EFFECTIVENESS OF BASE ISOLATION IN MULTISTORY BUILDING FOR DIFFERENT SOIL CONDITIONS USING ETABS

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Abstract— The estimation of earthquake motions at the site of a structure is the most important phase of seismic design as well as retrofit of a structure. In classical methods used in structural analysis, it is assumed that, the motion in the foundation level of structure is equal to ground free field motion. This assumption is correct only for the structures resting on rock or very stiff soils. For the structures constructed on soft soils, foundation motion is usually different from the free field motion and a rocking component caused by the support flexibility on horizontal motion of foundation has been added. The phrase soil-structure interaction may be defined as influence of the behavior of soil immediately beneath and around the foundation on the response of soil-structure subjected to either static or dynamic loads.

A foundation is a means by which superstructure interfaces with underlying soil or rock. Under static conditions, generally only vertical loads of structure need to be transfer to supporting rock. In seismic environment, the loads imposed on a foundation from a structure under seismic excitation can greatly exceed the static vertical loads as even produce uplift; in addition, there will be horizontal forces and possibly movement at foundation level. The soil and rock at site have specific characteristics that can significantly amplify the incoming earthquake motions travelling from the earthquake source

Index Terms— Elastic Methods of Analysis, Qualitative method, Analytical method, Seismic zone ETABS, SAP Software

I. INTRODUCTION

1.1 General

High-rise buildings can be classified as residential or commercial. Now days, more and more complex high-rise buildings with various architectural feature and style are appearing. The degree of high-rise buildings indicates the economics and technological strength of a country. Most of the cities are dominated by high-rise building because of the growth of economy and population density. The influence of its tallness creates different conditions and difficulties in design, construction and operation. Therefore, a proper understanding of methods and techniques is required of the planning, design, construction and operation.

High-rise buildings should be designed to have a capacity to carry combined actions include permanent actions, variable actions and seismic actions at certain safety level and at certain degree of reliability. Therefore, proper account of actions, material properties, structural systems and method of analysis should be considered while designing the high-rise buildings. Nonlinear static analysis, or pushover analysis, has been developed over the past twenty years and has become the preferred analysis procedure for design and seismic performance evaluation purposes as the procedure is relatively simple and considers post elastic behavior. However, the procedure involves certain approximations and simplifications that some amount of variation is always expected to exist in seismic demand prediction of pushover analysis.

1.2 Push over Analysis

As the name states "Push - over", push the building until you reach its maximum capacity to deform. It helps in understanding the deformation and cracking of a structure in case of earthquake and gives you a kind of fair understanding of the deformation of building and formation of plastic hinges in the structure. It is a sort of approximate tool to understand your building performance.

The pushover analysis of a structure is a static non-linear analysis under permanent vertical loads and gradually increasing lateral loads. A plot of the total base shear verses top displacement in a structure is obtained by this analysis that would indicate any premature failure or weakness. The analysis is carried out up to failure, thus it enables determination of collapse load and ductility capacity.

1.3 Soil Structure Interaction

Most previous studies assume a fixed support between the structure and the soil and that neither the structure nor the soils affect one another. However, in reality, the soil and structure move independently of each other. An analysis should consider SSI, particularly in the construction of heavy and rigid structures. Soil environments may have undesired behavioral effects on structures, depending on the properties of the seismic waves. Therefore, the properties of the soil on which the structure is built are of great importance.

In a system exposed to a dynamic load, damping ratio (C) and stiffness (K) are the two main parameters that affect the displacement of the system. Thus, in the SSI analysis, modeling should take into account not only the elasticity module, Poisson ratio, density and shear wave velocity of the soil but also the damping ratio and stiffness values. Including these parameters is important when selecting the mathematical model to be used for the analysis. The studies conducted to date have attempted to simplify the properties of the soil, which is regarded as an unlimited environment, by idealized methods. Determining the dynamic properties of the soil-structure for a common system by analytical methods is not easy. Such properties can be analyzed using numerical methods (Kramer 2003).

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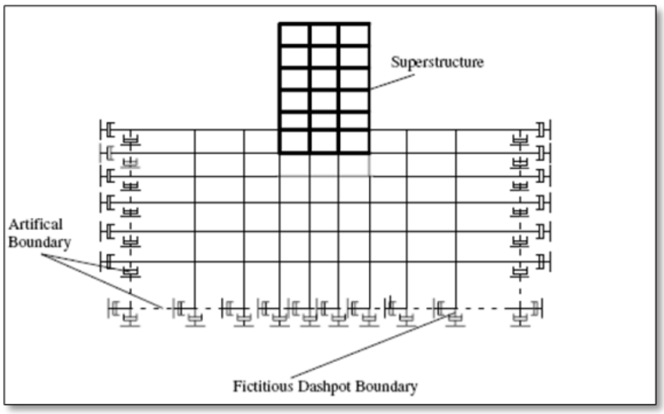


Figure 1.1 Direct method for SSI analysis

1.4 Modeling

The superstructure model used in the scope of the present study is a plane, three-spacing, 15-story, reinforced concrete frame that is 12 m in width and 45 m in height (Fig. 4). All of the beams are 30 × 50 cm and all of the columns are 40 × 40 cm in size. By changing the lateral stiffness characteristics of the HDRBs, three different base-isolated structure models are developed. The behaviors of these models are compared with the behaviors of the “without isolator” model.

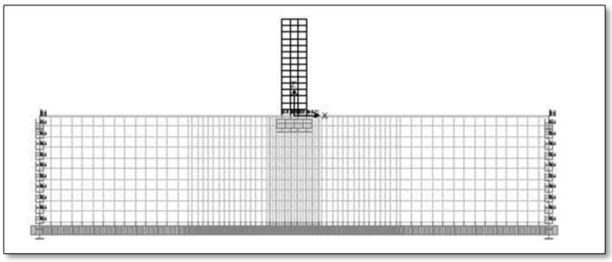


Figure 1.2 Base isolation model developed when considering SSI

1.5 **Base Isolation**

A system attached at base of a structure that controls the longitudinal and lateral movements of the structure is called Base Isolation.

1.5.1 Base Isolation Devices

Bearings are designed to transmit the vertical load and to dissipate energy through friction, viscous damping or hysteretic damping. Usually they are also intended to reduce or control the horizontal force and displacement demand.

A. Low and High Damping Laminated Rubber Bearings

In laminated rubber bearings, steel plates are inserted in a vulcanized piece of rubber to confine the rubber laterally and reduce its tendency to bulge, as shown in Figure. Hence, shims increase the vertical stiffness and improve stability under horizontal forces. This type of bearing shows a substantially linear response and the rubber

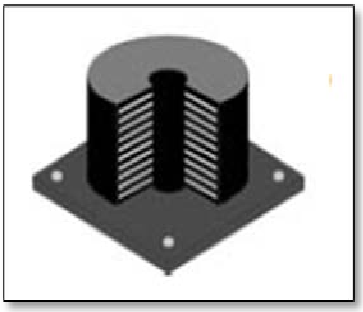


Figure 1.3 Laminated rubber bearing structure

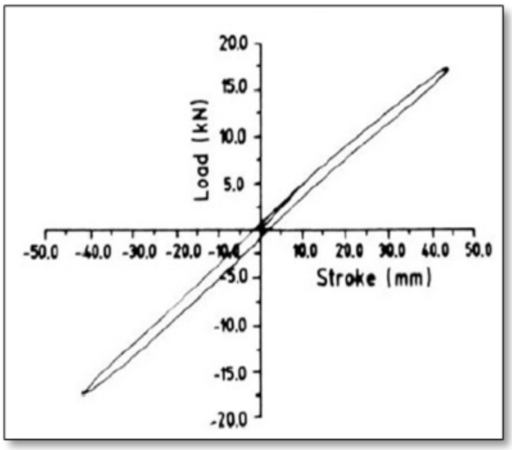


Figure 1.4 Laminated low damping rubber bearing (LDRB) force-displacement relation

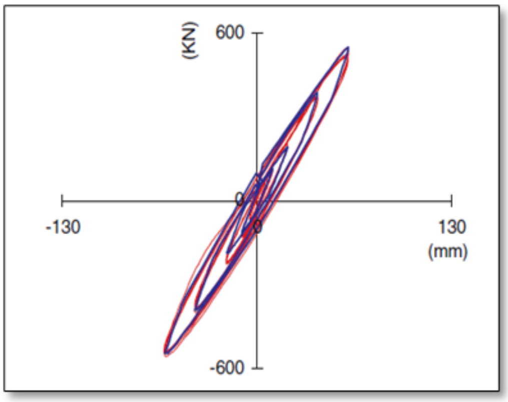


Figure 1.5 Laminated high damping rubber bearing (HDRB) force-displacement relation

1.6 Objective

1. To study the literature available regarding Soil Structure Interaction (SSI), base isolation and understanding the effect of both on structural performance.
2. To study the structure without considering SSI.
3. To study the structure with considering SSI.
4. To study the performance of base isolated structure considering Soil Structure Interaction.
5. To highlight the effect of SSI on base isolated system.

II. THEORETICAL FORMULATIONS

2.1 Preliminary Remark

As India is developing country, the population has increasing rapidly. As population increases the rise for building the structures also increases. Nowadays, the heavy and tall structures are developed in small areas due to unavailability of space. Therefore, to overcome such situations, structures of more height than previous one are taken for further study. Accordingly, different types of bracings are provided to this structure to know the behavior of building.

The projects aim at comparative study on analysis of High rise structure using Pushover analysis. Analysis is done for high rise buildings as G+2, G+6, G+10 structures. All the three structures are provided with different soil conditions:

Hard Strata

Medium Strata

Soft Strata

2.2 Methods of Analysis

Several analysis methods, both elastic and inelastic, are available to predict the seismic performance of the structures.

2.2.1 Elastic Methods of Analysis

Seismic engineering is a sub discipline of the broader category of structural engineering. Its main objectives therefore are:

To understand interaction of structures with the shaky ground.

The methodologies available so for the evaluation of existing buildings can be divided into two categories-

(1) Qualitative method

(2) Analytical method

Structural analysis methods can be divided into the following categories as below:

Equivalent Static Analysis

Response Spectrum Analysis

Time-History Method

Linear Dynamic Method

2.2.1.1 Static Analysis of Buildings Using Is 1893 (Part 1)-2002

As per IS 1893 (part1)-2002, Seismic

Coefficient analysis Procedure is summarized in following steps

2.2.1.1.1 Design Base Shear

Design Seismic Base Shear- The total design lateral force or design seismic base shear (Vb) along any principal direction of the building shall be determined by the following expression VB= Ah W, Whereas= design horizontal seismic coefficient for the structure, and may be calculated using, (Z⁄2)*(I/R)*(Sa/g) 3.2.1.1.2 Seismic Weight of Building

2.2.1.1.3 Zone Factor

Here, Z is the “Zone Factor”. This is a factor used to obtain a design spectrum depending on the perceived maximum risk characterized by maximum considered earthquake (MCE) in the zone in which structure is located. Seismic zoning assesses the maximum severity of ground shaking that is anticipated in a particular region. The zone factor (Z), thus defined as a factor to obtain the design spectrum depending on the perceived seismic hazard in the zone in which the structure is located. The basis zone factors included in the code are reasonable estimate of effective peak ground acceleration. Zone factors as per IS 1893: 2002 (Part 1) are given in table 1.Z can also be determined from the seismic zone map of India, which is shown in figure 1 of IS 1893 (Part 1):2002[1]

Seismic zone	II	III	IV	V
Seismic intensity	Low	Moderate	severe	Very severe
Zone factor	0.10	0.16	0.24	0.36

Table 2.1 Zone factor

2.2.1.1.4 Importance Factor

I is the “Importance Factor”. The importance factors shown in Table are the factors used to obtain the design seismic force depending upon the functional use of the structure

The minimum values of I are given in Table 6 of IS 1893 (Part 1):2002.[1]

Structure	Importance Factor
Important service and community buildings, which as hospitals, schools; monumental structure; emergency building like telephone exchange, television stations, radio stations, railway stations, fire stations, buildings; large community halls like cinemas, assembly halls; and subway stations, power stations.	1.5
All other buildings	1.0

Table 2.2 Importance factor

2.2.1.1.5 Response Reduction Factor

The term R is “Reduction Factor”. This is the factor by which actual base shear force, which is generated if the structure were to remain elastic during its response to the design basis earthquake shaking, shall be reduced to obtain the designed lateral force. Response reduction factor for building system are given below in table as per IS 1893: 2002 (Part 1). In general, the response reduction factor depends on the perceived performance of the structure during seismic activity characterized by either ductile or brittle failure. The value of R is given in Table 7 of IS 1893 (Part 1):2002. [1]

Lateral load resisting system	Response reduction factor(R)
Ordinary RCC moment resisting frame (OMRF)	3.0
Special moment resisting frame (SMRF)	5.0

Table 2.3 Response reduction factor

The fundamental natural period is the first (Longest) model time period of vibration of the structure. Because the design loading depends on the building period, and the building period cannot be calculated until a design has been prepared, IS 1893 (Part 1): 2002 provides formulas from which T may be calculated for a moment resisting building without brick infill panels, Ta may be estimated by the empirical expression.

T = 0.075hˆ0.75 for RC frame building, For all other buildings including moment resisting frame building with brick infill panels, Ta may be estimated by the empirical expression ,T =0.09h/√d, Where h is height of building in meters (this includes the basement stories, where basement walls are connected with the ground floor deck or fitted between the building columns. But in includes the basement stories, when they are not so connected) and d is the base dimension of the building at the plinth level in meter, along the considered direction of the lateral force.

2.2.1.1.7 Response Acceleration Coefficient

Sa/g = Average response acceleration coefficient (Dimensionless Value). It is a factor denoting the acceleration response spectrum of the structure subjected to earthquake ground vibrations, and depends on natural period of vibration and damping of the structure. For R.C.C. structures, 5% damping three different curves are recommended in IS 1893: 2002 for different stiffness of supporting media – rock, medium soil and soft soil. The classification of soil is based on average shear wave velocity for top 30 m of rock/soil layers or based on average Standard Penetration Test (SPT) values for top 30m (Table 1, IS 1893: 2002)

Class I – Rock or Hard soil: Well graded gravel and sand gravel mixture with or without clay binder having corrected Standard Penetration Value N > 30

Class II – Medium soil: All soils with N between 10 and 30 or gravelly sand with little or no fines (classified SP) with N > 15

Class III – Soft soil: All soils other than SP with N< 10.

2.2.1.1.8 Design Force

Distribution of Design Force- The design base shear, VB computed above shall be distributed along the height of the building as per the following expression:

$$Q_i = V_B \frac{W_i h_i^2}{\sum_{j=1}^{n} W_j h_j^2}$$

Qpi = Lateral loads as per IS: 1893 – 2002 and ATC – 40 at each floor level

W = Total seismic weight the structure

Wi = Seismic weight floor of i hi = High of floor measured from base

n = is the number of leaves at which the masses are lumped

2.2.2 Inelastic Methods of Analysis

Structures suffer significant inelastic deformation under a strong earthquake and dynamic characteristics of the structure change with time so investigating the performance of a structure requires inelastic analytical procedures accounting for these features. Inelastic analytical procedures help to understand the actual behaviour of structures by identifying failure modes and the potential for progressive collapse. Inelastic analysis procedures basically include inelastic time history analysis and inelastic static analysis which is also known as pushover analysis.

2.3 Non-Linear Static Pushover Analysis

The model frame used in the static nonlinear pushover analysis is based on the procedures of the material, defining force – deformation criteria for the hinges used in the pushover analysis. Fig.1 describes the typical force-deformation relation proposed by those documents. Five points labeled A, B, C, D and E are used to define the force deflection behavior of the hinge and these points labeled A to B – Elastic state, B to IO- below immediate occupancy, IO to LS – between immediate occupancy and life safety, LS to CP between life safety to collapse prevention, CP to C – between collapse prevention and ultimate capacity, C to D- between C and residual strength, D to E- between D and collapse >E – collapse.

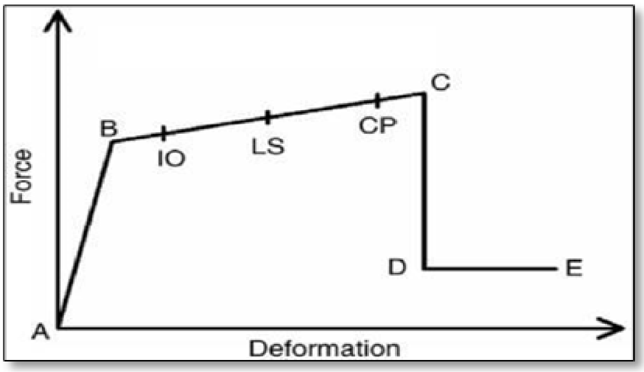


Figure 2.1 Deformation vs Force graph

2.3.1 Procedure of Nonlinear Static Pushover Analysis

The following general sequence of steps is involved in a nonlinear static pushover analysis:

Create a model.

Define arbitrary static load cases, if needed, for use in the pushover analysis. Note that the program also has built-in capability to define the distribution of lateral load over the height of the structure based on both uniform acceleration and mode shapes.

2.3.2 Load Cases

A load case defines how load patterns are applied, how the structure responds, and how analysis is performed (through modal analysis, direct integration, etc.). For each analysis to be performed, a load case is defined. Each load case may apply a single load pattern or a combination of load patterns. An unlimited number of load cases may be defined, then any set of load cases may be selected for analysis. Once analysis has run, load-case results may be selectively deleted or compiled for output reports.

Specifications for each load case include:

Case name – A unique name is applied to each individual load case to index analysis results (displacements, stresses, etc.), create load combinations, and possibly correlate with dependent load cases.

Applied loading – Load patterns are applied to the structure. In some instances, however, load patterns are not applicable.

Analysis type – Analysis type includes the method (static, response spectrum, buckling, etc.) and the formulation (linear, nonlinear, etc.).

2.3.3 Pushover Load Case

A pushover analysis can consist of more than one pushover load case. Each pushover load case can have a different distribution of load on the structure. For example, a typical pushover analysis might consist of three pushover load cases. The first would apply gravity load to the structure, the second would apply one distribution of lateral load over the height of the structure, and the third would apply another distribution of lateral load over the height of the structure.

2.3.4 Hinge Properties

Three kinds of hinge properties are available in ETABS:

Auto Hinge Properties.

Auto hinge properties are defined by the program. The program cannot fully define the auto properties until the section to which they apply has been identified. Thus, the auto property is assigned to a frame or wall object, and the resulting hinge property can then be reviewed.

User-Defined Hinge Properties.

User-defined hinge properties can be based on auto properties or they can be fully user defined.

Program Generated Hinge Properties.

The generated hinge properties are used in the analysis. They can be viewed, but they cannot be modified. Generated hinge properties have an automatic naming convention of Label, where Label is the frame or wall object label, H stands for hinge, and # represents the hinge number. The program starts with hinge number 1 and increments the hinge number by one for each consecutive hinge applied to the frame or wall object. For example, if a frame object label is F23, the generated hinge property name for the second hinge applied to the frame object is F23H2.

The main reason for the differentiation between defined properties (in this context, defined means both auto and user-defined) and generated properties is that typically the hinge properties are section dependent. Thus, it is necessary to define a different set of hinge properties for each frame or wall section type in the model. This could potentially mean that you would need to define a very large number of hinge properties. To simplify this process, the concept of generated properties is used in ETABS. When generated properties are used, the program combines its built-in criteria with the defined section properties for each object to generate the final hinge properties. The net effect of this is that you do significantly less work defining the hinge properties because you do not need to define every hinge. The nonlinear behavior occurs in discrete user-defined hinges. Hinges can be introduced into both frame and vertical wall objects. Hinges may be assigned at any location along the frame object, but are restricted to mid-height in the wall object.

2.4 Necessity of Pushover Analysis

The existing building can become seismically deficient since seismic design code requirements are constantly upgraded and advancement in engineering knowledge. Further, Indian buildings built over past two decades are seismically deficient because of lack of awareness regarding seismic behavior of structures. The widespread damage especially to RC buildings during earthquakes exposed the construction practices being adopted around the world, and generated a great demand for seismic evaluation and retrofitting of existing building stocks.

2.5 Limitations of Pushover Analysis

Although pushover analysis has advantages over elastic analysis procedures, underlying assumptions, the accuracy of pushover predictions and limitations of current pushover procedures must be identified. The estimate of target displacement, selection of lateral load patterns and identification of failure mechanisms due to higher modes of vibration are important issues that affect the accuracy of pushover results. Target displacement is the global displacement expected in a design earthquake. The roof displacement at mass center of the structure is used as target displacement.

2.6 Purpose of Doing Pushover Analysis

The purpose of pushover analysis is to evaluate the expected performance of structural systems by estimating its strength and deformation demands in design earthquakes by means of static inelastic analysis, and comparing these demands to available capacities at the performance levels of interest. The evaluation is based on an assessment of important performance parameters, including global drift, inter-story drift, inelastic element deformations (either absolute or normalized with respect to a yield value), deformations between elements, and element connection forces (for elements and connections that cannot sustain inelastic deformations), The inelastic static pushover analysis can be viewed as a method for predicting seismic force and deformation demands, which accounts in an approximate manner for the redistribution of internal forces that no longer can be resisted within the elastic range of structural behaviour.

2.7 Analysis of Frame Using ETab Software

Frame has been analyzed using ETABS software referring IS: 456-2000, IS 1893(Part-I) 2002.

Following are the advantages of ETABS software:

Easy to use interface.

Conformation with the Indian Standard Codes.

Versatile nature of solving any type of problem.

Accuracy of the solution.

Require less time than other software’s.

ETABS features a state-of-the art user interface, visualization tools, powerful analysis and design engines with advanced finite element and dynamic analysis.

III. PARAMETRIC INVESTIGATION

3.1 Preliminary Remark

So as to control the effect of earthquake on building the base isolation technique is one of the best solutions. Seismic isolation consists of essentially the installation of mechanisms such as isolators which decouple the structure from base. The seismic isolation system is mounted beneath the structure and is referred as ‘Base Isolation’. The idea of separating the superstructure from the substructure has dependably been an elegant thought in principle, yet just as of late has it turn into a suitable solution. The objective is to have flexible material in the horizontal plane that is equipped for anticipating vitality stream into the superstructure. This flexibility expands the superstructure's period, which, thus, lessens the induced acceleration.

In case of RCC multistoried buildings are more suspect able to dynamic vibrations. By providing base isolation in multistoried building (3 storey, 7 storey and 11 storey) the following parameters are analyzed in both directions.

Base Shear

Displacement

Peak Story value

Story Drift

3.2 Problem Validation

Problem Statement: -Earthquake resistance design of structure adopted from a book by S. K. Duggal.

A plan elevation of three storey RCC school building is shown in fig.4.1 The building is located in seismic zone V. the type of soil encountered is medium stiff and it is proposed to design the building with special moment resisting frame. The intensity of dead load is 10 KN/m2 and the floor is to cater to imposed load of 3 KN/m2. Determine the design seismic loads on the structure by static analysis.

The following results were obtained for analysis on ETABS software.

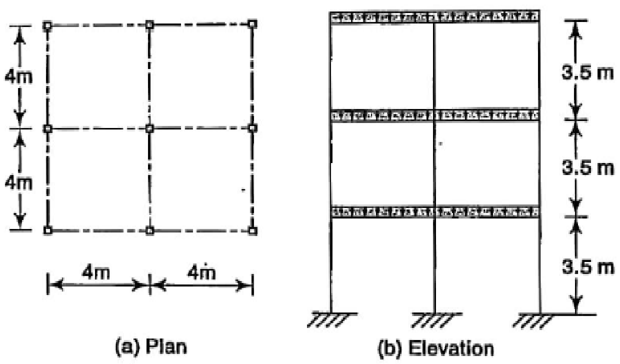


Figure 3.1: Validation Problem Plan and Elevation

Solution: -
Design Parameter: -
For seismic zone V, zone factor, Z=0.36
Importance factor, I=1.5
Response reduction factor R=5
Floor area = 8x8=64m2
For live load up to and including 3KN/ m2
Percentage of live load to be considered=25%
Seismic weight contribution from one floor = 64x (10+ 0.25 x 3) = 688KN
Load from roof = 64 x 10 = 640 KN
Hence, the total seismic weight of the structure = 2 x 688 + 640 = 2016 KN

Result: - As per Earthquake resistance design of structure (S. K. Duggal)

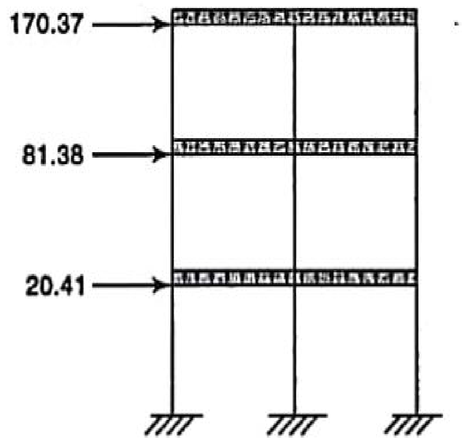


Figure 3.2: Problem Validation Lateral Forces

Storey	Elevation (m)	Location	Base Shear (Theoretically)	Base Shear (Software)
S3	9.9	Top	175.37	175.3958
S2	6.6	Second	86.38	86.4113
S1	3.3	First	25.41	25.3528
S0 (Base)	0	Base	277.16	277.1599

Table 3.1 Storey Response Values Total Base Shear

3.3.1 STRUCTURAL MODELLING

Live Load	4KN/m2
Density of RCC considered:	25KN/ m3
Steel	HYSD 500
Thickness of slab	125mm
Depth of beam	450mm
Width of beam	230mm
Dimension of column	400x500mm
Density of infill	20 kN/ m3
Thickness of outside wall	230mm
Thickness of inner partition wall	150mm
Height of each floor	3m
Height of soft storey (Stiffness irregularity)	4.5m
Unit Weight of wall	15 KN/ m2
Height of swimming pool	1.8 m
Weight of swimming tank (Mass irregularity)	18 KN/ m2
Earthquake Zone	IV
Damping Ratio	5%
Importance factor	1.5
Type of Soil	Rocky
Type of structure	Special Moment Resisting Frame
Response reduction Factor	5
No of floor	18 floor
No of modes	54 – Each floor 3 no of modes
Type of diaphragms	Rigid
Modal combination	SRSS
Type of irregularity	Stiffness, mass & vertical geometry irregularity
Location of soft storey	1st storey
Location of swimming tank	1st storey
Vertical geometry building	Cantilever type building from Is 1893- 2016
P-Delta effect	Non –iterative-Based on mass
Direction of lateral force	Both X and Y direction
Load combination	All load combinations are taken from IS 1893-2016
Type of support at base	Roller (Isolated)

3.3.2 Modeling

3.4 Parametric Formulation

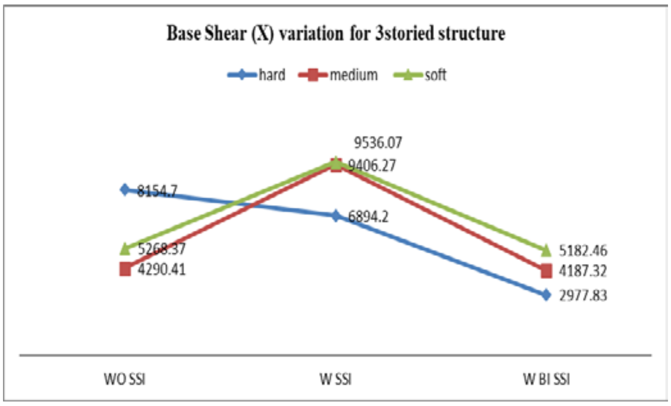
In the following case the (G+3), (G+7) & (G+11) regular buildings are considered with Base Isolation (BI) and Soil Structure Interaction (SSI). All cases are analyzed for hard, medium and soft soil strata. Isolators in structure are provided at base of footing for both longitudinal and lateral displacement. The parameters of base shear, displacement, peak storey and storey drift are obtained for all cases and compared by providing base isolators considering SSI of strata.

Analysis of Base Shear

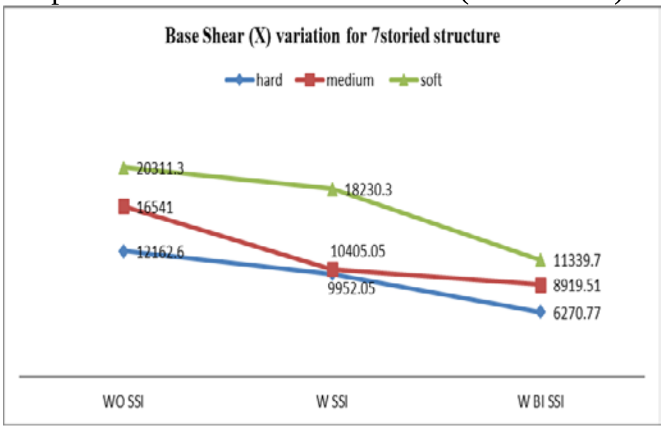
Structural behavior of 3, 7 and 11 storied building provided with base isolators on hard, medium and soft soil strata is analyzed. Observations obtained for base shear in X direction are as follows:

No	Type of Structure	Base Shear in kN					
		3 Storey		7 Storey		11 Storey	
		X	Y	X	Y	X	Y
1	WO SSI(hard soil)	8154.7	6649.01	12162.6	9560.4	17312.9	13831.8
2	WO SSI(medium soil)	4290.41	3602.66	16541	12999.4	23545.7	18811.54
3	WO SSI(soft soil)	5268.37	4423.86	20311.3	15962.5	28912.5	23100.14
4	W SSI(hard soil)	6894.2	5170.55	9952.05	8098.6	15147.4	12437.91
5	W SSI(medium soil)	9406.27	7058.36	10405.0	11389	21343.2	17272.37
6	W SSI(soft soil)	9536.07	8684.18	18230.3	14347.9	26855.5	21386.54
7	W BI SSI(hard soil)	2977.83	2510.79	6270.77	5384.22	10855.9	9283.11
8	W BI SSI(medium soil)	4187.32	3490.73	8919.51	7579.8	18042	12874.64
9	W BI SSI(soft soil)	5182.46	4328.6	11339.7	9557.6	18851.4	16050.75

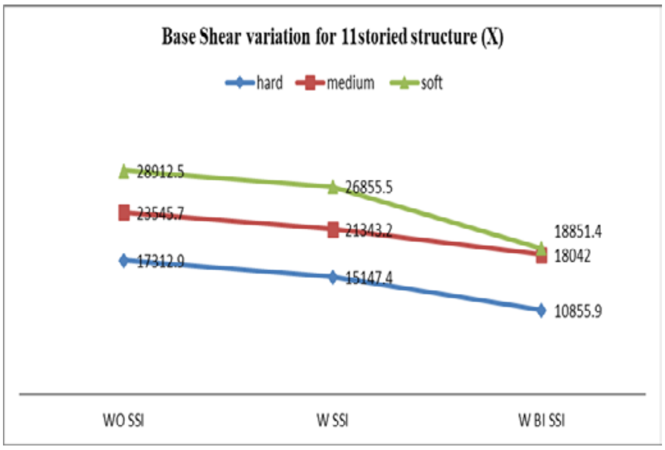
Table 3.2 Variation of Base Shear



Graph 3.1: Variation of Base Shear (X direction)

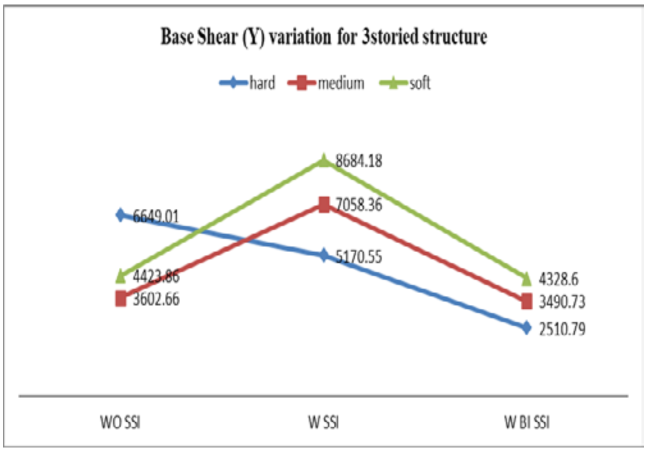


Graph 3.2: Variation of Base Shear (X direction)

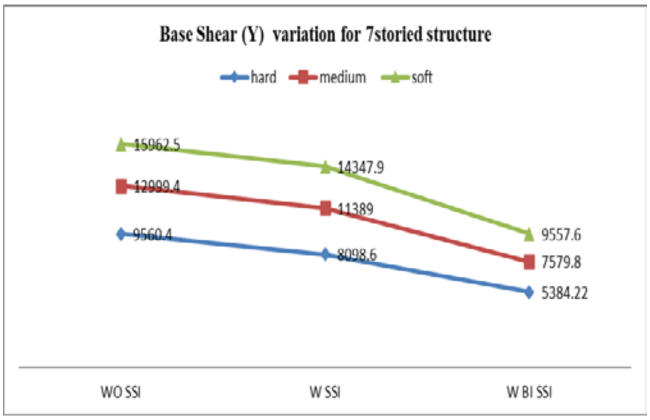


Graph 3.3: Variation of Base Shear (X direction)

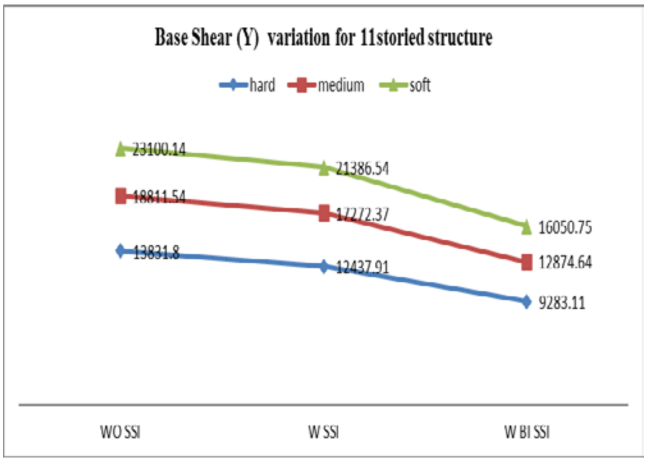
Observations	
For Soil Strata (Hard, Medium & Soft) & Condition (WO SSI, W SSI & W BI SSI)	
1	Base shear intensity is linear except for 3 storied structure
2	Magnitude of base shear is comparatively more in WO BI
3	Variations of base shear decrease linearly.



Graph 3.4: Variation of Base Shear (Y direction)

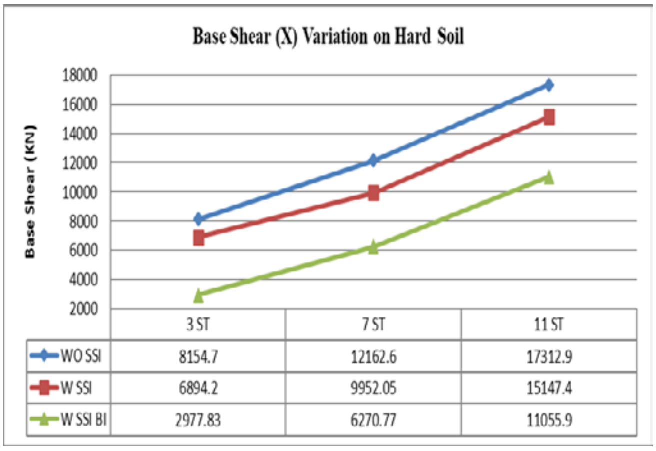


Graph 3.5: Variation of Base Shear (Y direction)

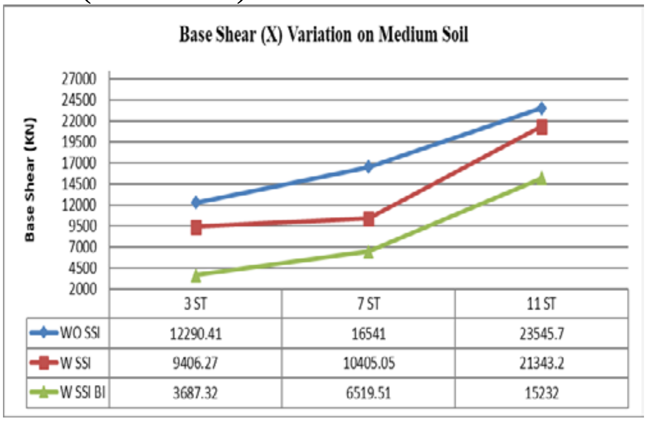


Graph 3.6: Variation of Base Shear (Y direction)

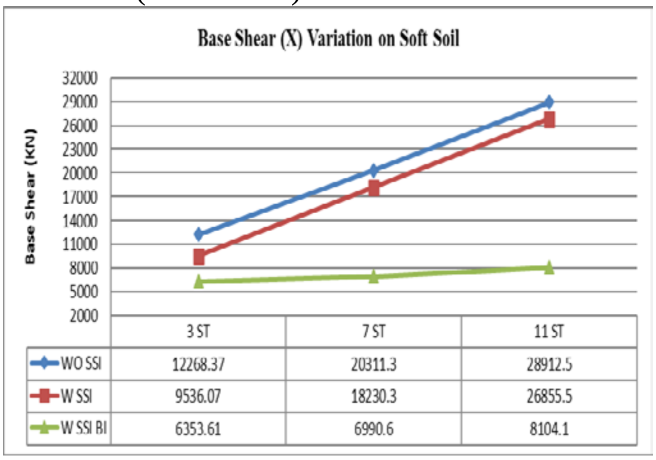
Observations	
For Soil Strata (Hard, Medium & Soft) & Condition (WO SSI, W SSI & W BI SSI)	
1	Base shear intensity is linear except for 3 storied structure
2	Magnitude of base shear is comparatively more in WO BI
3	Variations of base shear decrease linearly.



Graph 3.7: Variation of Base Shear on hard soil strata (X direction)

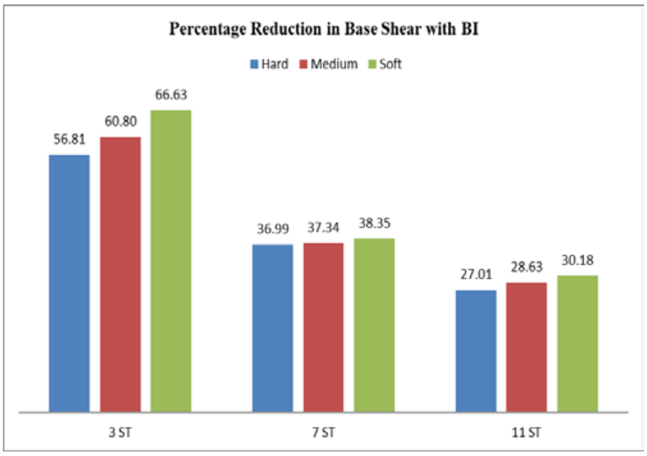


Graph 3.8: Variation of Base Shear on medium soil strata (X direction)



Graph 3.9: Variation of Base Shear on soft soil strata (X direction)

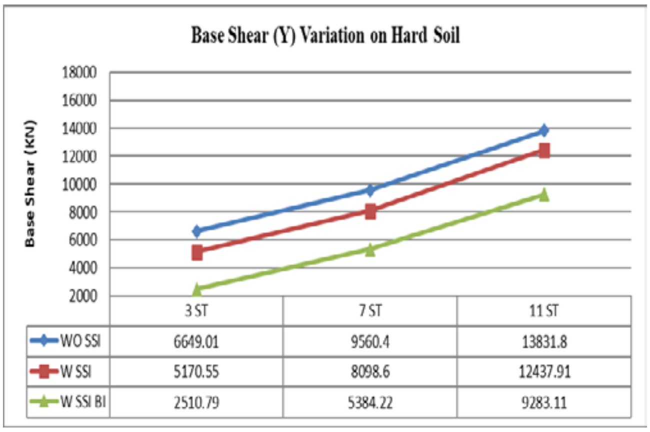
Observations	
For Soil Strata (Hard, Medium & Soft) & No. of Storey (3, 7 & 11)	
1	Base shear intensity is directly proportional to no. of storey
2	Magnitude of base shear is comparatively more is SSI and BI is not considered.
3	Variation of increase in base shear is almost linear in nature.



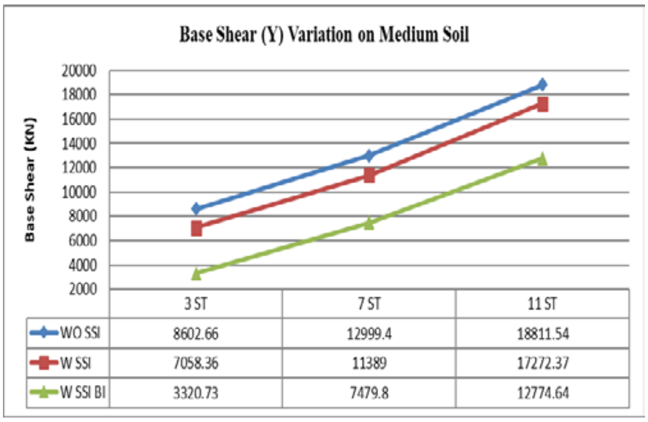
Graph 3.10: Percentage Variation of Base Shear for different soil strata (X direction)

Observations	
For	Soil Strata (Hard, Medium & Soft) & No. of Storey (3, 7 & 11)
1	The reduction in Base shear is maximum on soft strata i.e. almost 66.63 % and 60.80%, 56.81% for medium and hard strata respectively.
2	% reduction in base shear occurs as height of structure increases from 66.63% to 30.18%.
3	On hard soil strata % of base shear varies from 56.81% to 27.01%
4	In 3 storied building % variation in base shear is from 66.63% to 56.81%, 38.35% to 36.99%, 30.18% to 27.01% in 7 and 11 storied structure respectively.

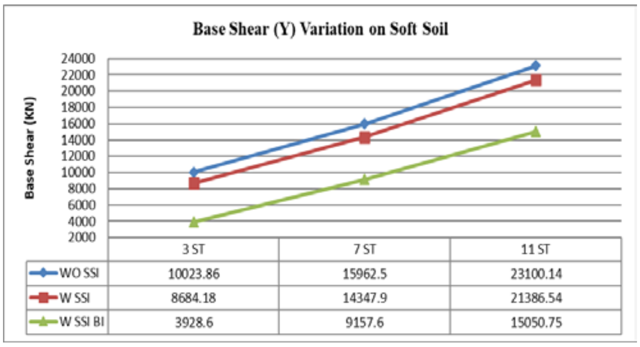
Structural behavior of 3, 7 and 11 storied building provided with base isolators on hard, medium and soft soil strata is analyzed. Observations obtained for base shear in Y direction are as follows:



Graph 3.11: Variation of Base Shear on hard strata (Y direction)

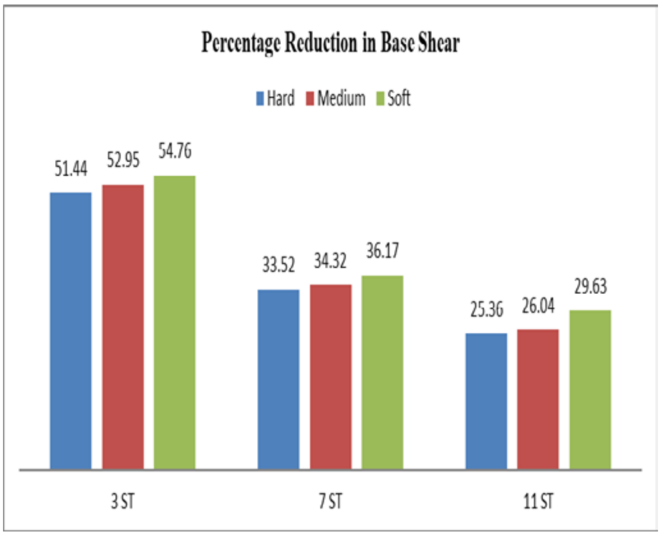


Graph 3.12: Variation of Base Shear on medium soil strata (Y direction)



Graph 3.13: Variation of Base Shear on hard soil strata (Y direction)

Observations	
Soil Strata (Hard, Medium & Soft) & No. of Storey (3, 7 & 11)	
1	Base shear intensity is directly proportional to no. of storey
2	Magnitude of base shear is comparatively more is SSI and BI is not considered.
3	Variation of increase in base shear is almost linear in nature.

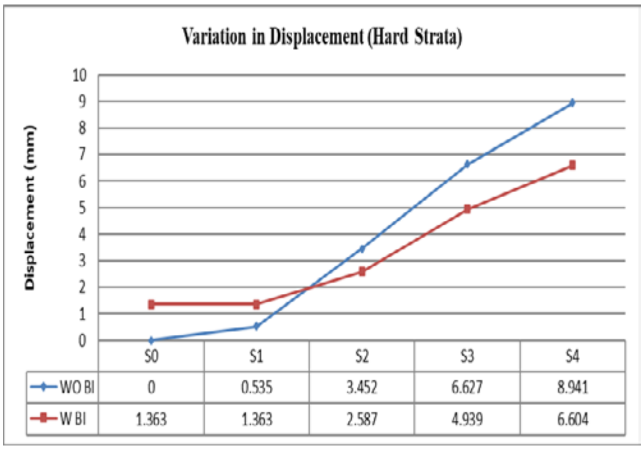


Graph 3.14: Percentage Variation of Base Shear for different soil strata (Y direction)

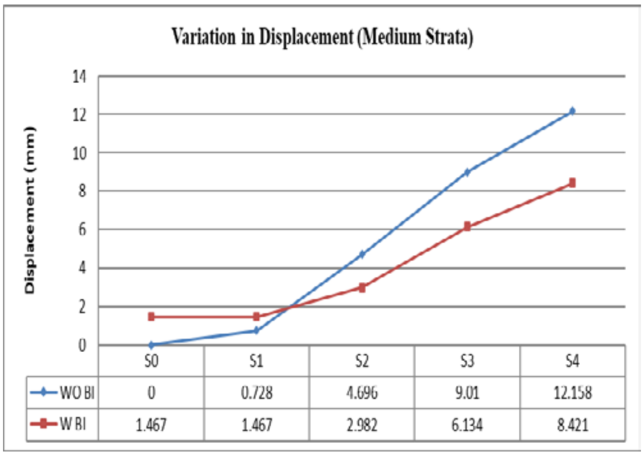
Observations	
For	Soil Strata (Hard, Medium & Soft) & No. of Storey (3, 7 & 11)
1	The reduction in Base shear is maximum on soft strata i.e. almost 54.76 % and 36.13%, 29.63% for medium and hard strata respectively.
2	% reduction in base shear occurs as height of structure increases from 54.76% to 29.63%.
3	On hard soil strata % of base shear varies from 54.76% to 29.63%
4	In 3 storied building % variation in base shear is from 51.44% to 54.76, 33.52% to 36.17%, 25.36% to 29.63% in 7 and 11 storied structure respectively.

Analysis of Deflection

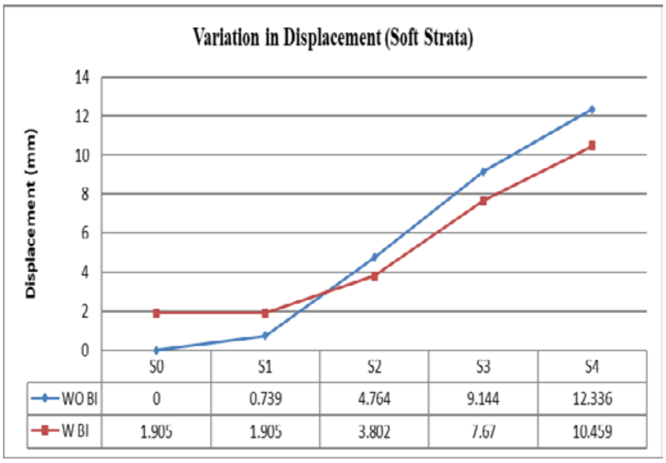
Structural behavior of 3, 7 and 11 storied building provided with base isolators on hard, medium and soft soil strata is analyzed. Observations obtained for deflection in X direction are as follows:



Graph 3.15: Variation of deflection on hard soil strata (X direction)

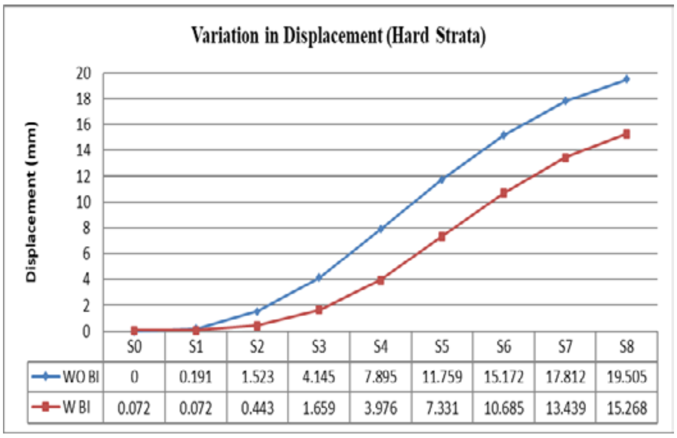


Graph 3.16: Variation of deflection on medium soil strata (X direction)

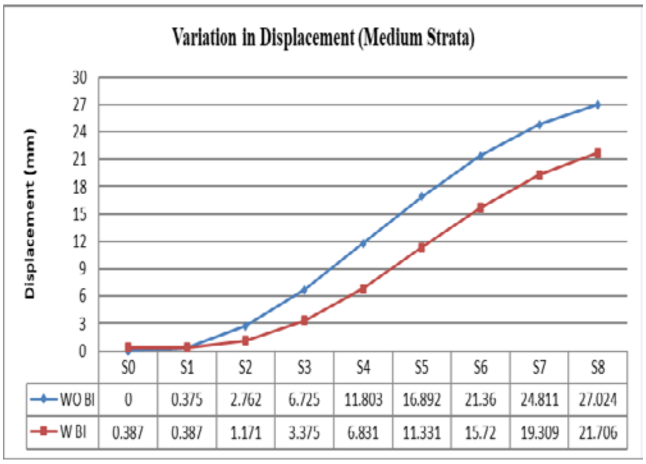


Graph 3.17: Variation of deflection on soft soil strata (X direction)

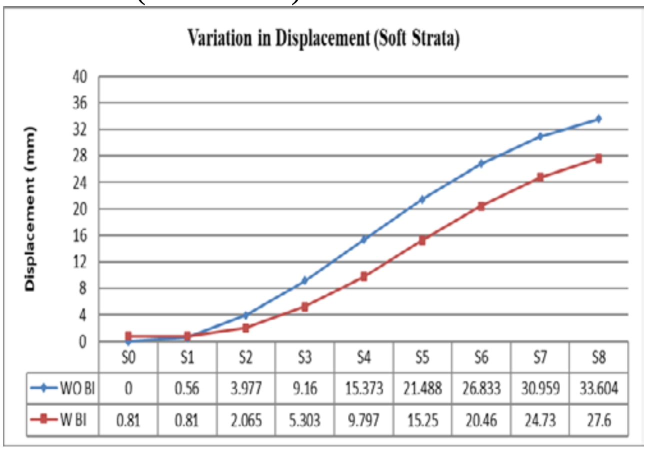
Observations	
For Soil Strata (Hard, Medium & Soft) & No. of Storey (3)	
1	At base of structure provided with isolators gets displaced by 1.905mm and with maximum 10.459mm at top on soft soil.
2	The variation in deflection tends to form parabolic in nature.
3	Both the curves intersect at a point indicating a neutral deflection in between 1st and 2nd slab



Graph 3.18: Variation of deflection on hard soil strata (X direction)

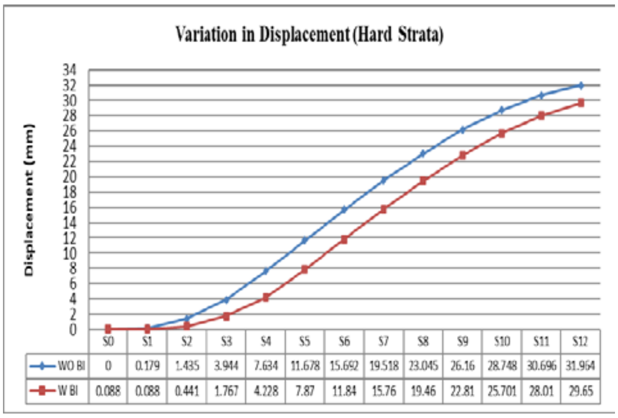


Graph 3.19: Variation of deflection on medium soil strata (X direction)

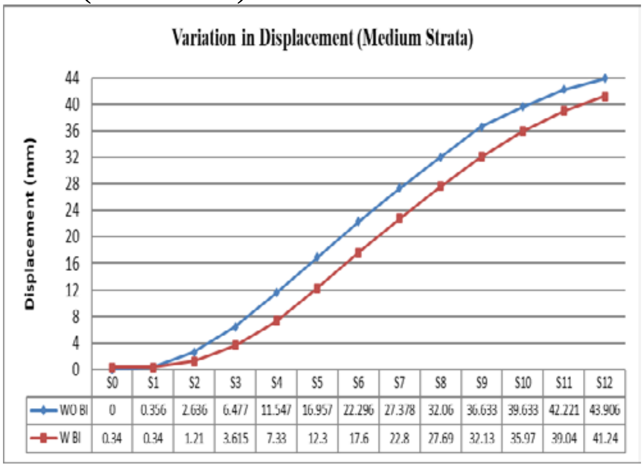


Graph 3.20: Variation of deflection on soft soil strata (X direction)

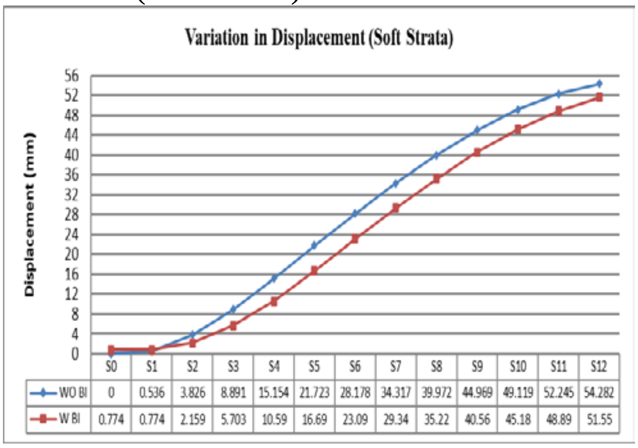
Observations	
For Soil Strata (Hard, Medium & Soft) & No. of Storey (7)	
1	At base of structure provided with isolators gets displaced by 0.81mm and with maximum 27.60 mm at top on soft soil.
2	The variation in deflection form parabolic curve in nature.
3	Both the curves intersect at a point indicating a neutral deflection in between 1st and 2nd slab



Graph 3.21: Variation of deflection on hard soil strata (X direction)

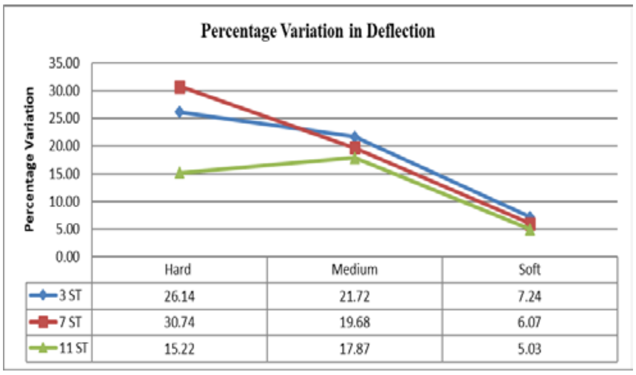


Graph 3.22: Variation of deflection on medium soil strata (X direction)



Graph 3.23: Variation of deflection on soft soil strata (X direction)

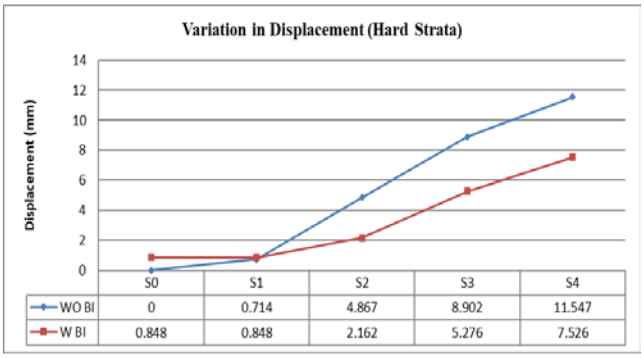
Observations	
For Soil Strata (Hard, Medium & Soft) & No. of Storey (11)	
1	At base of structure provided with isolators gets displaced by 0.77mm and with maximum 51.55 mm at top on soft soil.
2	The variation in deflection form parabolic curve in nature.
3	Both the curves intersect at a point indicating a neutral deflection in between 1st and 2nd slab



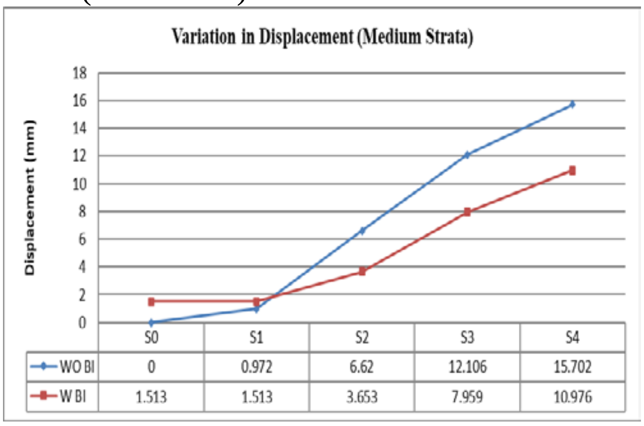
Graph 3.24: Percentage variation of deflection (X direction)

Observations	
For Soil Strata (Hard, Medium & Soft) & No. of Storey (3, 7 & 11)	
1	% reduction in deflection is comparatively more on hard soil strata i.e. 30.74%.
2	Variation of deflection decreases linearly to a minimum of 5.03%
3	As height of building increases % variation in deflection also decreases.

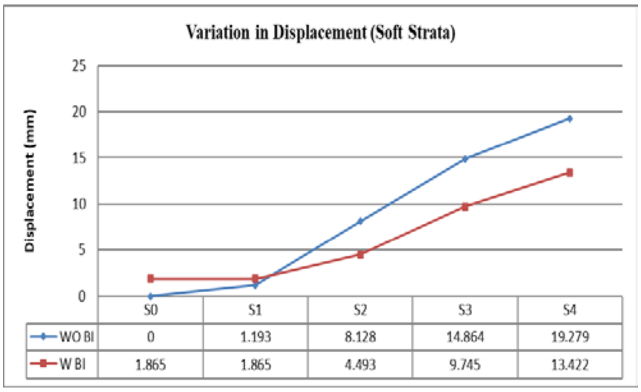
Structural behavior of 3, 7 and 11 storied building provided with base isolators on hard, medium and soft soil strata is analyzed. Observations obtained for deflection in Y direction are as follows:



Graph 3.25: Variation of deflection on hard soil strata (Y direction)

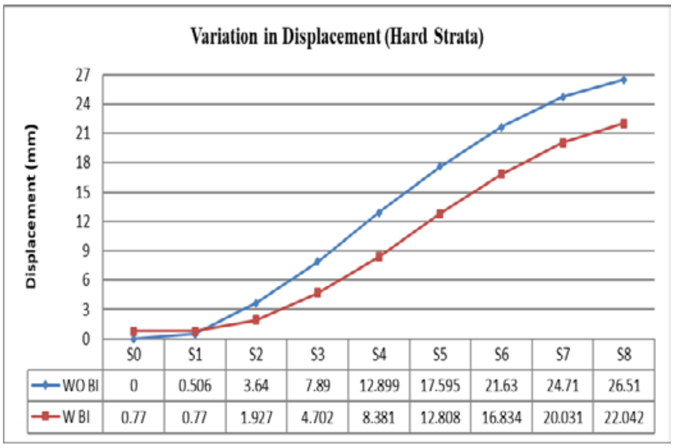


Graph 3.26: Variation of deflection on medium soil strata (Y direction)

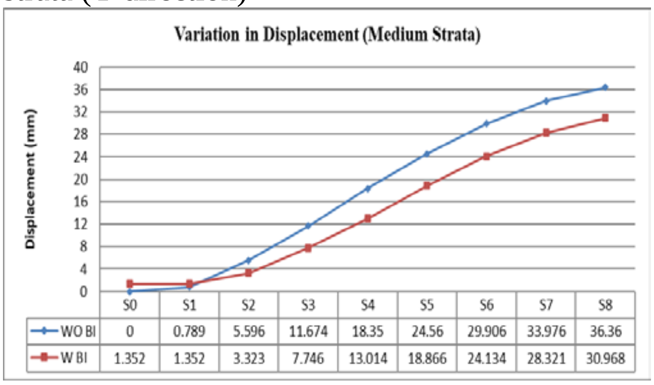


Graph 3.27: Variation of deflection on soft soil strata (Y direction)

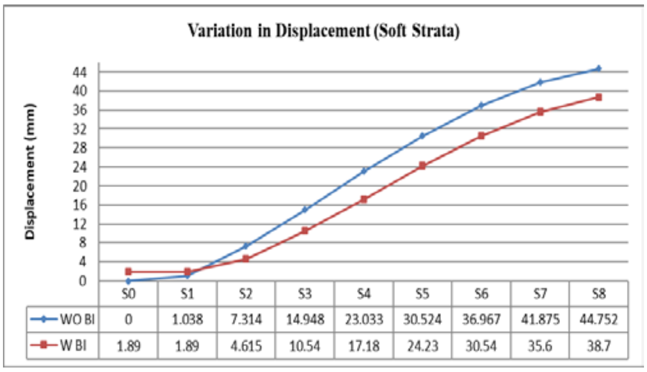
Observations	
For Soil Strata (Hard, Medium & Soft) & No. of Storey (3)	
1	At base of structure provided with isolators gets displaced by 1.865mm and with maximum 13.422mm at top on soft soil.
2	The variation in deflection tends to form parabolic in nature.
3	Both the curves intersect at a point indicating a neutral deflection in between 1st and 2nd slab



Graph 3.28: Variation of deflection on hard soil strata (Y direction)

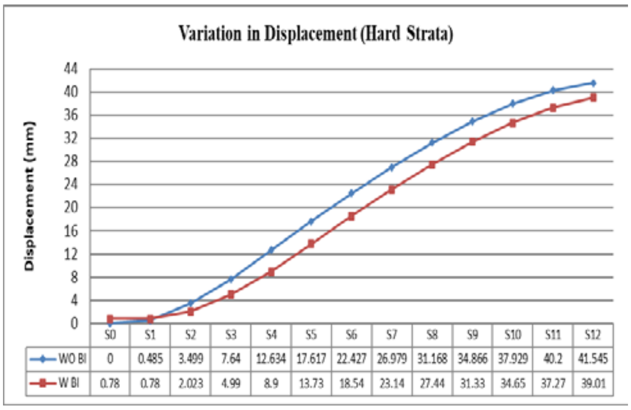


Graph 3.29: Variation of deflection on medium soil strata (Y direction)

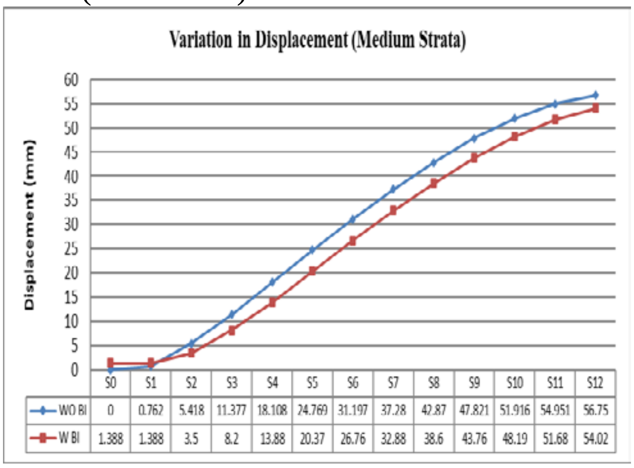


Graph 3.30: Variation of deflection on soft soil strata (Y direction)

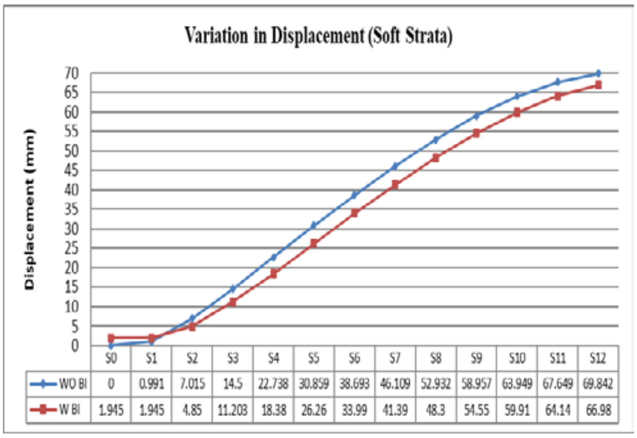
Observations	
For Soil Strata (Hard, Medium & Soft) & No. of Storey (7)	
1	At base of structure provided with isolators gets displaced by 1.89mm and with maximum 38.70 mm at top on soft soil.
2	The variation in deflection form parabolic curve in nature.
3	Both the curves intersect at a point indicating a neutral deflection in between 1st and 2nd slab



Graph 3.31: Variation of deflection on hard soil strata (Y direction)

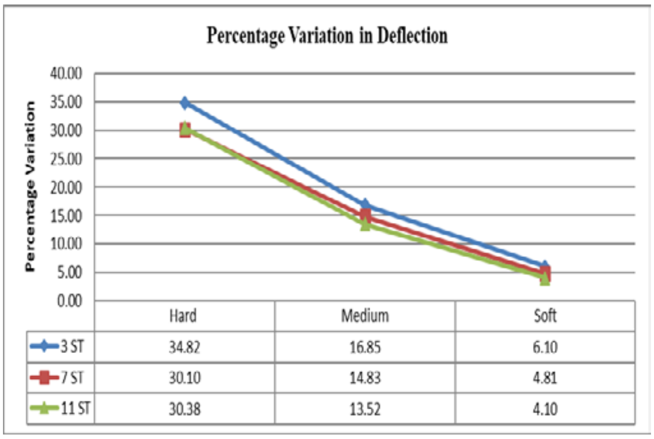


Graph 3.32: Variation of deflection on medium soil strata (Y direction)



Graph 3.33: Variation of deflection on soft soil strata (Y direction)

Observations	
For Soil Strata (Hard, Medium & Soft) & No. of Storey (11)	
1	At base of structure provided with isolators gets displaced by 1.945mm and with maximum 66.98 mm at top on soft soil.
2	The variation in deflection form parabolic curve in nature.
3	Both the curves intersect at a point indicating a neutral deflection in between 1st and 2nd slab

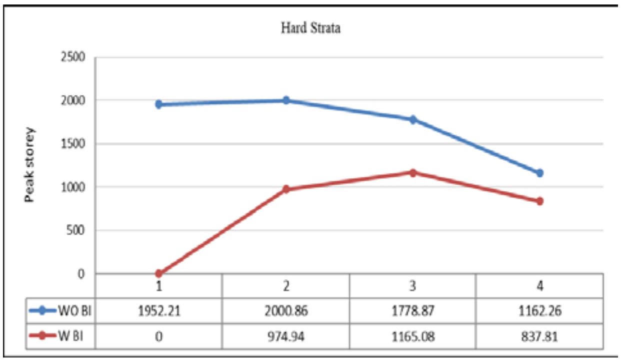


Graph 3.34: Percentage variation of deflection (Y direction)

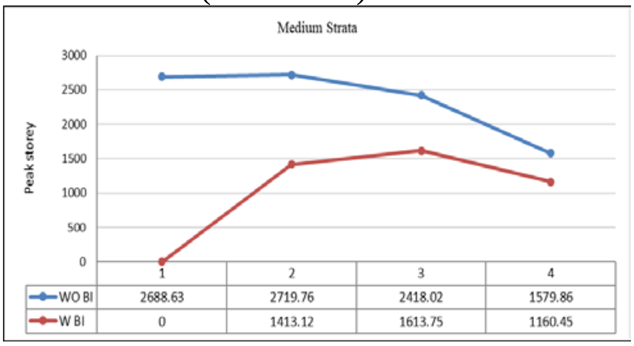
Observations	
For Soil Strata (Hard, Medium & Soft) & No. of Storey (3, 7 & 11)	
1	% reduction in deflection is comparatively more on hard soil strata i.e. 34.82%.
2	Variation of deflection decreases linearly to a minimum of 4.10% in soft soil strata.
3	As height of building increases % variation in deflection also decreases.

Peak Storey Value

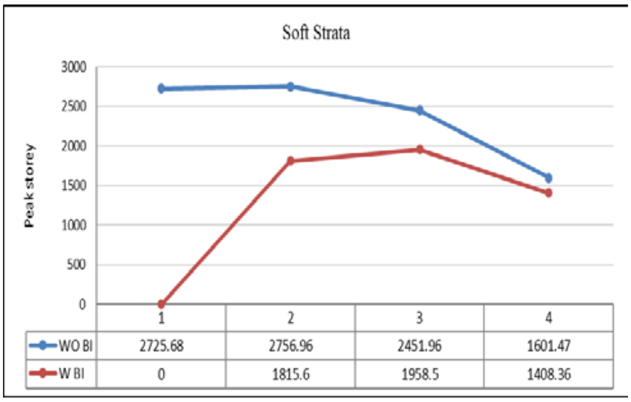
Structural behavior of 3, 7 and 11 storied building provided with base isolators on hard, medium and soft soil strata is analyzed. Observations obtained for peak storey value in X direction are as follows:



Graph 3.35: Variation of peak storey value on hard soil strata (X direction)

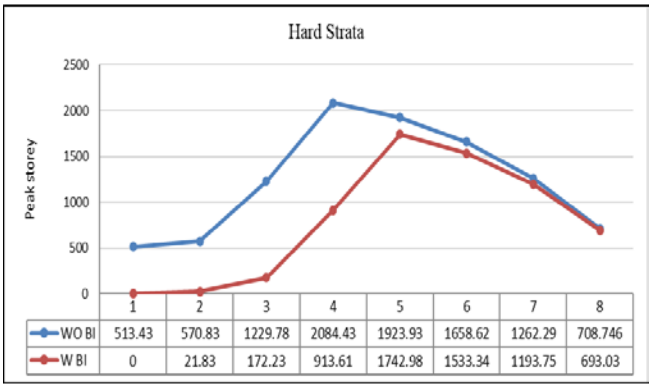


Graph 3.36: Variation of peak storey value on medium soil strata (X direction)

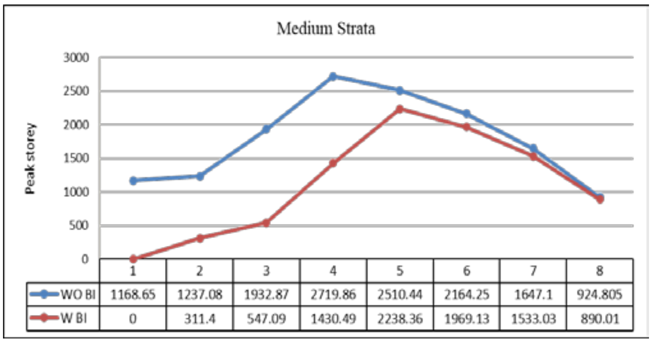


Graph3.37: Variation of peak storey value on soft soil strata (X direction)

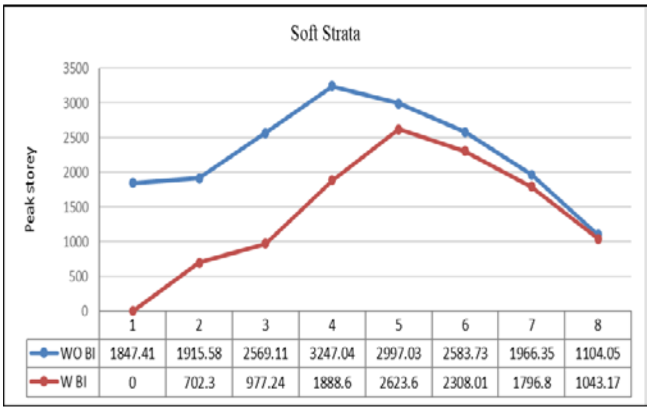
Observations	
For Soil Strata (Hard, Medium & Soft) & No. of Storey (3)	
1	Peak storey value is zero in all cases of soil for structure with base isolation
2	Variation obtained is inverted parabolic in nature for structure with base isolation
3	Maximum difference occurs at base of the structure in both cases



Graph3.38: Variation of peak storey value on hard soil strata (X direction)

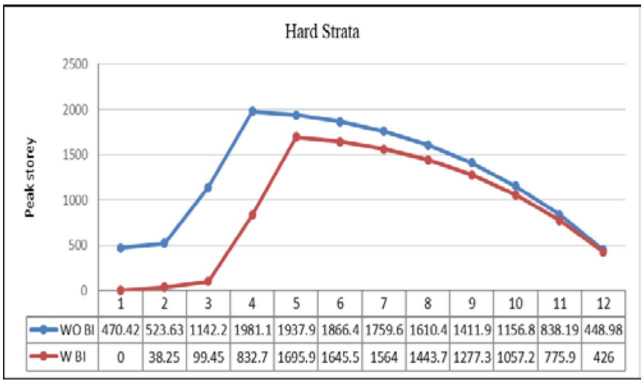


Graph 3.39: Variation of peak storey value on medium soil strata (X direction)

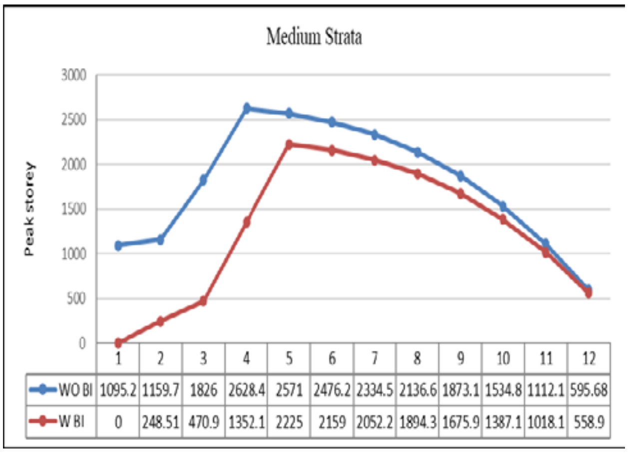


Graph 3.40: Variation of peak storey value on soft soil strata (X direction)

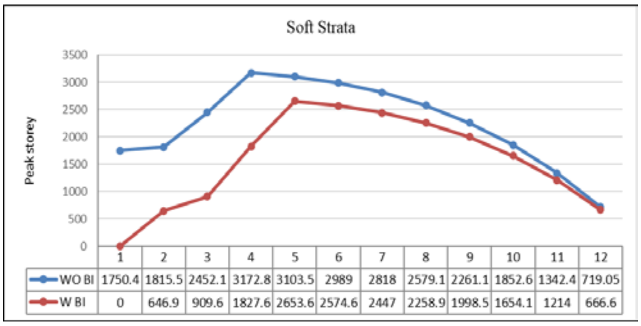
Observations	
For Soil Strata (Hard, Medium & Soft) & No. of Storey (7)	
1	Peak storey value is zero in all cases of soil for structure with base isolation
2	Magnitude of peak storey increases up to 3rd, 4th storey and decreases further with parabolic variation in WO BI, W BI structures respectively
3	Maximum difference occurs at base of the structure in both cases



Graph3.41: Variation of peak storey value on hard soil strata (X direction)



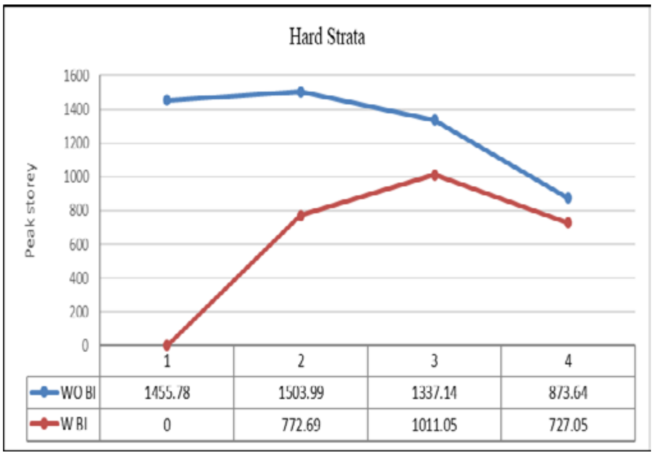
Graph 3.42: Variation of peak storey value on medium soil strata (X direction)



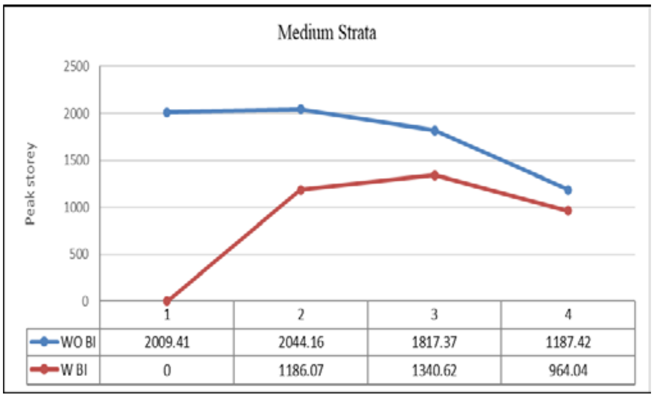
Graph 3.43: Variation of peak storey value on soft soil strata (X direction)

Observations	
For Soil Strata (Hard, Medium & Soft) & No. of Storey (11)	
1	Peak storey value is zero in all cases of soil for structure with base isolation
2	Magnitude of peak storey increases up to 3rd, 4th storey and decreases further with parabolic variation in WO BI, W BI structures respectively
3	Maximum difference occurs at base of the structure in both cases

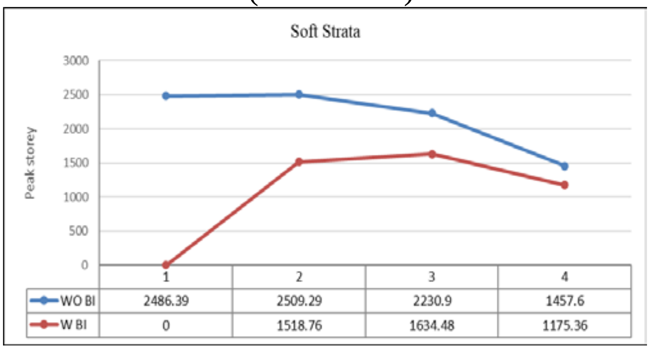
Structural behavior of 3, 7 and 11 storied building provided with base isolators on hard, medium and soft soil strata is analyzed. Observations obtained for peak storey value in Y direction are as follows:



Graph 3.44: Variation of peak storey value on hard soil strata (Y direction)

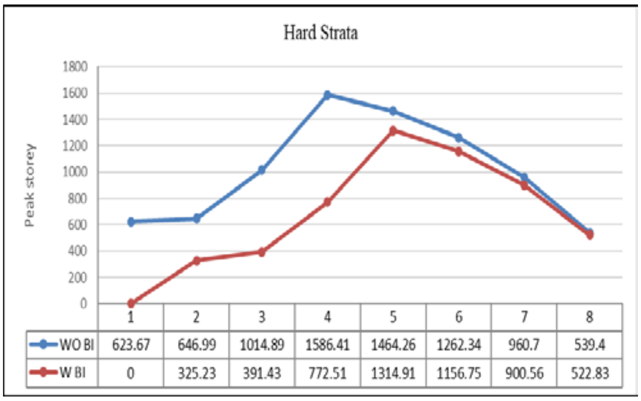


Graph 3.45: Variation of peak storey value on medium soil strata (Y direction)

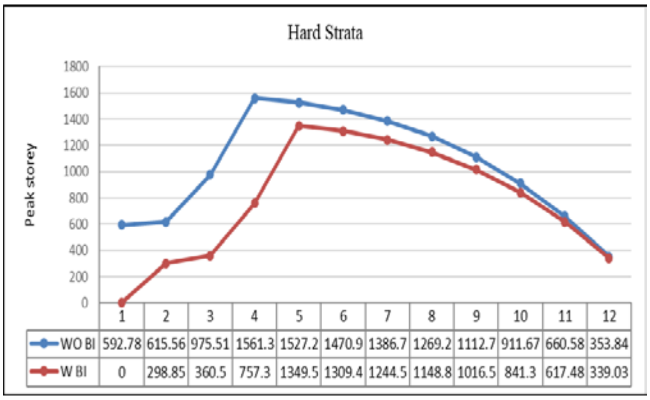


Graph 3.46: Variation of peak storey value on soft soil strata (Y direction)

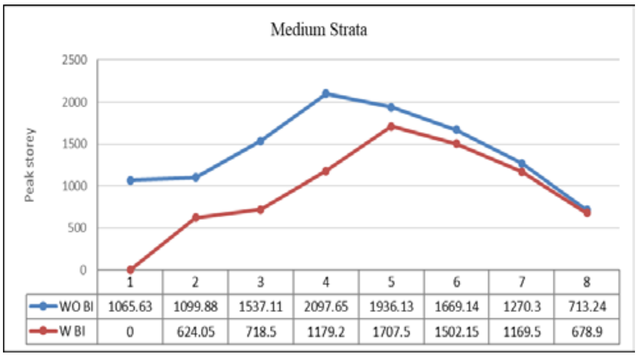
Observations	
For Soil Strata (Hard, Medium & Soft) & No. of Storey (3)	
1	Peak storey value is zero in all cases of soil for structure with base isolation
2	Variation obtained is inverted parabolic in nature for structure with base isolation
3	Maximum difference occurs at base of the structure in both cases



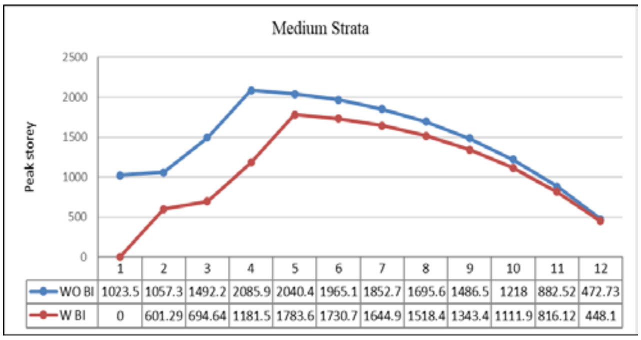
Graph 3.47: Variation of peak storey value on hard soil strata (Y direction)



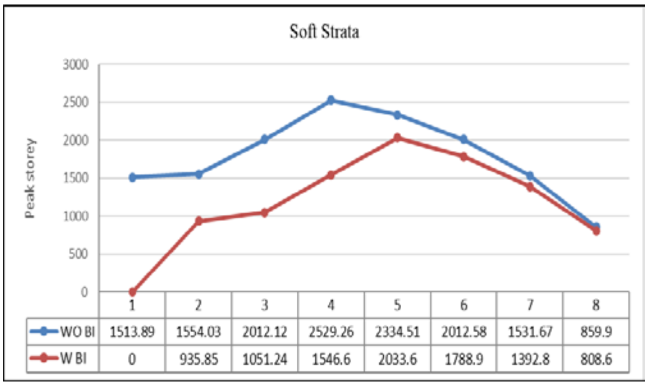
Graph 3.50: Variation of peak storey value on hard soil strata (Y direction)



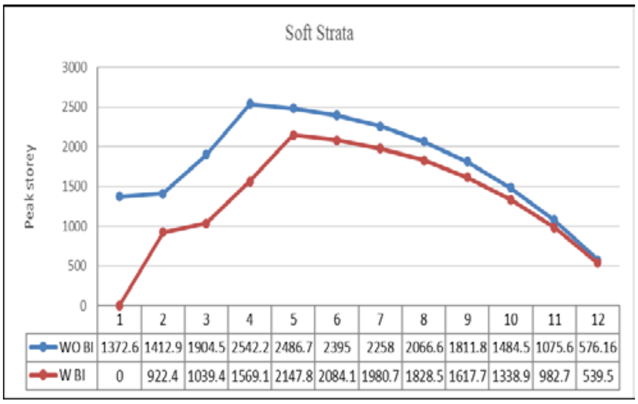
Graph 3.48: Variation of peak storey value on medium soil strata (Y direction)



Graph 3.51: Variation of peak storey value on medium soil strata (Y direction)



Graph 3.49: Variation of peak storey value on soft soil strata (Y direction)



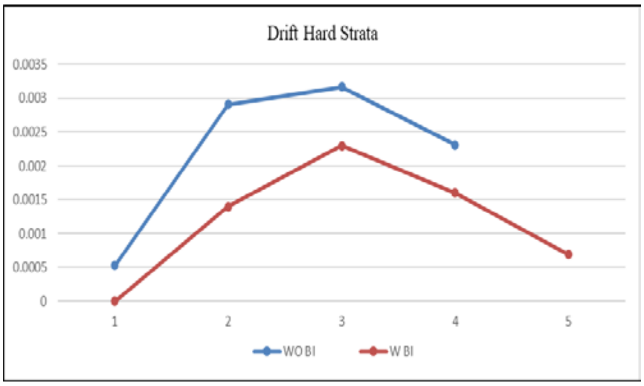
Graph 3.52: Variation of peak storey value on soft soil strata (Y direction)

Observations	
For Soil Strata (Hard, Medium & Soft) & No. of Storey (11)	
1	Peak storey value is zero in all cases of soil for structure with base isolation
2	Magnitude of peak storey increases up to 3rd, 4th storey and decreases further with parabolic variation in WO BI, W BI structures respectively
3	Maximum difference occurs at base of the structure in both cases

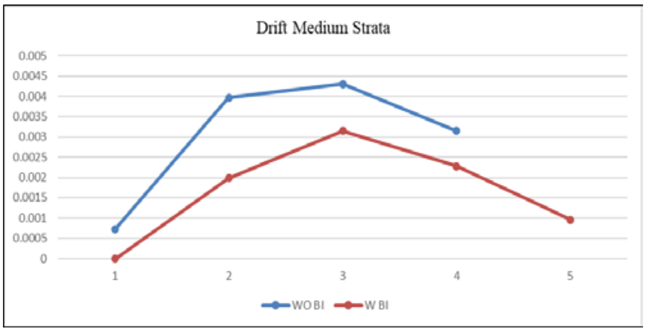
Observations	
For Soil Strata (Hard, Medium & Soft) & No. of Storey (11)	
1	Peak storey value is zero in all cases of soil for structure with base isolation
2	Magnitude of peak storey increases up to 3rd, 4th storey and decreases further with parabolic variation in WO BI, W BI structures respectively
3	Maximum difference occurs at base of the structure in both cases

Variation of Storey Drift

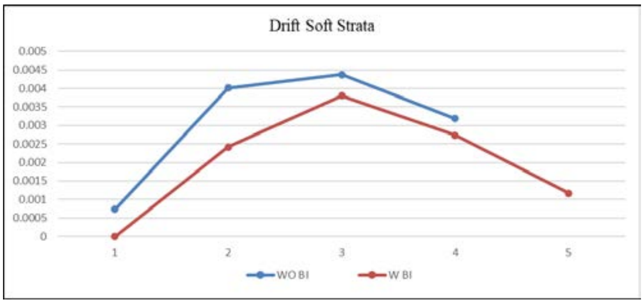
Structural behavior of 3, 7 and 11 storied building provided with base isolators on hard, medium and soft soil strata is analyzed. Observations obtained for storey drift in X direction are as follows:



Graph 3.53: Variation of storey drift on hard soil strata (X direction)

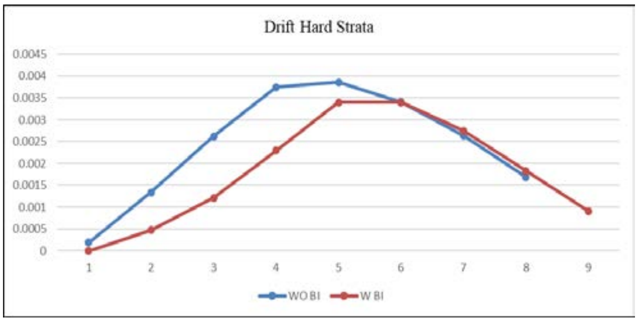


Graph 3.54: Variation of storey drift on medium soil strata (X direction)

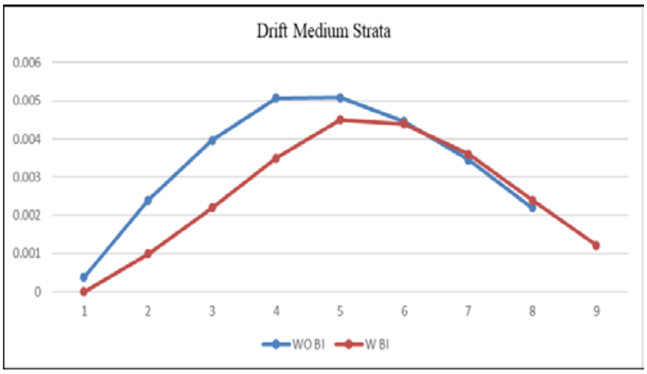


Graph 3.55: Variation of storey drift on soft soil strata (X direction)

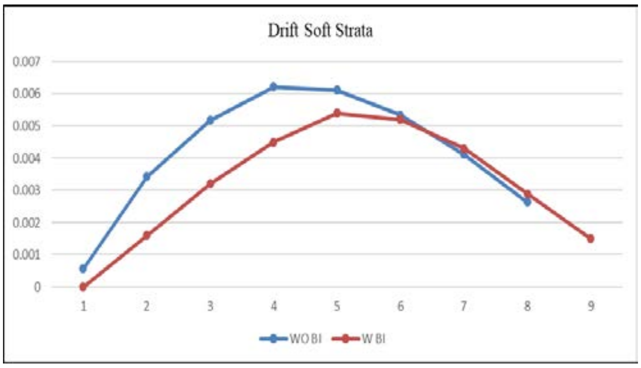
Observations	
For Soil Strata (Hard, Medium & Soft) & No. of Storey (3)	
1	Peak storey value is zero in all cases of soil for structure with base isolation
2	Magnitude of drift increases up to 2nd storey and decreases further with parabolic variation in WO BI, W BI structures respectively
3	Maximum % reduction in isolated structure is almost 62.5% at 1st floor



Graph 3.56: Variation of storey drift on hard soil strata (X direction)

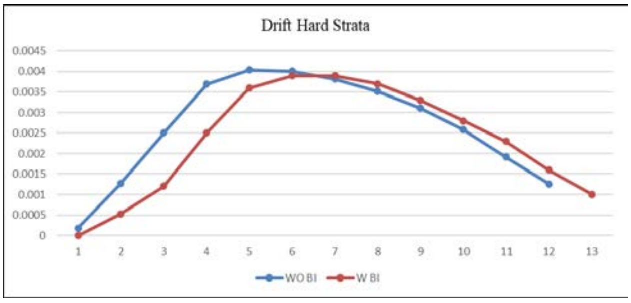


Graph 3.57: Variation of storey drift on medium soil strata (X direction)

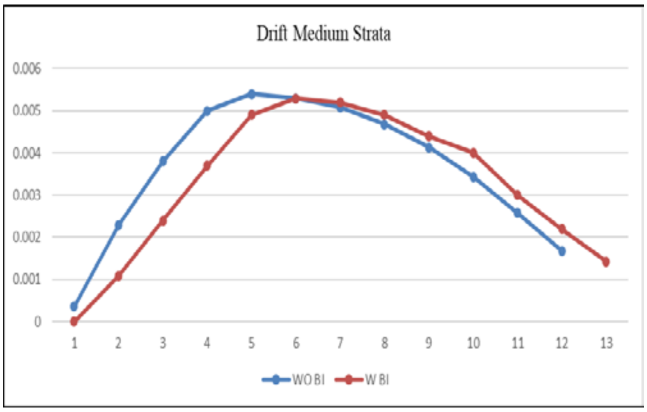


Graph3.58: Variation of storey drift on soft soil strata (X direction)

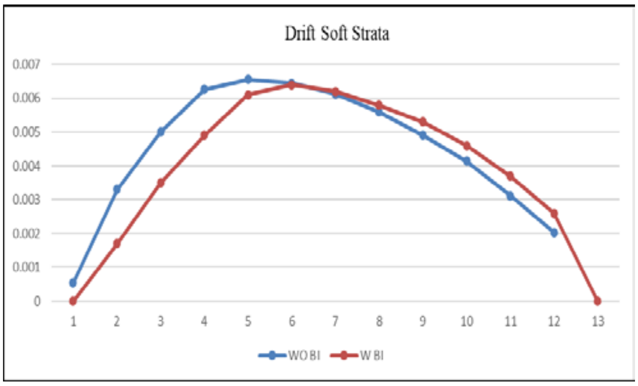
Observations	
For Soil Strata (Hard, Medium & Soft) & No. of Storey (7)	
1	Peak storey value is zero in all cases of soil for structure with base isolation
2	Magnitude of drift increases up to 3rd storey and decreases further with parabolic variation in WO BI, W BI structures respectively
3	Maximum % reduction in isolated structure is almost 61.11% at 2nd floor



Graph 3.59: Variation of storey drift on hard soil strata (X direction)



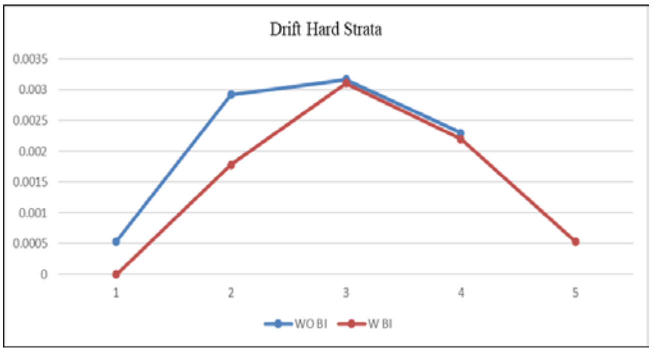
Graph 3.60: Variation of storey drift on medium soil strata (X direction)



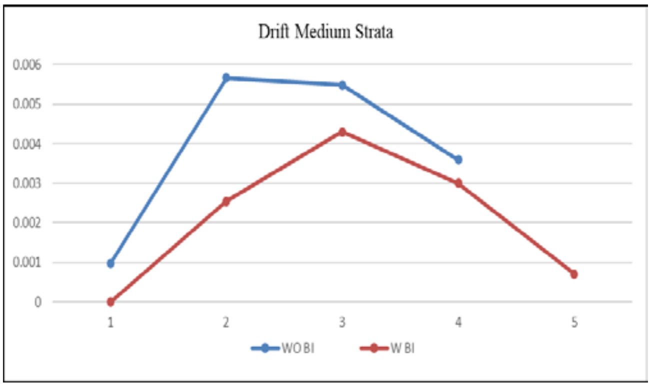
Graph 3.61: Variation of storey drift on soft soil strata (X direction)

Observations	
For Soil Strata (Hard, Medium & Soft) & No. of Storey (11)	
1	Peak storey value is zero in all cases of soil for structure with base isolation
2	Magnitude of drift increases up to 2nd storey and decreases further with parabolic variation in WO BI, W BI structures respectively
3	Maximum % reduction in isolated structure is almost 53.84% at 1st floor

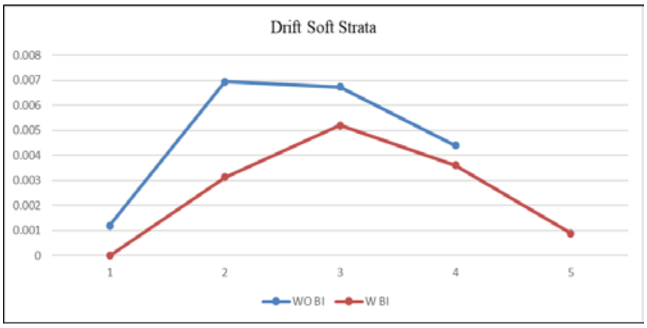
Structural behavior of 3, 7 and 11 storied building provided with base isolators on hard, medium and soft soil strata is analyzed. Observations obtained for storey drift in Y direction are as follows:



Graph3.62: Variation of storey drift on hard soil strata (Y direction)

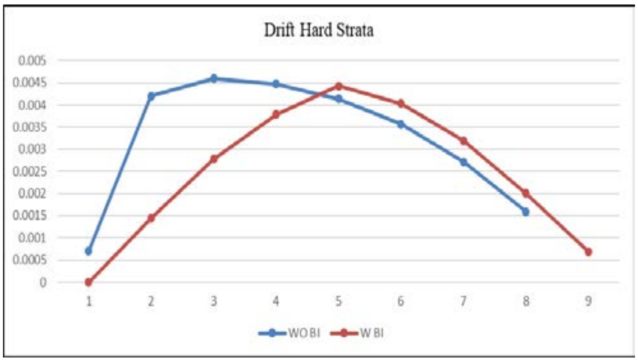


Graph 3.63: Variation of storey drift on medium soil strata (Y direction)

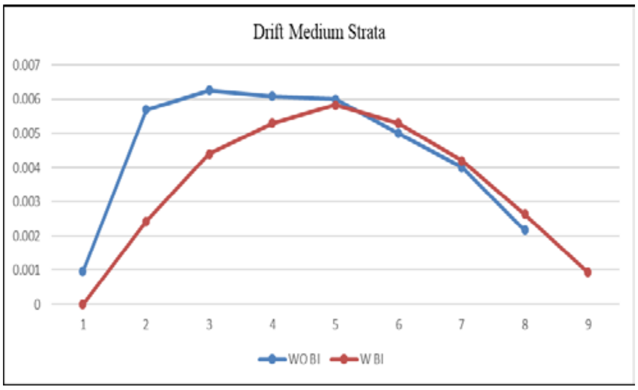


Graph3.64: Variation of storey drift on soft soil strata (Y direction)

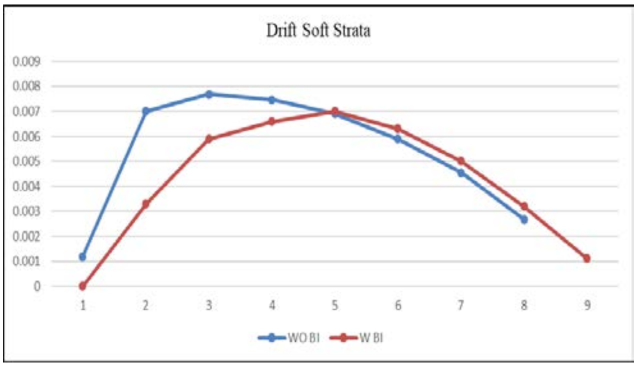
Observations	
For Soil Strata (Hard, Medium & Soft) & No. of Storey (3)	
1	Peak storey value is zero in all cases of soil for structure with base isolation
2	Magnitude of drift increases up to1st & 2nd storey and decreases further with parabolic variation in WO BI, W BI structures respectively
3	Maximum % reduction in isolated structure is almost 42.85% at 1st floor



Graph 3.65: Variation of storey drift on hard soil strata (Y direction)

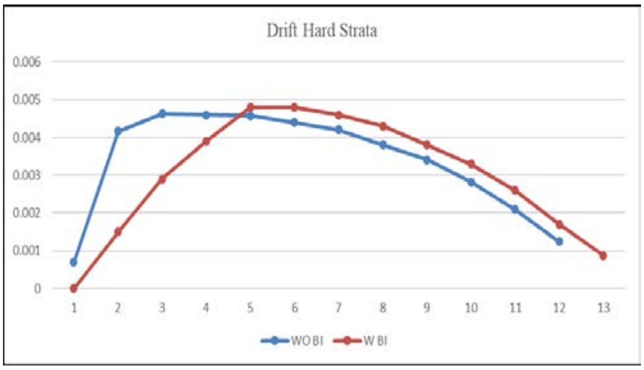


Graph 3.66: Variation of storey drift on medium soil strata (Y direction)

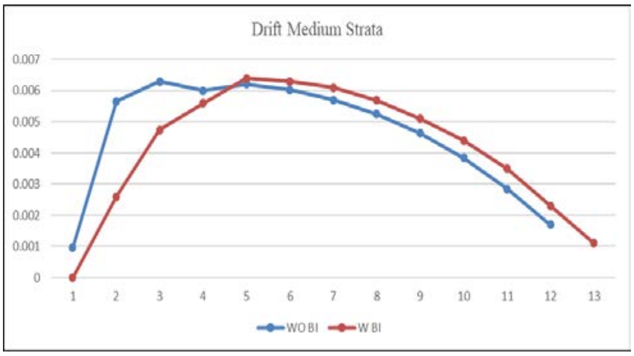


Graph 3.67: Variation of storey drift on soft soil strata (Y direction)

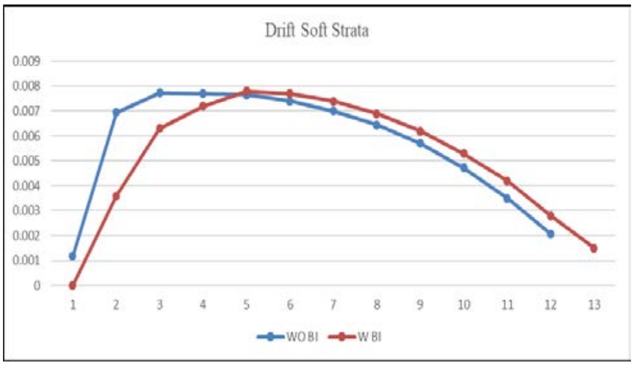
Observations	
For Soil Strata (Hard, Medium & Soft) & No. of Storey (7)	
1	Peak storey value is zero in all cases of soil for structure with base isolation
2	Magnitude of drift increases up to 2nd storey and decreases further with parabolic variation in WO BI, W BI structures respectively
3	Maximum % reduction in isolated structure is almost 45.10% at 1st floor



Graph 3.68: Variation of storey drift on hard soil strata (Y direction)



Graph 3.69: Variation of storey drift on medium soil strata (Y direction)



Graph 3.70: Variation of storey drift on soft soil strata (Y direction)

Observations	
For Soil Strata (Hard, Medium & Soft) & No. of Storey (11)	
1	Peak storey value is zero in all cases of soil for structure with base isolation
2	Magnitude of drift increases up to 2nd & 4th storey and decreases further with parabolic variation in WO BI, W BI structures respectively
3	Maximum % reduction in isolated structure is almost 52.14% at 1st floor

IV. CONCLUSIONS

4.1 Introduction

The series of analyses has proven the benefits of base isolation. The stiffness parameters of bearings were designed and analyzed to maximize the seismic performance of the structure. Base isolation has displayed significant positive effects by increasing the structure's natural period and hence reducing inertia forces on the structure. This investigation outlined the major relevant issues concerning the conceptual design of a base isolated structure. The parameters of the building and the site conditions chosen for the study were deliberately chosen in such a way that the earthquake effects were most severe. In reality, the stiffness calibration approach can be integrated together with the base isolation design in early stages of projects in order to develop structures of high seismic performance.

5.2 Conclusions

1. The benefits of implementing an isolation system were investigated by comparing the performance of base isolated multistory buildings with and without SSI. With the inclusion of seismic isolation devices, the base isolated wit SSI have significantly reduced top floor deflections, accelerations, inter storey drifts and base shears when compared without considering SSI on different soil strata (hard, medium, soft).

2. From a strictly strength viewpoint, the base isolated building does not show a great reduction in base shear for 3 storied building.

3. The percentage reduction in base shear is maximum in soft soil strata (66.63%) compared to medium and hard soil with SSI effect. As the height of building increases the % reduction in base shear also decreases.

4. The maximum reduction in deflection attains on hard soil strata (34.82%) for the building with base isolation and SSI effect.

5. The variation for peak storey value remains same for all buildings with increasing in magnitude on hard, medium and soft soil strata considering the effect of both SSI and BI. The maximum value attained is zero at ground floor when BI is taken into consideration.

6. The maximum % reduction in drift decreases as height of structure increase. The maximum % reduction obtained is 62.5% for 3 storied building considering the effect of BI.

4.3 Scope for Future Studies

After complete research related to SSI and BI effect on multistoried buildings the following points can be considered for future studies.

1. The effect of SSI and BI can be considered for multistoried buildings on clayey soil strata.
2. Using modified base isolation techniques can also be co related with the considered parameters.
3. The effect of geometries in plan for multistoried buildings can also be considered.
4. Dynamic analysis for multistoried buildings can be performed by using dampers and various BI techniques.

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