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Seismic Effect of RC Frame with and without Base Isolation for Different Soil Condition using Soil Structure Interaction Effect

[1]Bharti Aswani, [2]Dr. J N Vyas

[1]PG Student, [2]Professor
[1,2]Department of Civil Engineering
[1,2]Mahakal Institute of Technology and Management, Ujjain, India

Abstract—

The seismic response of a structure is greatly influenced by Soil Structure Interaction (SSI). In this study the effect of flexibility of the structure under different soil conditions on the performance of building frame is investigated. Different conditions are considered for the analysis; one is replacing support condition at base by spring of equivalent stiffness and second by considering the base isolation system under same effect. For SSI study three types of soil are generally considered i.e. Hard, Medium Hard and Soft Soil. The aim of this study is to observe the behaviour of such system for seismic control for different conditions and soil effect and find its sustainability for seismic control. Symmetric space frames resting on isolated footing of configurations 5 bays in x and y direction with G+ 5 storeys is considered with fixed base and flexible base with and without different types of base isolator. The spring model is developed by using stiffness equation along all 6 DOF and elastic continuum model is developed by Finite Element Method using Etabs V18. The dynamic analysis is carried out using Response Spectrum, given in IS1893-2016. The influence of soil structure interaction on various structural parameters i.e. natural time period, base shear, roof displacement, drift and overturning moment are presented. The study reveals that the SSI significantly affects on the response of the structure.

Keywords–Base Isolation System, Soil Structure Interaction, Lead Rubber Bearing, Friction Sliding Isolator, Seismic Analysis, Etabs.

1. 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. However, the buildings are not built in isolation in reality. The seismic response of buildings, especially when closely spaced, do not act independently and, considering that their foundations are in the same soil, the response is affected by each other. Further, contradictory to the belief that Soil-Foundation-Structure Interaction (SFSI) increases natural time period of structure and is beneficial, as assumed while designing, studies have shown that the increase in natural period of structure due to SFSI can lead to resonance. Additionally, the ductility can also significantly increase with increase in natural period of structure due to SSI. The seismic response of the structure may be further aggravated by the permanent deformation and failure of soil.

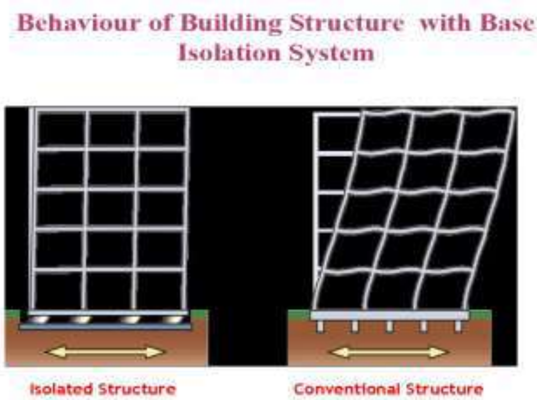
1.1 Soil Structure Interaction -

Ground structure interaction (SSI) consists of the interaction between soil (ground) 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 especially applicable 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 rather than deformable ground will tend to suffer greater damage. A second interaction effect, tied to mechanical properties of soil, is the sinking of foundations, worsened by a seismic event. This phenomenon is called soil liquefaction.

Most of the civil engineering structures involve some type of structural element with direct contact with ground. When the external forces, such as earthquakes, act on these systems, neither the structural displacements nor the ground displacements, are independent of each other. The process in which the response of the soil influences the motion of the structure and the motion of the structure influences the response of the soil is termed as soil-structure interaction (SSI).

1.2 Base Isolation System –

Base isolation of structures is one of the most desired means 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 reduction of inter storey drift and effective displacement in the floors of base isolated structural system, that ensures the least damage to facilities and also provides safety to life and property. The concept of base isolation had been suggested in last few decades, the technologies are made available, the knowledge of base isolation system are getting used, developed and hence well established. Seismic isolation systems are more effective when applied to high stiffness, low-rise buildings, owing to their abilities to alter the characteristic of the building from rigid to flexible. And the gradual increase in number of structures to be isolated enhances the fact that base isolation system is gradually becoming accepted as a proven technology in earthquake hazard mitigation. Interestingly, base isolation is a passive control system; it does not require any external force or energy for its activation.



2. 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 study the behavioural pattern of structures during earthquakes having fixed and flexible base.
- To study the parameters of storey displacements, Maximum storey drift of all models during earthquake.
- To study the time periods & mass participating ratios in different modes.
- To study the effect of different types of base isolation system along with fixed and flexible base.

3. 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.

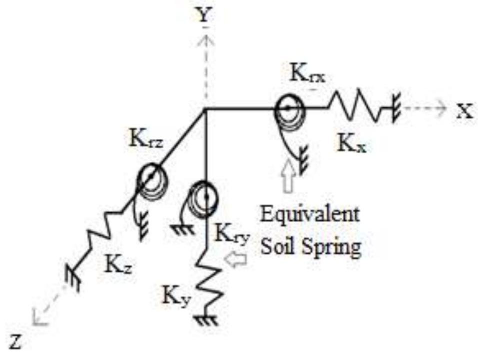
Soil Structure Interaction & Isolated Footings-

The impacts of the SSI are more centred around 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.

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.

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.

ELEMENTS OF BASE ISOALTOR: -

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.

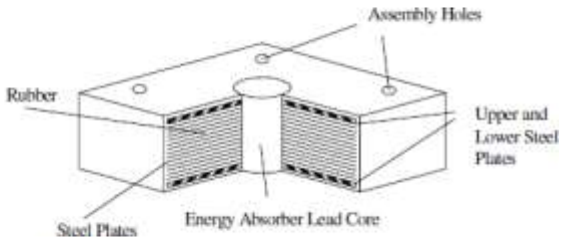
TYPES OF BASE ISOLATERS `

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.

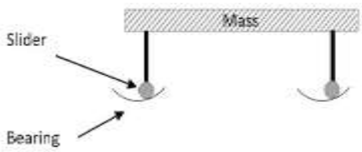
LEAD RUBBER BEARING

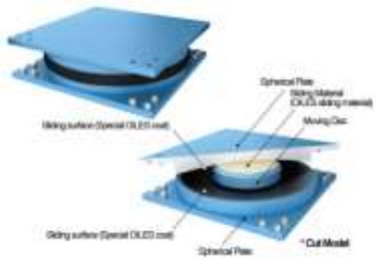
The second type of elastomeric bearings is lead-rubber bearings (LRB). This type of base isolation system provides the combined features of vertical load support, horizontal flexibility, restoring force, and damping in a single unit. A lead-rubber bearing is formed of a lead plug force- fitted into a 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.



Frictional Sliding Base Isolator

For large vibrations, sliding materials slide to provide the same deformation performance as large-scale isolation systems. Friction pendulum system (FPS): Sliding friction pendulum isolation system is one type of flexible isolation system suitable for small to large-scale buildings. It combines sliding a sliding action and a restoring force by geometry. Functions of FPS are same as SSR system.





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

Model 9 – SMRF RC structure with fixed support at base with Frictional Sliding base isolator

Model 10 - SMRF RC structure with spring property of hard strata at base with Frictional Sliding base isolator

Model11 - SMRF RC structure with spring property of medium strata at base with Frictional Sliding base isolator

Model 12 - SMRF RC structure with spring property of soft strata at base with Frictional Sliding base isolator

Soil Properties –

SOIL TYPE	DESIGNATION	Modulus of Elasticity	Poisson’s Ratio	Unit Weight of Soil
Hard	Hard	65000	0.3	18

Medium	Medium	35000	0.4	16
Soft	Soft	15000	0.4	16

Footing Property –

Footing TYPE	Size	Modulus of Elasticity of concrete	Poisson's Ratio
Isolated	2m x 2m x 1m	2.5×10^7 kN/m^2	0.2

Spring Property –

Degrees of freedom	Stiffness of equivalent soil spring	HARD	MEDIUM	SOFT
Horizontal (longitudinal direction)	*[2GL/(2-ν)](2+2.50χ0.85) with χ = Ab/4L^2*	132352.9	70312.5	30133.9
Horizontal (lateral direction)	*[2GL/(2-ν)](2+2.50χ0.85) with χ = Ab/4L^2*	132352.9	70312.5	30133.9
Vertical	*[2GL/(2-ν)](2+2.50χ0.85)-[0.2/(0.75-ν)]GL[1-(B/L)] [2GL/(1-ν)](0.73+1.54χ0.75) with χ = Ab/4L^2*	162142.9	94583.3	40535.7
Rocking (about longitudinal)	*[G/(1-ν)]Ibx 0.75(L/B)0.25[2.4+0.5(B/L)]*	128512.1	74965.4	32128.0
Rocking (about lateral)	*[G/(1-ν)]Iby 0.75(L/B)$^{0.15}$*	132943.6	77550.4	33235.9
Torsion	*3.5G Ibz 0.75(B/L)0.4(Ibz/B4)$^{0.2}$*	59528.0	29764.0	12756.0

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

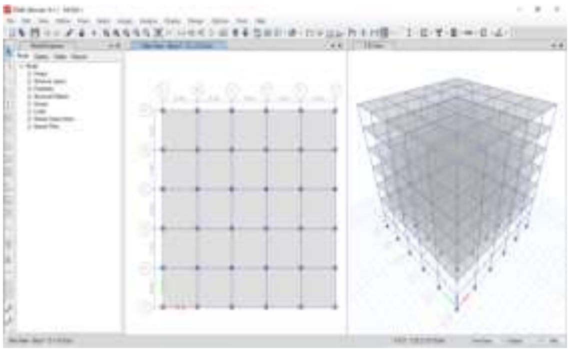
Design Parameters for LRB

Particulars	For the base of building
Kv (Vertical Stiffness)	986193.48 KN/m
Keff (Effective Stiffness)	2063.38 KN/m
Kh (Horizontal Stiffness)	2713.95 KN/m
Yield Strength Fo	55.674
Stiffness Ratio	0.1
Damping	0.05

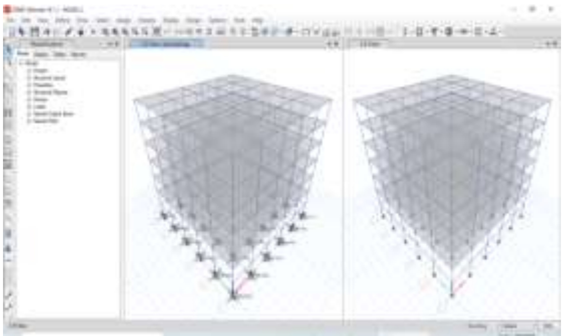
Design Parameters for Friction Sliding Base Isolator

Particulars	For the base of building
Mass (kn-sec^2/mm)	5×10^{-7}
Element height (mm)	50
Vertical Stiffness (kn/mm)	4000
Horizontal Effective Stiffness	0.524
Shear Deformation Location (mm)	25
Yield Displacement (mm)	0.01
Unloading Stiffness (kn/mm)	50
Coeff of Friction - slow	0.01
Coeff of Friction - Fast	0.02
Rate parameter (sec/mm)	0.05
Radius (mm)	106
Rotational Stiffness (kn-mm/rad)	3×10^6

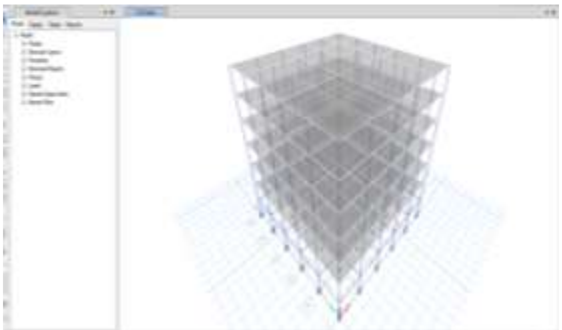
MODEL 1



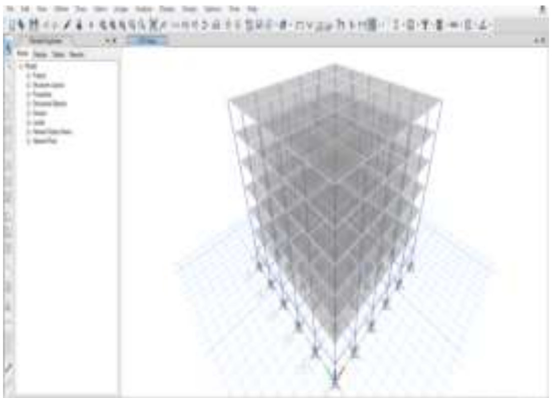
MODEL 2, 3 & 4 with different properties of soil



MODEL – 5 WITH LRB

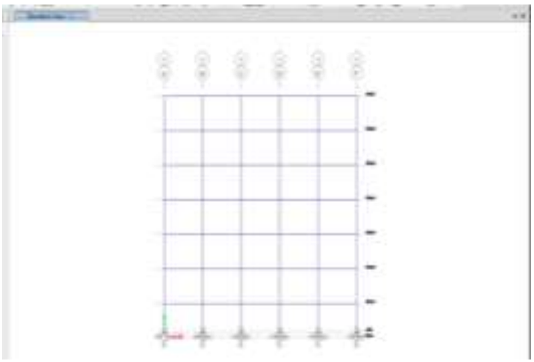


MODEL – 6,7,& 8 with different properties of soil with LRB

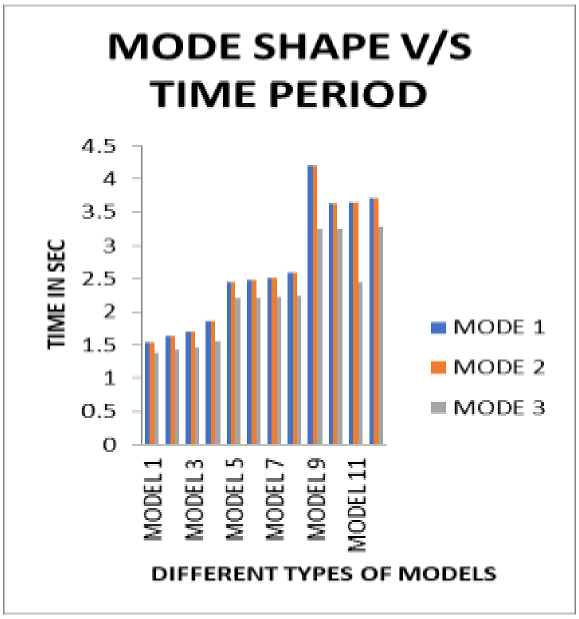


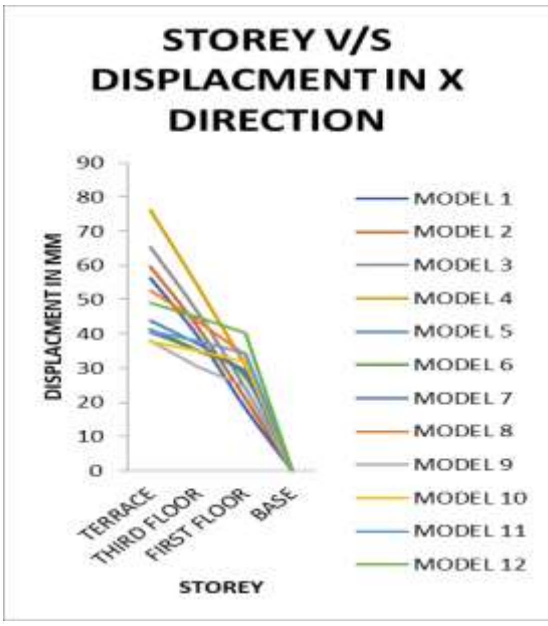
MODEL 9 WITH FRICTION SLIDING ISOLATOR –

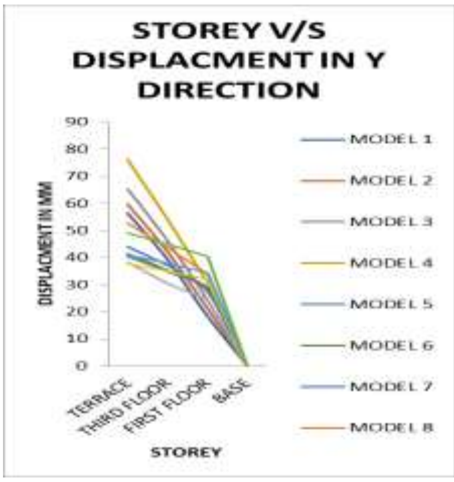
MODEL – 10, 11,& 12 with different properties of soil with Friction Sliding Isolator

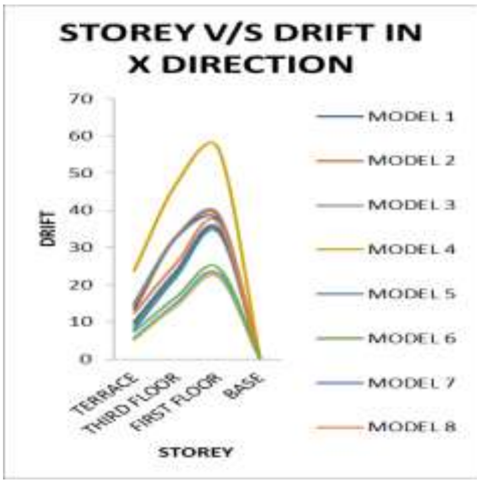


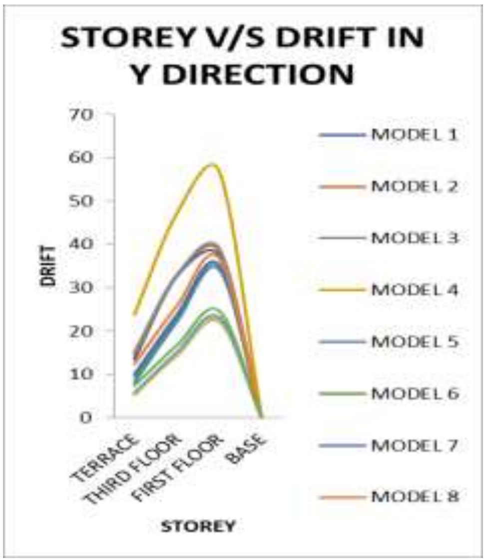
4. Results –

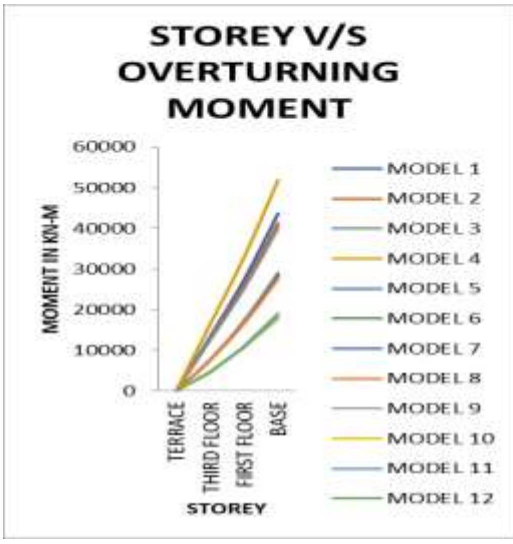


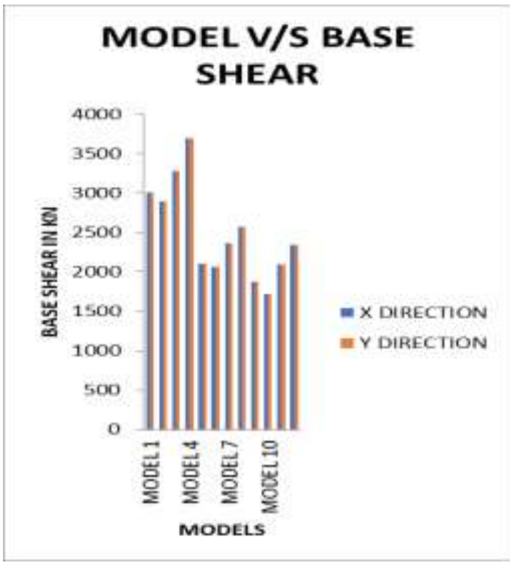












5. Conclusion –

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 with the properties of spring as per the type of soil as compare to the FEM support property.

3. Natural Time period of the building also increases with the use of 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.

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