduced the base shear of the structure by 42%, thereby reducing the seismic load applied on it, which in turn reduces the earthquake forces on the structure. Fixed base buildings have zero displacement at base and in case of base isolated model appreciable amount of lateral displacement is observed. Also at higher stories, high lateral displacement is being detected with isolators as the building becomes flexible. The isolated structure vibrates almost like a rigid body with large deformations or displacements (26% more than fixed base) endured by the isolation bearings. The conventional fixed base structure without seismic isolation is subjected to substantial storey drifts, which may lead to damage or even collapse of the building.

5.2 Effect of variation of Bay width on dynamic response

Buildings with larger bay width have higher fundamental modal time period than those with smaller width. This is because overall mass of the structure increases with increase in bay width. Hence, the modal time period and base shear of the building show increasing trend as shown in fig- 3 & 4.

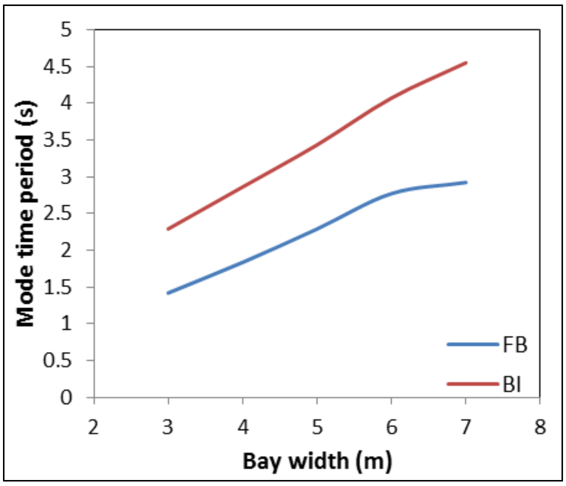


***Fig-3**: Comparison of modal time period for fixed base& base isolated structures with varying bay width*

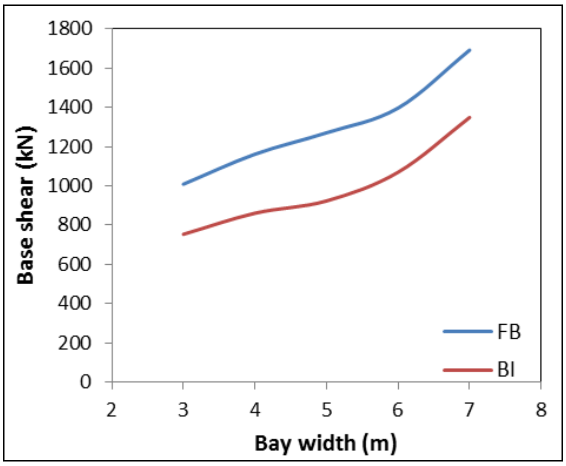


***Fig-4:** Comparison of base shear for fixed base & base isolated structures with varying bay width*

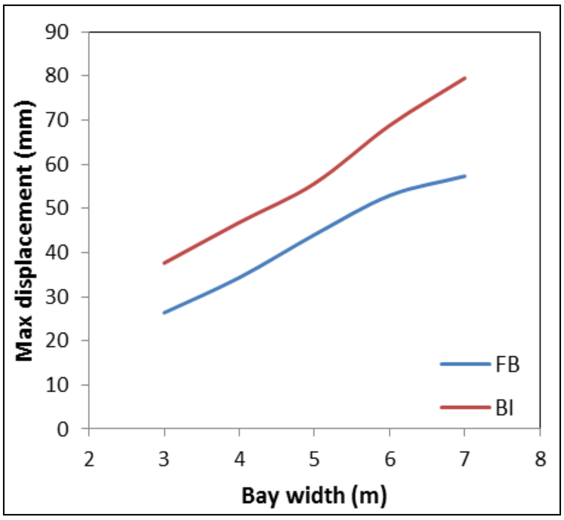


***Fig-5:** Comparison of max displacement for fixed base &base isolated structures with varying bay width*

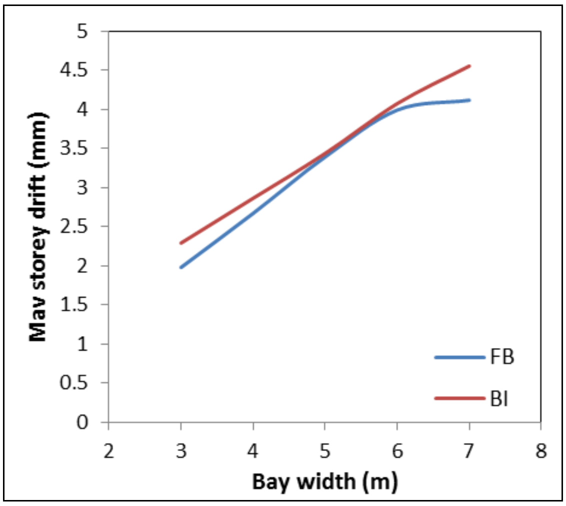


***Fig-6**: Comparison of max storey drift for fixed base& base isolated structures with varying bay width*

Fig-5 & 6 shows that with increase in bay width the load on the structure as well as beam and column spacing increases, thereby higher displacements are encountered. On varying the bay width, the change in maximum story drift for fixed and base isolated structures is negligible.

5.3 Effect of variation of number of bays on dynamic response

As the number of bays of the structure increases, its seismic weight increases, hence the base shear of building intensifies as shown in fig- 8. The difference in base shear for fixed base and base isolated structures shows larger variation with increase in number of bays. With variation in number of bays, there is not much difference in the other dynamic responses of the structure. The modal time period, story displacement and drift show almost a straight curve as depicted in fig – 7, 9 &10. Similar trend is observed for both base isolated and fixed base structures.

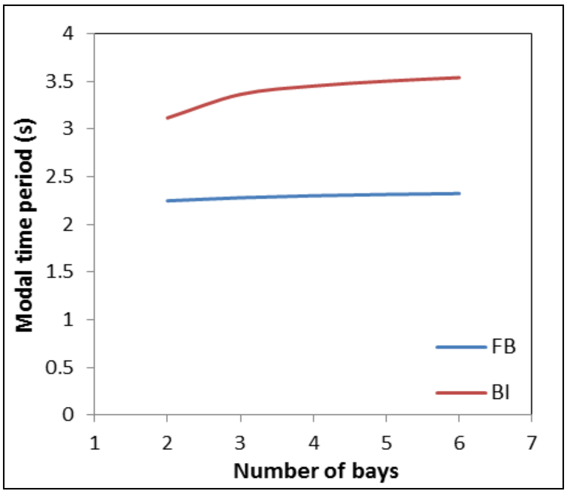


***Fig-7**: Comparison of modal time period for fixed base& base isolated structures with varying number of bays*

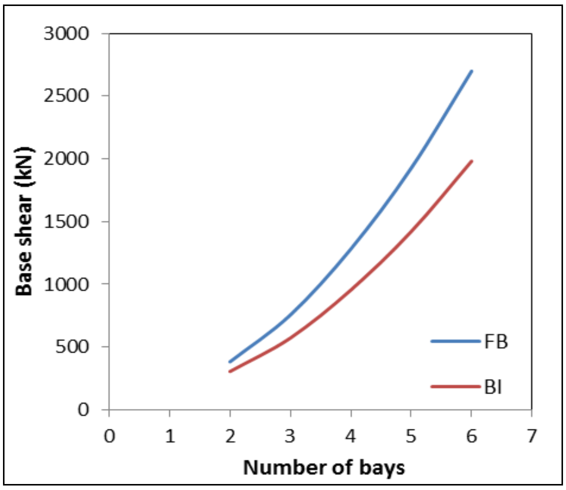


***Fig-8**: Comparison of base shear for fixed base & base isolated structure with varying number of bays*

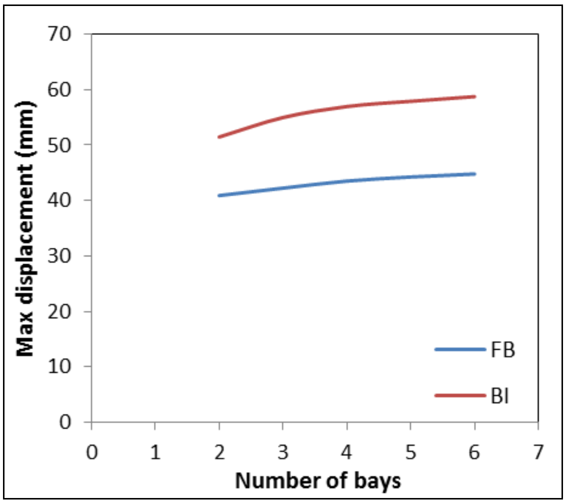


***Fig-9**: Comparison of max displacement for fixed base& base isolated structures with varying number of bays*

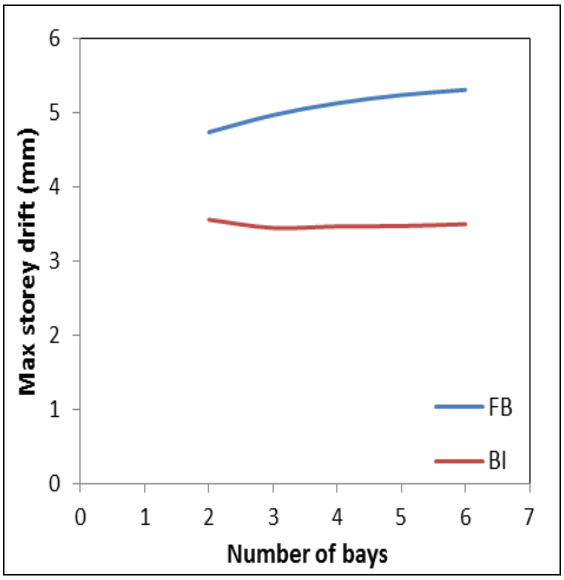


***Fig10**: Comparison of max story drift for fixed base & base isolated structure with varying number of bays*

5.4 Effect of variation of number of stories on dynamic response

Taller buildings have higher mass of the structure but its overall stiffness decreases. Hence, the modal time period and base shear of the building increases with increase in height (i.e number of stories) as shown in fig- 11& 12. The reduction in base shear due to base isolation is prominent for low rise and medium rise structures, whereas the reduction in high rise buildings is negligible.

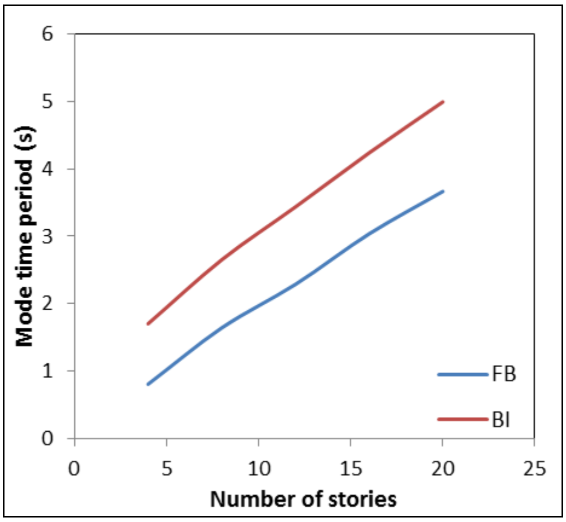


***Fig-11:** Comparison of modal time period for fixed base & base isolated structures with varying number of stories*

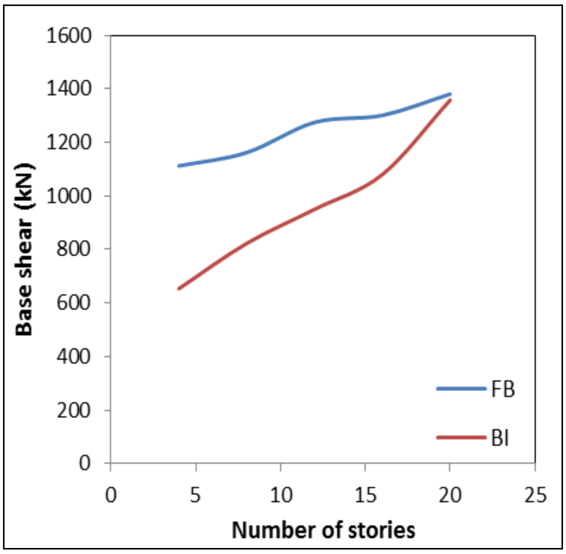


***Fig-12**: Comparison of base shear for fixed base & base isolated structure with varying number of stories*

The variation of roof displacement is dependent on slenderness ratio (H/L and H/B) in the two directions. Structure shows higher roof displacement and drift with higher slenderness ratio i.e when the height of the structure (H) is increased keeping plan dimensions (LxB) constant. Buildings become laterally flexible as their height increases as seen in fig- 13& 14.

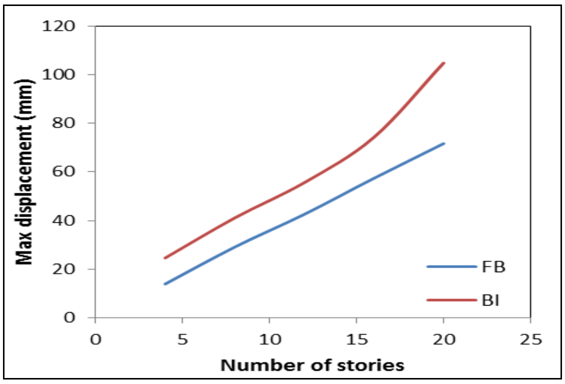


Fig-13: *Comparison of max displacement for fixed base &base isolated structures with varying number of stories*

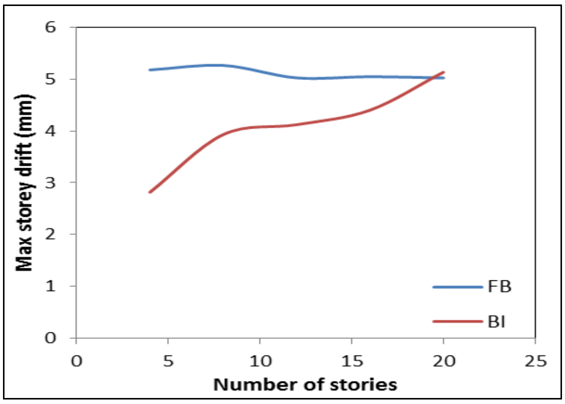


Fig-14: *Comparison of max story drift for fixed base & base isolated structure with varying number of stories*

5.5 Effect of variation of storey height on dynamic response

As seen in fig-15 the modal time period increases with increase in story height making it flexible. Also with decrease in story height considerable increase in base shear is observed in fig- 16. Buildings become laterally flexible as their story height increases as depicted in fig- 17& 18. Hence increasing displacement and drift values are observed with the increase in story height of the structure.

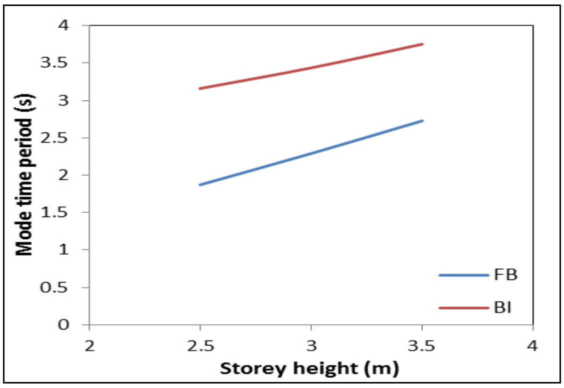


Fig-15*: Comparison of modal time period for fixed base & base isolated structures with varying storey height*

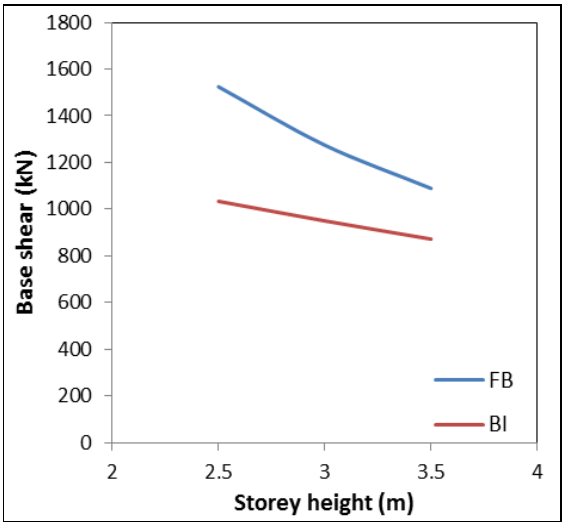


Fig-16*: Comparison of base shear for fixed base & base isolated structure with varying storey height*

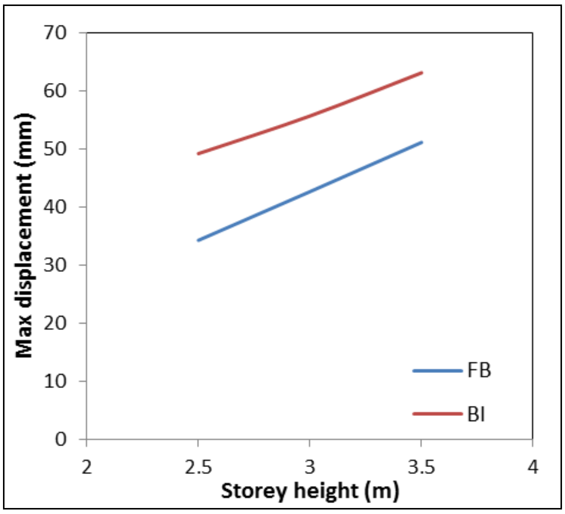


Fig-17*: Comparison of max displacement for fixed base & base isolated structures with varying storey height*

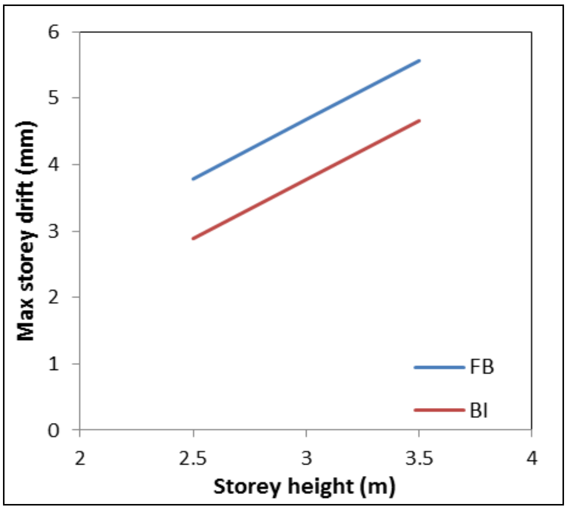


Fig-18*: Comparison of max story drift for fixed base& base isolated structure with varying storey height*

6. Correlations analysis

The correlation value of +1 confirms perfect direct linear relationship (correlation), −1 for perfect decreasing linear relationship (anti-correlation). Values between −1 and +1 in all other cases indicate the degree of linear dependence between the variables. The closer the coefficient is to either −1 or 1, the stronger the correlation between the variables. As it approaches to zero there is less of a relationship (closer to uncorrelated).

Table-5 shows the correlation coefficients of independent geometrical parameters of the fixed base structure with dynamic response quantities. Modal time period and maximum displacement is mostly dependent on number of stories (by 84.7%) of the structures and almost independent of number of bays present (around 2-5%). Variation in bay width and story height has lesser impact on modal time period and maximum displacement values (47% and 22%). Base shear values are strongly correlated to number of bays (>90%). The other parameters such as bay width and number of stories have less influence on base shear of the structure (25% & 10%). Story drift is mainly governed by variation of the bay width values (88%). Number of bays and story height has lesser effect on story drift of a building (12% & 40%). Whereas, the story height and number of stories are inversely correlated to base shear (-15%) and story drift (4.5%) respectively.

***Table-5**: Correlations for fixed base and base isolated structure*

Parameter		Mode-time period	Base shear	Max Displ	Base Displ	Story drift
Bay width	FB	0.4712	0.2566	0.4745	-	0.8868
	BI	0.5666	0.2902	0.4664	0.5873	0.8599
No. of bays	FB	0.0224	0.9282	0.0577	-	0.1221
	BI	0.0972	0.8704	0.0772	0.2929	0.0219
No. of stories	FB	0.8473	0.1081	0.8478	-	-0.0456
	BI	0.8051	0.3453	0.8530	0.7060	0.3446
Story height	FB	0.2284	-0.1557	0.2222	-	0.3982
	BI	0.1309	-0.0751	0.1372	-0.1205	0.2684

Table-6 shows the independent geometrical parameters of the base isolated structure sufficiently represented in a correlation form with dynamic response quantities. Modal time period, base shear and story drift are mostly influenced by number of stories (80%), no of bays (87%) and bay width (86%) of the structure respectively. Modal time period and story drift are less influenced by change in number of bays (9% & 2%). Story height is inversely correlated to base shear (-7.5%). Roof displacement and base displacement are mainly dependent on two parameters - number of stories and bay width (70-85% & 45-60%). Number of bays is almost uncorrelated with maximum displacement at top storey (8%), but it necessarily affects the base displacement (30%). Maximum displacement is directly correlated to story height (14%); whereas the displacement at base is inversely correlated (12%).

7. Conclusions

The parametric study in the present paper offers a relative understanding on the effect of structural configuration on seismic behavior of structures. Correlation coefficients and multiple linear regression equations derived from the models show good relationship between geometrical parameters of the structure and response variables from dynamic analysis. The conclusions that are drawn from the present work are as follows

- Base isolated structure can be conveniently analyzed using ETABS to obtain the dynamic response of a structure. Base isolation proved to be a reliable method of earthquake resistant design. Time period and story displacement of the structure are increased using a suitable base isolation system in comparison to the fixed base structure. Base shear and story drift are also considerably reduced.
- Configuration of building is critical to good seismic performance. Correlation technique adopted shows the sensitivity of each geometrical parameter on the dynamic response of the structure.
- For fixed base structures modal time period and maximum displacement mostly depend on number of stories. Base shear values are strongly correlated to number of bays. Story drift is mainly governed by variation in bay width.
- In case of base isolated structure modal time period, base shear and story drift are mostly influenced by number of bays, number of stories and bay width respectively. Roof displacement and base displacement are mainly dependent on two parameters - number of stories and bay width.

8. Limitations

The correlation coefficients derived in the present paper are applicable for buildings with:-

- symmetrical configurations with same dimensions along both axes
- constant bay width condition throughout the plan
- maximum limit of 20 stories
- the cases of 2x2 to 6x6 bays only
- located in seismic zone V and soil type II.

Acknowledgement

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References

[1] Ang A H S & Tang W H "Probability Concepts in Engineering Planning and Design, Volume-1: Basic Principles" John Wiley & Sons, Inc., New York, 1975

[2] Ang A H S & Tang W H "Probability concepts in engineering planning and design, Volume-II: Decision, risk and reliability" John Wiley & Sons, Inc., New York, 1984

[3] Charleson A W & Allaf N J (2012) "Cost of Base-isolation and Earthquake insurance in New Zealand" *New Zealand Society for Earthquake Engineering (*NZSEE) Conference, Paper no.-41

[4] Huang D M, Ren W X & Mao Y (2013) "Modified complex mode superposition design response spectrum method and parameters optimization for linear seismic base-isolation structures" Techno Press-Earthquake and structures, Vol-4, PP: 341-363

[5] IS: 456 (2000) "Indian Standard for Plain and reinforced concrete – Code of Practice" Fourth revision, Bureau of Indian Standards, New Delhi

[6] IS: 1893 (2002) "Indian Standard code of practice for criteria for Earthquake resistant design of structures, Part-1: General provisions and buildings" Bureau of Indian Standards, New Delhi

[7] Kabeer S A & Kumar K S (2014) "Comparison of Two Similar Buildings with and without Base Isolation" International Journal of Advance research Ideas and Innovations in technology, Volume-1, Issue-1

[8] Kelly J M (1997) "Earthquake-resistant design with rubber" 2nd edition, London: Springer-Verlag.

[9] Kelly T E (2001) "Base isolation of Structures - Design guidelines" Holmes Consulting Group Ltd

[10] Monfared H, Shirvani A & Nwaubani S (2013) "An investigation into the seismic base isolation from practical perspective" International Journal of Civil and Structural Engineering, Vol-3, Issue-3

[11] Murty C V R, Goswami R, Vijayanarayanan A R & Mehta V V (2012) "Some Concepts in -Earthquake Behaviour of Buildings" Gujarat State Disaster Management Authority, Government of Gujarat

[12] Ribakov Y & Iskhakov I (2008) "Experimental Methods for Selecting Base Isolation Parameters for Public Buildings" The Open Construction and Building Technology Journal, 2008, 2, 1-61

[13] Thakare P P & Jaiswal O R (2011) "Comparative Study of Fixed Base and Base Isolated Building using Seismic Analysis" International Journal of Earth Sciences and Engineering

[14] Torunbalci N & Ozpalanlar G (2008) "Earthquake response analysis of mid-story buildings isolated with various seismic isolation techniques" The 14th World Conference on Earthquake Engineering, October 12-17, 2008, Beijing, China