Comparative Analysis of RC Structures under Different Soil Strata with & Without Base Isolation Using Soil Structure Interaction Effect

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Abstract — The seismic response of a structure is highly influenced by Soil Structure Interaction (SSI). In this study, the flexibility effect on the behaviour of building was investigated under different soil conditions i.e. soft, medium & hard. In this study we also considered fixed support & replaced it by different conditions for better enhancement of results. The use of base isolation system also has been introduced for better considerable effect & to understand the behaviour of the structure. The aim of this study is to observe the behaviour of such system for seismic control under different configuration of soil with different behaviour which is useful to find its sustainability and is to review such kind of technologies for seismic control. In this study, a G+ 5 storeys building is considered with fixed base and base with different spring properties of soil with & with base isolators. The dynamic analysis is carried out using Response Spectrum, given in IS1893-2016 using Etabs Software. The influence of different properties of soil with base isolation effect on various structural parameters i.e. natural time period, base shear, roof displacement, drift and overturning moment are observed, studied and presented which reveals that the Soil structure interaction effect along with base isolation properties significantly affects on the response of the structure.

Keywords: Base Isolation System, Soil Structure Interaction, Lead Rubber Bearing, Friction Sliding Isolator, Seismic Analysis, ETABS

I. INTRODUCTION

In seismic design of building structure, usually, the soil is assumed to be rigid, which is realistic only if the foundation is on solid rock or when soil stiffness is very high. For all other cases, the soil surface interaction (SSI) constitutes of two distinct effects – kinematic and inertial interaction, which is complex. The soil-structure interaction (SSI) refers to the action in which the response of the soil influences, the response of the structure and the response of the structure influence the motion of the soil (Kramer, 1996). The buildings are considered isolated with fixed base while designing for simpler calculations. Since, the buildings are not constructed in isolation practically. The seismic behaviour of buildings which are closely spaced to each other, do not act autonomously and, considering that their foundations are in the same soil, the reaction is affected by each other for such kind of structure. Further, contrary to the credence that Soil-Foundation-Structure Interaction (SFSI) increases natural time period of structure and is useful, as assumed while designing, several studies have shown that the surge in natural period of structure due to SFSI can lead to resonance. Moreover, the ductility can also expressively rise with increase in natural period of structure due to SSI. The seismic behaviour of the structure may be further intensified by the permanent deformation and failure of soil.

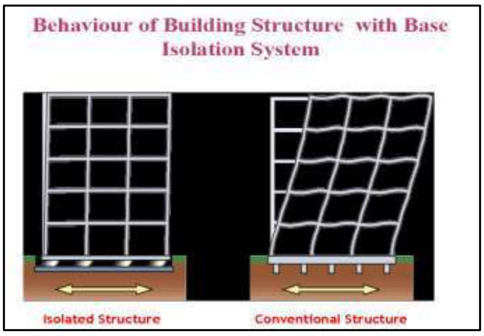
A. Soil Structure Interaction

Soil structure interaction (SSI) entails of the interaction between soil and a structure built upon it. It is primarily an exchange of mutual stress, whereby the movement of the ground-structure system is influenced by both the type of ground and the type of structure. This is particularly appropriate to areas of seismic activity. Various combinations of soil and structure can either amplify or diminish movement and subsequent damage. A building on stiff ground relatively than deformable ground will lead to ache greater damage. An interaction effect due to the mechanical properties of soil which tend to the sinking of foundations by seismic effect. This phenomenon is called soil liquefaction.

Utmost of the civil engineering structures include some type of structural element which do have direct interaction with ground. When the external lateral forces, like earthquakes, act on these systems, neither the structural displacements nor the ground displacements, are liberated of each other. The phenomenon in which the behaviour of the soil effects the motion of the structure and the motion of the structure effects the response of the soil is termed as soil-structure interaction (SSI).

B. Base Isolation System

Base isolation of structures is one of the utmost anticipated resources to protect it against earthquake forces. It is the fundamental concepts for earthquake engineering which can be defined as separating or decoupling the structure from its foundation. This effect in drop of inter storey drift and actual displacement in the floors of base isolated structural system, that safeguards the minimum damage to facilities and also offers safety to life and property. The perception of base isolation had been recommended in last few decades, the technologies are through available, and information of base isolation system are getting used, advanced and hence well established. Seismic isolation systems are more operative when applied to high stiffness, low-rise buildings, due to their abilities to modify the properties of the building from rigid to flexible. And the steady surge in number of structures to be isolated improves the fact that base isolation system is progressively becoming acknowledged as a proven technology in earthquake hazard extenuation. Fascinatingly, base isolation is a passive control system; it does not need any external force or energy for its initiation.



II. OBJECTIVES OF THE STUDY

Structural stability is a useful parameter which is responsible to co-relate the seismic elastic response of RC structures. The study is carried out by two SSI methods i.e. discrete support (using spring) and Elastic Continuum (using FEM). An attempt is also made to understand the effectiveness and utility of this study and its effect on the structure. Following studies are considered for the research work -

- To observe the behaviour of such kind of low rise structures during earthquakes having fixed and spring property allotted at base.
- To observe the parameters of storey displacements, Maximum storey drift of all models during earthquake.
- To observe the time periods & mass participating ratios in different modes.
- To study the effect of base isolation system along with fixed support and with spring property of soil.

III. METHODOLOGY

The purpose of the carrying out the process of seismic analysis is to find actually the several parameters which purely included the force, the deformation, capacities of each of the components in the building structure.

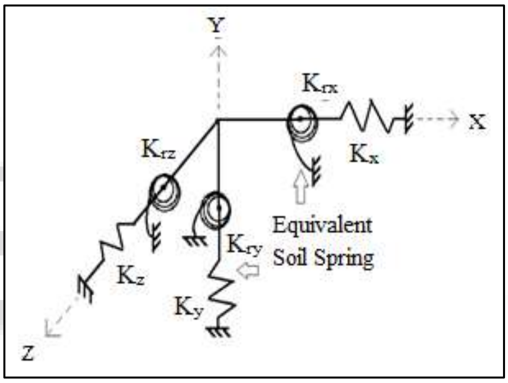
A. *Soil Structure Interaction & Isolated Footings-*

The impacts of the SSI are more centred on its unfavourable impacts. As referenced, regardless of whether studies have informed that the plan in light of soil structure connection builds the time span, expansion in time-frame isn't generally a valuable element. There is prolongation of seismic waves when it is on a site of delicate soil residue. This occurs with a significant stretch vibration. Assuming the regular period builds, the interest for malleability additionally increments. This might bring about long-lasting disfigurement and soil disappointment that will additionally deteriorate the primary seismic reaction. A design under the activity of seismic power (seismic excitation), there is association between the dirt and establishment which acquires changes the ground movement. The dirt design association can have two kinds of peculiarities or impacts (according to FEMA P-750 and NEHRP).

Isolated footings (otherwise called Pad or Spread footings) are normally utilized for shallow establishments to convey and spread concentrated loads, caused for instance by sections or points of support. Disconnected footings can comprise both of supported or non-built up material. For the non-built up balance in any case, the tallness of the balance must be greater to give the fundamental spreading of burden. Disconnected footings should possibly be utilized when it is sure beyond a shadow of a doubt that no changing settlements will happen under the whole structure. Spread footings are unsatisfactory for the course of broad burdens. For this situation, either strip (consistent) footings or mat footings are utilized. There are different sorts of secluded footings, for example, spread balance, ventured balance, inclined balance and so on They are normally square, rectangular or round in shape. Each sort of balance is chosen in view of the dirt condition and design of forced loads. Secluded footings are quite possibly the most conservative kinds of balance and are utilized when sections are divided at generally significant distances. Disengaged or single footings are underlying components used to send and circulate heaps of single segments to the dirt without surpassing its bearing limit, as well as forestalling inordinate settlement and giving sufficient well being against sliding and upsetting. Besides, they are utilized on account of light section loads, when segments are not firmly divided, and on account of good homogeneous soil.

B. *Idealization of Discrete Support*

Effect of soil flexibility is incorporated by considering equivalent springs with 6 DOF as shown in Figure below. The stiffness along these 6 degrees of freedom is determined as per Gazetas [1] and is shown in Table below.



Kx, Ky, Kz = Stiffness of equivalent soil springs along the translational DOF along X,Y and Z axis.
Krx, Kry, Krz = Stiffness of equivalent rotational soil springs along the rotational DOF along X, Y and Z axis.

C. *Principle of Base Isolation:*

In practice, isolation is limited to a consideration of the horizontal forces to which buildings are most sensitive. Vertical isolation is less needed and much more difficult to implement. Although each earthquake is unique, it can be stated in general that earthquake ground motions result in a greater acceleration response in a structure at shorter periods than at longer periods. A seismic isolation system exploits this phenomenon by shifting the fundamental period of the building from the more force-vulnerable shorter periods to the less force-vulnerable longer periods. The principle of seismic isolation is to introduce flexibility in the basic structure in the horizontal plane, while at the same time adding damping elements to restrict the resulting motion. In an ideal system, the isolation would be total. In the real world, there needs to be some contact between the structure and the ground. A building that is perfectly rigid will have a zero period. When the ground moves, the acceleration induced in the structure will be equal to the ground acceleration and there will be zero relative displacement between the structure and the ground. Thus, the structure and ground move by same amount.

D. Elements of Base Isolator:

1) Isolation system- The various isolators, which reduce the time period shift of the structure to a period, range of 2 to 3 seconds, with the isolation system. In base isolation structure, only isolation system show non-linear behaviour, while structure and soil system are shows linear behaviour.
2) Structural system- This system consists of structural component of superstructure as well as foundation. The inter storey drift for isolated structure is very low so, that the super structure can conveniently be assume to behave like linear elastic manner.
3) Soil system- The sub soil system exhibits its own stiffness and damping properties which may or may not affect the response of the structure which is situated upon it. This influence of the interaction between the soil and structure becomes significant in case of loose subsoil strata.

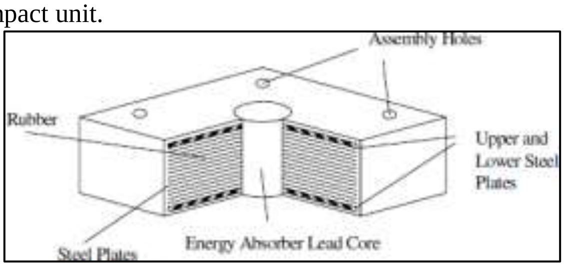
E. Types of Base Isolators

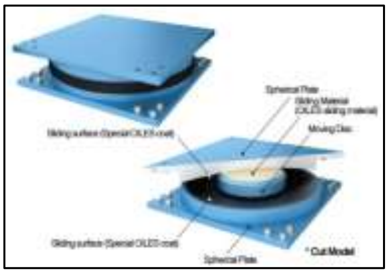
The most common use of base isolator in building is

- Laminated Rubber (Elastomeric) Bearing.
- High Damping Rubber (HDR) Bearing.
- Lead Rubber Bearing (LRB)
- Sliding bearings
- Friction Pendulum (FPS) System Bearing.

F. Lead Rubber Bearing

The second type of elastomeric bearings is lead-rubber bearings (LRB). This type of base isolation system provides the combined features of vertical load support, horizontal flexibility, restoring force, and damping in a single unit. A lead-rubber bearing is formed of a lead plug force- fitted into a pre-formed hole in an elastomeric bearing. The lead core provides rigidity under service loads and energy dissipation under high lateral loads. When subjected to low lateral loads such as minor earthquake the lead-rubber bearing is stiff both laterally and vertically. The lateral stiffness results from the high elastic stiffness of the lead plug and the vertical rigidity. A major advantage of the lead-rubber bearing is that it combines the functions of rigidity at service load levels flexibility at earthquake load levels and damping into a single compact unit.





G. Model Details –

- Model 1 – SMRF RC structure with fixed support at base
- Model 2 - SMRF RC structure with spring property of hard strata at base
- Model 3 - SMRF RC structure with spring property of medium strata at base
- Model 4 - SMRF RC structure with spring property of soft strata at base
- Model 5 – SMRF RC structure with fixed support at base with LRB base isolator
- Model 6 - SMRF RC structure with spring property of hard strata at base with LRB base isolator
- Model 7 - SMRF RC structure with spring property of medium strata at base with LRB base isolator
- Model 8 - SMRF RC structure with spring property of soft strata at base with LRB base isolator

General Properties	
Location of Building	Gujrat, India
No. of storeys	G+5
Typical Storey Height	3.5 m.
Size of Column	300 mm x 600 mm
Size of Beam	300 mm x 450 mm
Thickness of Slab	150 mm.
Thickness of Wall	230 mm.
Material Properties	
Grade of Concrete	M25
Grade of HYSD Bars	Fe500
Type of Loading	
Wall Load	12.5 KN/m
Live Load	3 KN/m^2
Floor Finishing	1.5 KN/m^2
Seismic Details (IS 1893:2016)	
Seismic Zone	V
Zone Factor	0.36
Importance Factor	1
Type of Soil	I – Hard / II – Medium / III - Soft
Building Type (R)	5 (SMRF)

1) Soil Properties

Soil Type	Designation	Modulus of Elasticity	Poisson's Ratio	Unit Weight of Soil
Hard	Hard	64685	0.3	20
Medium	Medium	33645	0.4	18
Soft	Soft	16125	0.4	16

2) *Footing Property –*

Footing TYPE	Size	Modulus of Elasticity of concrete	Poisson's Ratio
Isolated	2.1m x 1.5m x 0.75 m	25000 N/mm^2	0.2

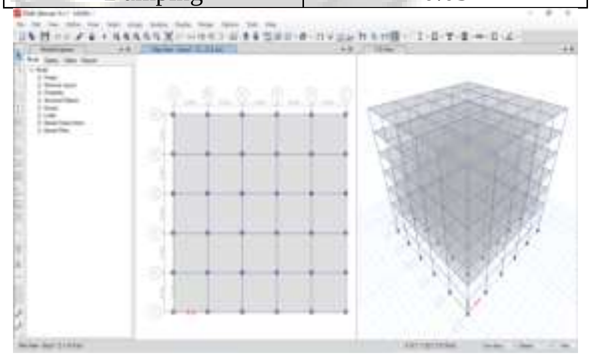
3) *Spring Property –*

Degrees of freedom	Stiffness of equivalent soil spring	HARD	MEDIUM	SOFT
Horizontal (longitudinal direction)	$[2GL/(2-v)]\ (2+2.50\ \chi\ 0.85)$ with $\chi = A/4L^2$	125233	66416	28654
Horizontal (lateral direction)	$[2GL/(2-v)\ ]\ (2+2.50\ \chi\ 0.85)$ with $\chi = A/4B^2$	146823	78968	34198
Vertical	$[2GL/(2-v)]\ (2+2.50\chi 0.85) - [0.2 / (0.75-v)\ ]\ GL\ [1-(B/L)]\ \ [2GL/(1-v)]\ (0.73+1.54\chi 0.75)$ with $\chi = A/4L^2$	168208	96254	42636
Rocking (about longitudinal)	$[G/(1-v)]\ Ibx\ 0.75(L/B)0.25[2.4+0.5(B/L)]$	132520	76121	34255
Rocking (about lateral)	$[G/(1-v)]Iby\ 0.75\ (L/B)^{0.15}$	133680	78143	34687
Torsion	$3.5G\ Ibz\ 0.75\ (B/L)\ 0.4(Ibz/B4)^{0.2}$	58368	28632	11960

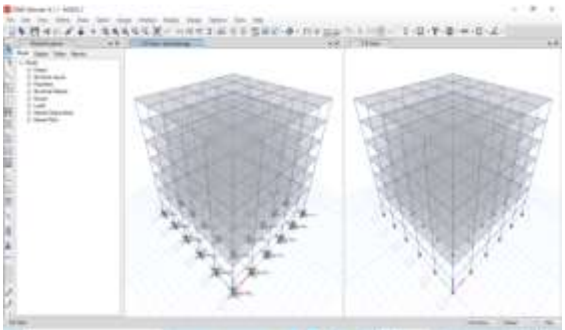
A_b= Area of the foundation considered; B and L= Half-width and half-length of a rectangular foundation, respectively; I_{bx}, I_{by}, and I_{bz} = Moment of inertia of the foundation area with respect to longitudinal, lateral and vertical axes, respectively

4) *Design Parameters for LRB*

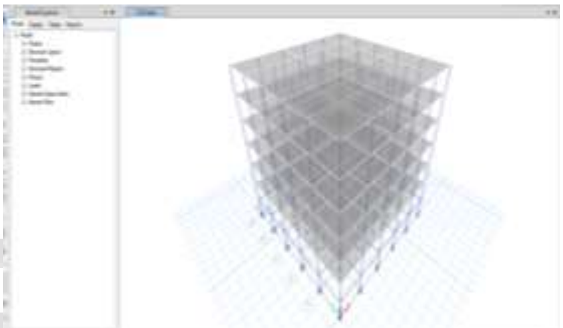
Particulars	For the base of building
Kv (Vertical Stiffness)	1007256 KN/m
Keff (Effective Stiffness)	2110 KN/m
Kh (Horizontal Stiffness)	2755 KN/m
Yield Strength Fo	52.68
Stiffness Ratio	0.1
Damping	0.05



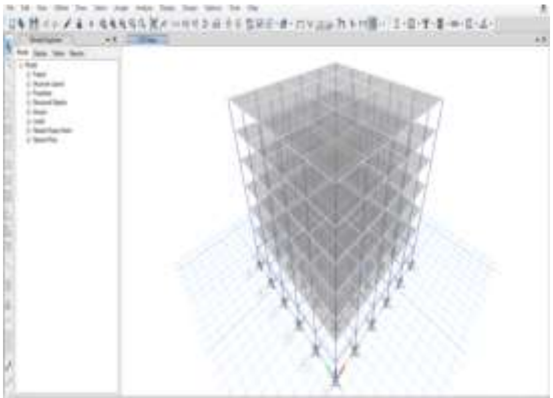
MODEL 1



MODEL 2, 3 & 4 with different properties of soil

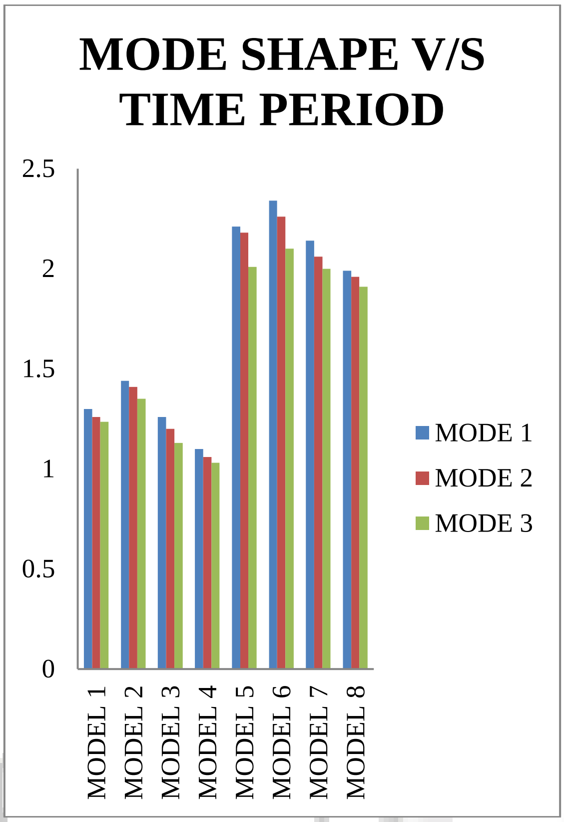


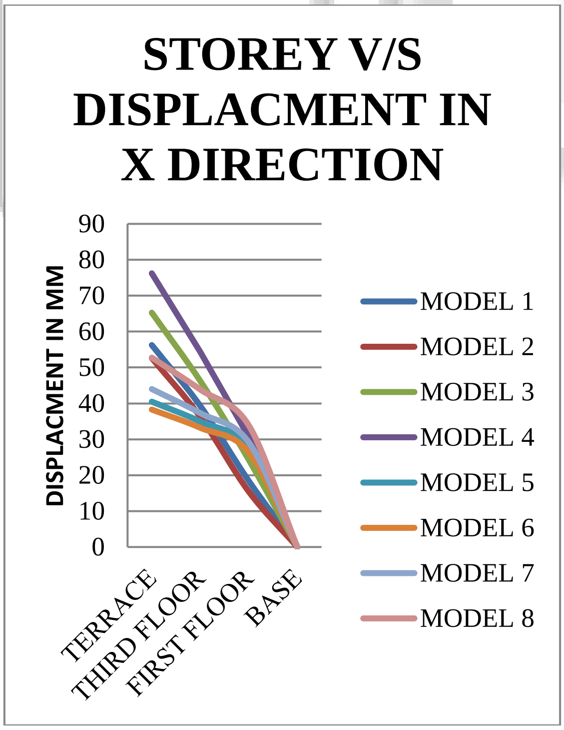
MODEL – 5 WITH LRB

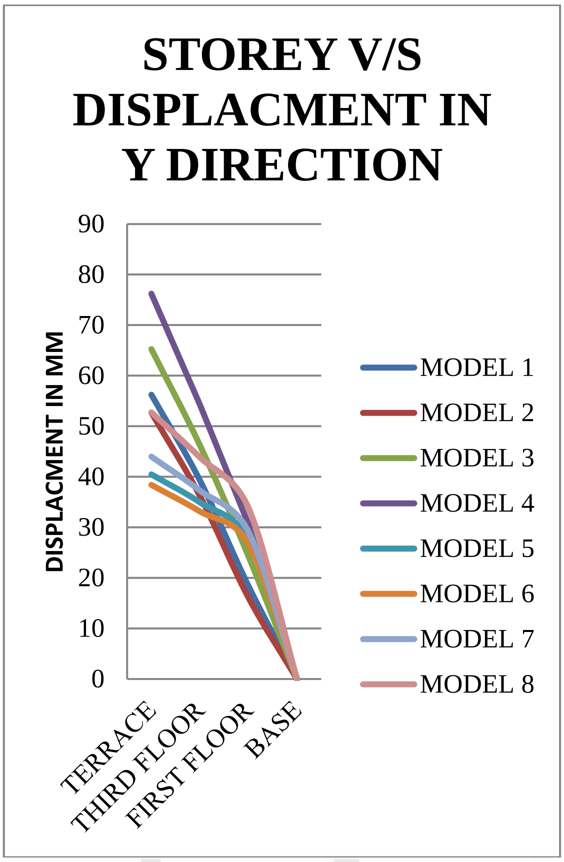


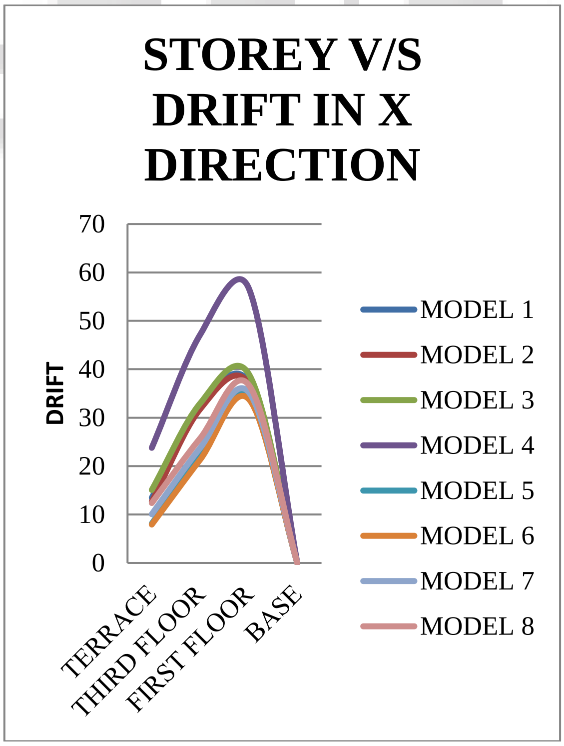
MODEL – 6,7,& 8 with different properties of soil with LRB

IV. RESULTS


MODE SHAPE V/S TIME PERIOD
2.5
2
1.5
1
0.5
0
MODEL 1
MODEL 2
MODEL 3
MODEL 4
MODEL 5
MODEL 6
MODEL 7
MODEL 8
MODE 1
MODE 2
MODE 3


STOREY V/S DISPLACMENT IN X DIRECTION
DISPLACMENT IN MM
90
80
70
60
50
40
30
20
10
0
TERRACE
THIRD FLOOR
FIRST FLOOR
BASE
MODEL 1
MODEL 2
MODEL 3
MODEL 4
MODEL 5
MODEL 6
MODEL 7
MODEL 8


STOREY V/S DISPLACMENT IN Y DIRECTION
DISPLACMENT IN MM
90
80
70
60
50
40
30
20
10
0
TERRACE
THIRD FLOOR
FIRST FLOOR
BASE
MODEL 1
MODEL 2
MODEL 3
MODEL 4
MODEL 5
MODEL 6
MODEL 7
MODEL 8


STOREY V/S DRIFT IN X DIRECTION
DRIFT
70
60
50
40
30
20
10
0
TERRACE
THIRD FLOOR
FIRST FLOOR
BASE
MODEL 1
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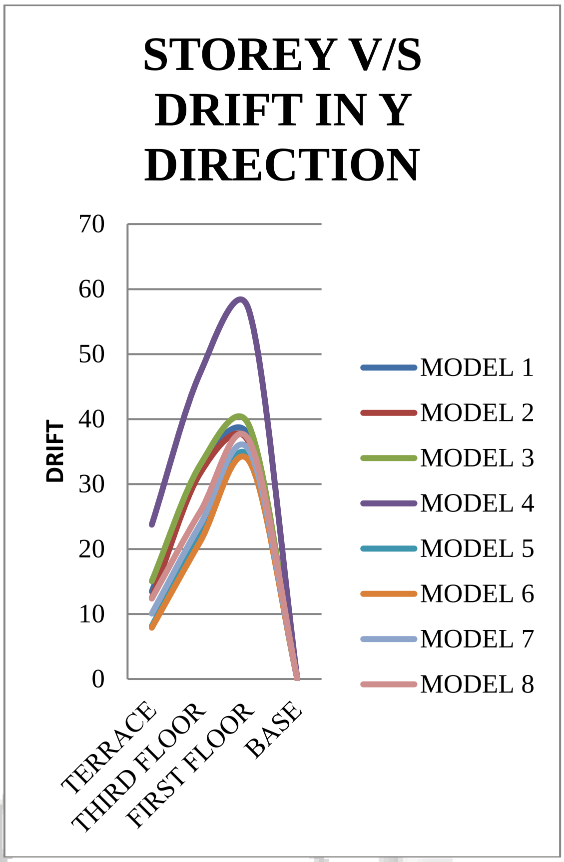
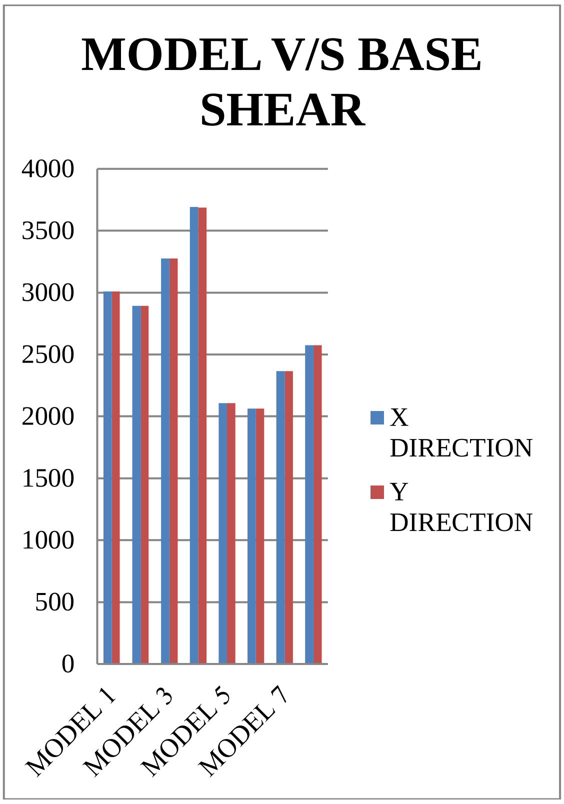
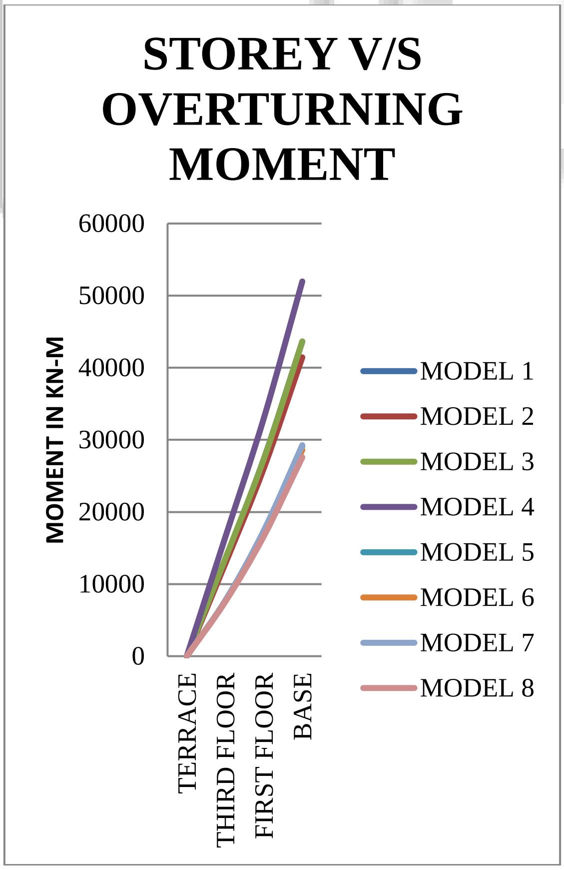
MODEL 6
MODEL 7
MODEL 8







V. CONCLUSION

From above study it has been concluded that,

1) Base shear of building with base isolation is 30% less than that of building without base isolation.
2) Base shear of building increases 20% with the properties of spring for soft soil, increases 8% for medium soil and decreases 5% for hard type of soil as per the type of soil as compare to the FEM support property.
3) Natural Time period of the building also increases 60% with the use of Lead Rubber Bearing base isolation and increases thrice with the use of friction sliding base isolation, due to which the natural frequency of the structure is low which is much desirable as the higher frequencies have higher displacement of the component which incurs higher fatigue damage to the component.
4) The displacement in both directions with the use of friction sliding base isolation reduces up to 30% for each type of soil as it gives less movement structure due to the stiffness of support.
5) The displacement of FEM Support building is 5% high than the building having fixed property at base.
6) The storey drift in both directions with the use of friction sliding base isolation reduces up to 60% for each type of soil. Also due to the property of base isolation, only base is displaced more and the ratio of displacement of upper storeys as compare to lower storey is less.
7) The storey drift of FEM Support building is 10% less than the building having spring property at base.
8) The overturning moment with the use of friction sliding base isolation reduces up to 50% for each type of soil.
9) The overturning moment of FEM Support building is 5% high than the building having fixed property at base.

Idealization of supporting soil by spring is an approximate approach. This doesn't reflect the flexibility with high precision. Thus it yields the less accurate results. However the realistic idealization of supporting soil is possible by FEM. This will produce the precise data than spring model. The study also reveals that there is difference in the results of both. The spring model underestimates the values.

REFERENCES

[1] George Gazetas, (1991) Member, ASCE, "Formulas and charts for impedances of surface and embedded foundations."
[2] Sekhar Chandra Dutta, Rana Roy, "A critical review on idealization and modelling for interaction among soil-foundation structure system", Computers and Structures 80 (2002), pp.1579_1594
[3] Koushik Bhattacharya, Shekhar Chandra Datta, "Assessing lateral period of building frames incorporating soil flexibility", Journal of sound and vibration, 269 (2004), pp.795-821
[4] B.R. Jayalekshmi, (2007) "Earthquake response of multi-storeyed R.C. frames with soil structure interaction effects."
[5] Vivek Garg, M.S. Hora, "A review on interaction behaviour of structure foundation- soil system.", International Journal of Engineering Research and Applications, Vol. 2, Issue 6, November- December 2012, pp.639-644
[6] Bowles, J.E.(1998)."Foundation Analysis and design",McGraw Hills, New York.
[7] B.R. Jayalekshmi, Chandrashekhar.A, KattaVenkataramana, R.Shivashankar, Dynamic FE Analysis of multi-storeyed frames including soil foundation structure interaction effects, NITK Research Bulletin Vol.16. No.1, June 2007, pp 14 to 18
[8] Shiji P.V, Suresh S., Glory Joseph, "Effect of Soil Structure Interaction in Seismic Loads of Framed Structures"; International Journal of Scientific & Engineering Research Volume 4, Issue 5, May-2013 ISSN 2229-5518.
[9] Brown CB, Laurent JM, Tilton JR. Beamplate system on winkler foundation. JEng Mech Div ASCE 1977;103(4): 589-600.
[10] Hetenyi M. A general solution for the bending of beams on elastic foundations of arbitrary continuity. Journal of Appl Phys 1950; 21:55-8.
[11] Cancellara, F. De Angelis (2016) ,Assessment and dynamic nonlinear analysis of different base isolation systems for a multi-storey RC building irregular in plan, Computers and Structures .
[12] Athanasios A. Markou (2016) Response simulation of hybrid base isolation systems under earthquake excitation Soil Dynamics and Earthquake Engineering 84(2016) 120–133.
[13] Fabio De Angelis (2016) Nonlinear dynamic analysis for multi-storey RC structures with hybrid base isolation systems in presence of bi-directional ground motions Composite Structures 154 (2016) 464–492
[14] N Murali Krishna et al (2016), nonlinear time History Analysis of Building with Seismic Control Systems, International Journal of Science Technology and Engineering.
[15] Radmila B. Salic et al (2008), Response of lead rubber bearing isolated structure,14th world conference on earthquake engineering October 12-17,2008,China.
[16] Juan C Ramallo (2008) "Smart'' Base Isolation Systems Journal of Engineering Mechanics, Vol. 128, No. 10, October 1, 2002. ©ASCE.
[17] Leblouba M. (2007),Combined Systems for Seismic Protection of Building, International symposium on strong vrancea earthquakes and risk mitigation, Bucharest, Romania, pp. 1-11, Oct. (4-6) 2007.
[18] Minal Ashok Somwanshi (2015), Seismic Analysis of Fixed Based and Base Isolated Building Structures, International Journal of Multidisciplinary and Current Research, Vol 3.

