



Seismic Impact of Reinforced Concrete Frames with and without Base Isolation under Varied Soil Conditions Utilizing Soil-Structure Interaction Effects

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ABSTRACT—

Seismic events present a considerable risk to reinforced concrete (RC) edifices, especially in areas marked by intense seismic activity and diverse soil conditions. The seismic behavior of structures is affected not solely by their design and the nature of the earthquake but also by the interplay between the soil and the foundation, known as soil–structure interaction (SSI). Base isolation is a proficient seismic defense method that diminishes the transfer of earthquake-generated stresses from the ground to the superstructure by incorporating flexible isolation mechanisms between the foundation and the structure. The current research seeks to examine the seismic behavior of reinforced concrete frameworks both with and without base isolation across various soil conditions, taking into account the implications of soil-structure interaction. Analytical models of reinforced concrete frames will be constructed and assessed utilizing appropriate structural analysis software. The research will analyze several soil profiles, including hard, medium, and soft soil, to assess their impact on the dynamic properties and seismic behavior of the structures. Both fixed-base and soil-interaction models will be examined, with and without base isolation, to conduct a comparative evaluation of their performance under seismic loading. The primary reaction metrics will encompass natural time period, base shear, storey displacement, inter-storey drift, acceleration response, and overall structural integrity. The study will concentrate on comprehending the effects of soil pliability and base isolation on the allocation of seismic pressures and the deformation traits of reinforced concrete frames. The findings are anticipated to reveal the comparative effectiveness of base isolation in enhancing seismic performance under various soil conditions and to ascertain the impact of soil-structure interaction on the behavior of both isolated and traditional structures. The results could aid in the creation of more secure and cost-effective earthquake-resistant structural systems by elucidating the synergistic impacts of base isolation and soil-structure interaction during seismic occurrences. Symmetric spatial frameworks supported by isolated foundations with 5 bays in both the x and y axes, comprising G+5 stories, are examined with both fixed and flexible bases, incorporating various forms of base isolators. The spring model is formulated utilizing the stiffness equation across all six degrees of freedom, while the elastic continuum model is constructed through the Finite Element Method with Etabs V18. The dynamic assessment is conducted utilizing the Response Spectrum outlined in IS1893-2016. The impact of soil-structure interaction on several structural parameters, such as natural time period, base shear, roof displacement, drift, and overturning moment, is discussed. The research indicates that the SSI has a substantial impact on the structural response.

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

1. Introduction -

In the seismic design of building structures, it is typically presumed that the soil is unflexible, a notion that holds true only when the foundation rests on solid rock or when the soil exhibits considerable stiffness. In all other instances, the soil surface interaction (SSI) comprises two separate effects – kinematic and inertial interaction, which is intricate. Soil-structure interaction (SSI) denotes the phenomenon where the soil's reaction affects the structure's response, and conversely, the structure's reaction impacts the soil's movement (Kramer, 1996). The structures are regarded as detached with a stationary foundation for the purpose of facilitating easier computations. Nevertheless, the structures are not constructed in seclusion in actuality. The seismic behaviour of structures, particularly when in proximity, does not function autonomously; given that their foundations rest on the same substrate, their responses influence one another. Moreover, contrary to the assumption that Soil-Foundation-Structure Interaction (SFSI) prolongs the natural time period of a structure and is advantageous during design, research indicates that this extension can result in resonance. Furthermore, SSI can cause the ductility to rise dramatically when the natural period of the structure increases. Permanent soil deformation and failure may worsen the structure's seismic reactivity.

Due to the recent surge in population, there has been a marked increase in the demand for multi-story buildings. However, as the number of stories increases, particularly in relation to seismic events, the safety of the structure must be taken into consideration [1-4]. Seismic forces are unpredictable and can cause significant damage when they occur, so understanding how structures behave and react during an earthquake is crucial. Devastation in terms of life, money, and structural failure is immense in the aftermath of an earthquake. Historical evidence from earthquakes shows that

traditional buildings often crumbled or suffered damage when the ground shook. Modern cities are characterized by skyscrapers because to the rising demand for office and residential space caused by the fast expansion of both populations and businesses. Furthermore, structures must be erected inside earthquake zones. thus, seismic energy dissipation devices and base isolation are appropriate strategies that must be incorporated into the design of our building structure to withstand seismic forces. The world over, seismic control strategies are embraced. It can be utilized for retrofitting reasons to enhance the structure's flexibility.

The main rationale for building at a higher level is to safely transfer the main gravity load. Gravity loads can be either dead or live. Furthermore, the building must be able to resist the lateral loads imposed by wind, blasting, and earthquakes, all of which vary according to the types of terrain. Sway moments and high stresses caused by the lateral load reduce the structure's stability. Therefore, under these situations, stiffness is comparable to strength when it comes to resisting lateral loads. In order to enhance the seismic performance of structures, there are multiple methods for providing a lateral load resisting system, such as bracing, base isolation, and dampers. A passive vibration control system, base isolations harness the motion of the structure to provide control force without the need for external power sources. Advantages of this approach include ensuring security in the face of massive earthquakes while keeping the structure essentially flexible.

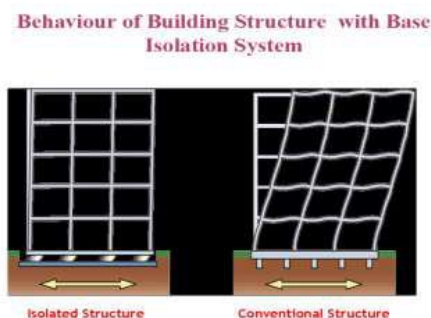
1.1 Soil Structure Interaction -

Soil-structure interaction (SSI) refers to the relationship between the ground and a construction erected on it. It is fundamentally a reciprocal exchange of stress, in which the dynamics of the ground-structure system are affected by the nature of both the substrate and the edifice. This is particularly relevant to regions with seismic activity. Different configurations of soil and structure can either enhance or reduce movement and ensuing damage. A structure situated on rigid terrain as opposed to pliable soil is likely to incur more significant damage. A secondary interaction impact related to the mechanical characteristics of soil is the subsidence of foundations, exacerbated by a seismic occurrence. This occurrence is referred to as soil liquefaction.

The majority of civil engineering constructions incorporate a structural component that directly interacts with the ground. When external pressures like earthquakes influence these systems, the structure displacements and ground displacements are interdependent. The phenomenon where the soil's response affects the movement of the structure and vice versa is referred to as soil-structure interaction (SSI).

1.2 Base Isolation System –

Base isolation of edifices is among the most sought-after methods for safeguarding them against seismic pressures. The essential principles of earthquake engineering can be characterized as the process of isolating or decoupling the structure from its foundation. This phenomenon minimizes inter-storey drift and optimizes displacement in the floors of base-isolated structural systems, hence ensuring minimal damage to facilities and safeguarding life and property. The notion of base isolation has been proposed throughout the past few decades, with technology now accessible, and the understanding of base isolation systems being utilized, refined, and therefore well-established. Seismic isolation technologies demonstrate greater efficacy in high stiffness, low-rise structures due to their capacity to transform the building's properties from rigid to flexible. The progressive rise in the quantity of structures requiring isolation underscores the growing acceptance of base isolation systems as a validated technique for mitigating seismic hazards. Notably, base isolation functions as a passive control mechanism; it operates without the necessity for external forces or energy to initiate its action.



2. OBJECTIVES OF THE STUDY

Structural stability serves as a valuable metric that correlates with the seismic elastic response of reinforced concrete structures. The research is conducted utilizing two SSI techniques, namely discrete support (employing springs) and Elastic Continuum (utilizing FEM). An effort is also undertaken to comprehend the efficacy and applicability of this research and its impact on the framework. The research aims to offer a comparative analysis of the influence of soil conditions and soil-structure interaction on the seismic performance of isolated versus non-isolated reinforced concrete frames, thereby facilitating more dependable and cost-effective earthquake-resistant structural design. The subsequent studies are deemed pertinent for the research endeavour —

- To examine the seismic response of reinforced concrete frame edifices with and without base isolation.
- To examine the impact of varying soil conditions, including hard, medium, and soft soil, on the seismic response of structures.

- To examine the behavioural dynamics of structures with fixed and flexible bases during seismic events.
- To assess the influence of soil-structure interaction on the dynamic properties and seismic response of reinforced concrete frameworks.
- To analyse the factors influencing storey displacements, including the peak storey drift across all models during seismic events.
- To examine the temporal durations and mass participation percentages across various modalities.
- To evaluate the efficacy of base isolation in mitigating structural demands caused by earthquakes, considering soil pliability.
- To examine the impact of various base isolation systems in conjunction with both fixed and flexible bases.
- To determine the optimal pairing of soil characteristics with base isolation systems for enhancing the seismic resilience of reinforced concrete frame constructions.

3. METHODOLOGY –

Emerging structures are not merely sought after but have also become essential to meet personnel needs and obligations. To meet these requirements, structural reform has become essential to adhere to safety standards and facilitate such structural configurations. Numerous structural theories are put out with other solutions, specifically structural measures recommended to fulfill this requirement while ensuring the safety of the building against lateral forces.

A thorough examination of multiple research papers addressing lateral loading induced by seismic or wind forces across various seismic zones has led to the conclusion that structural engineers have made significant advancements in meeting human needs by developing intricate yet reliable structural systems to guaranty safety and functionality. In addition to various structural configurations, the shear wall at the core, functioning as a dual system with disparate concrete grades in the outrigger and wall belt supported system, has yet to be analyzed for optimizing building architecture and layout against lateral forces.

The objective of conducting seismic analysis is to ascertain many factors, including the forces, deformations, and capacities of each component inside the building structure.

Soil Structure Interaction & Isolated Footings-

The effects of the SSI predominantly focus on its adverse consequences. As mentioned, irrespective of studies indicating that the strategy based on soil structure correlation extends the duration, an increase in time span is not necessarily advantageous. Seismic waves experience an extension while traversing areas with fragile soil deposits. This transpires with a considerable elongation oscillation. Presuming the standard duration of development, the interest for flexibility also rises. This could result in enduring deformities and exacerbate dissatisfaction, which will further intensify the primary earthquake response. A design subjected to seismic forces (seismic excitation) exhibits a relationship between the soil and the structure that induces alterations in ground motion. The dirt design association may exhibit two types of characteristics or effects (as per FEMA P-750 and NEHRP).

The reaction of a structure is influenced by the interplay of three interconnected systems subjected to seismic forces: the foundation, the structure itself, and the soil that encases and supports the foundation. Soil-structure interaction study assesses the collective reaction of these systems to a defined ground motion.

Elements Influencing Soil Structure Interaction -

The primary elements that affect the behaviour of framed structure foundation-soil interaction are :

- Types of soil available surrounding and below the foundation at various depths.
- Stiffness between footing and soil, and also between super-structure and footing.
- Size, shape and types of footing/foundation.
- Stress-strain relationship and soil nonlinearity of foundation soil.
- Type of loading: Static or Dynamic
- Water table depth from surface.

PRINCIPLE OF BASE ISOLATION: -

In application, isolation is confined to an examination of the horizontal forces that mainly affect buildings. Vertical isolation is less essential and considerably more challenging to do. While every earthquake possesses distinct characteristics, it can generally be asserted that ground vibrations from earthquakes induce a more pronounced acceleration reaction in structures with shorter periods compared to those with longer periods. A seismic isolation system utilizes these phenomena by altering the fundamental period of the structure from the more susceptible shorter intervals to the less susceptible longer periods. The concept of seismic isolation involves incorporating flexibility into the fundamental structure in the horizontal dimension, while simultaneously integrating dampening components to limit the resultant movement. In a perfect system, the seclusion would be complete. In reality, there

must be some interaction between the edifice and the earth. A structure that is entirely unflexible will possess a period of zero. When the earth shifts, the acceleration experienced by the structure will match the ground's acceleration, resulting in no relative displacement between the structure and the ground. Consequently, the structure and foundation shift by an equivalent distance.

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.

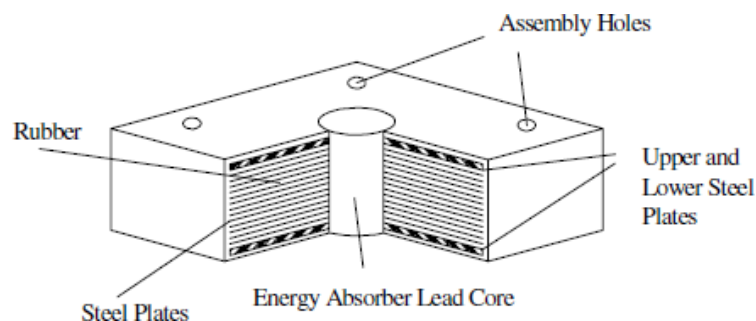
TYPES OF BASE ISOLATORS

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.

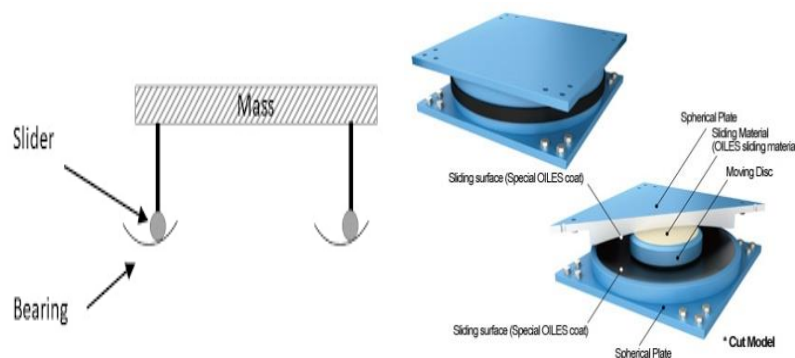
LEAD RUBBER BEARING

The elastomeric bearings are 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	68000	0.35	20
Medium	Medium	36000	0.35	16.5
Soft	Soft	18000	0.35	16

Footing Property –

Footing TYPE	Size	Modulus of Elasticity of concrete	Poisson's Ratio
Isolated	2.4m x 2.4m x 0.6m	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)	$[2GL/(2-\nu)](2+2.50\chi^{0.85})$ with $\chi = Ab/4L^2$	162352.9	80312.5	35133.9
Horizontal (lateral direction)	$[2GL/(2-\nu)](2+2.50\chi^{0.85})$ with $\chi = Ab/4L^2$	162352.9	80312.5	35133.9
Vertical	$[2GL/(2-\nu)](2+2.50\chi^{0.85}) - [0.2/(0.75-\nu)]GL[1-(B/L)]$ $[2GL/(1-\nu)](0.73+1.54\chi^{0.75})$ with $\chi = Ab/4L^2$	182142.9	99583.3	43535.7
Rocking (about longitudinal)	$[G/(1-\nu)]I_{bx} 0.75(L/B)0.25[2.4+0.5(B/L)]$	138512.1	84965.4	42128.0
Rocking (about lateral)	$[G/(1-\nu)]I_{by} 0.75(L/B)^{0.15}$	142943.6	87550.4	43235.9
Torsion	$3.5G I_{bz} 0.75(B/L)0.4(I_{bz}/B^4)^{0.2}$	65528.0	33764.0	15756.0

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

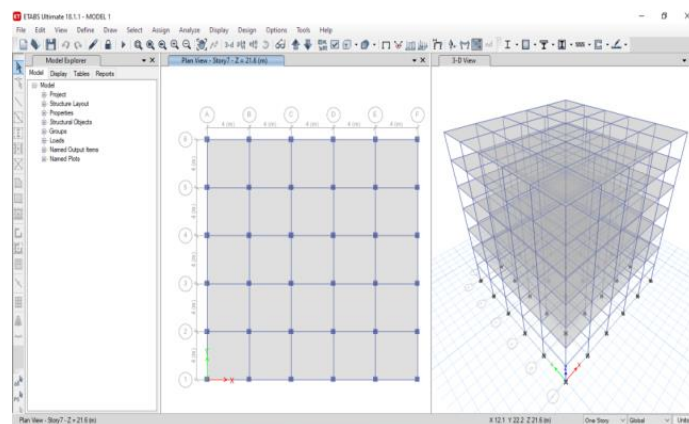
Design Parameters for LRB

Particulars	For the base of building
Kv (Vertical Stiffness)	956193.48 KN/m
Keff (Effective Stiffness)	2021.38 KN/m
Kh (Horizontal Stiffness)	2531.95 KN/m
Yield Strength Fo	51.674
Stiffness Ratio	0.15
Damping	0.05

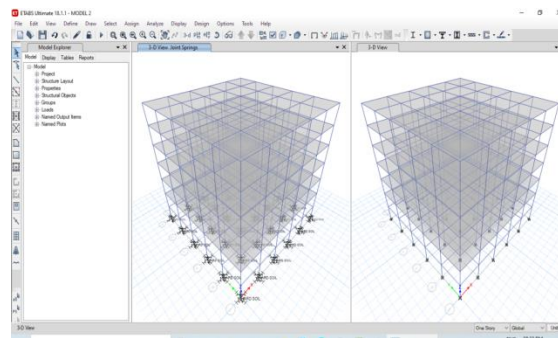
Design Parameters for Friction Sliding Base Isolator

Particulars	For the base of building
Mass (kn-sec ² /mm)	5×10^{-7}
Element height (mm)	75
Vertical Stiffness (kn/mm)	5000
Horizontal Effective Stiffness	0.775
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

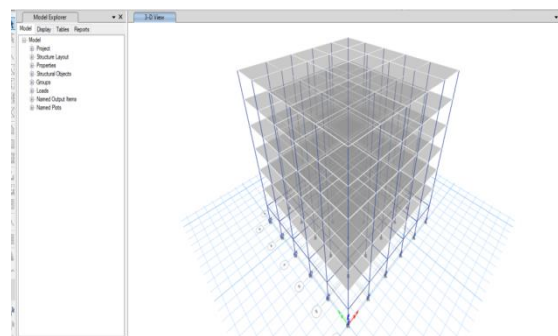
MODEL 1



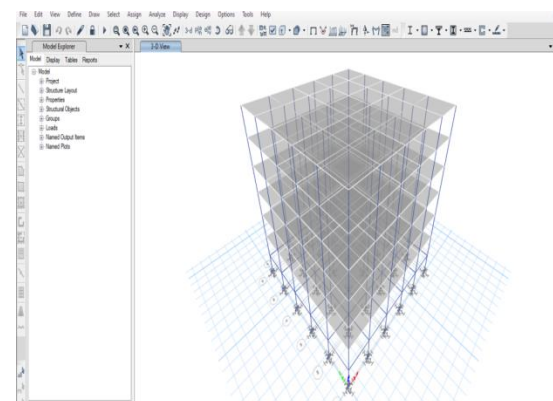
MODEL 2, 3 & 4 with different properties of soil



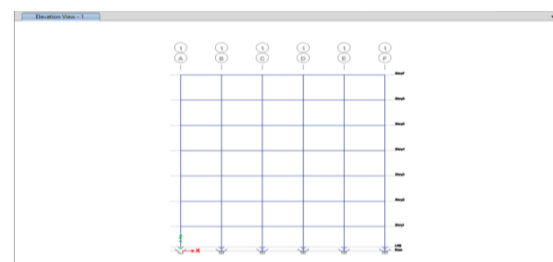
MODEL – 5 WITH LRB



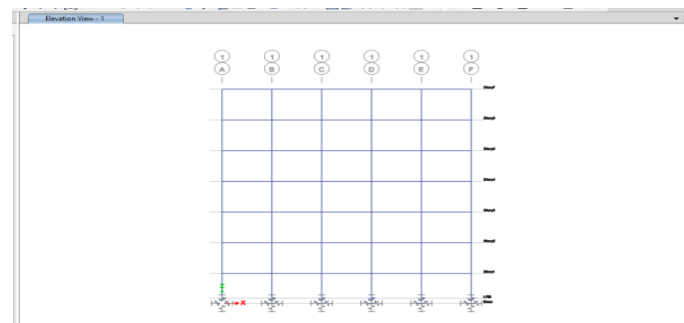
MODEL – 6,7,& 8 with different properties of soil with LRB



MODEL 9 WITH FRICTION SLIDING ISOLATOR –

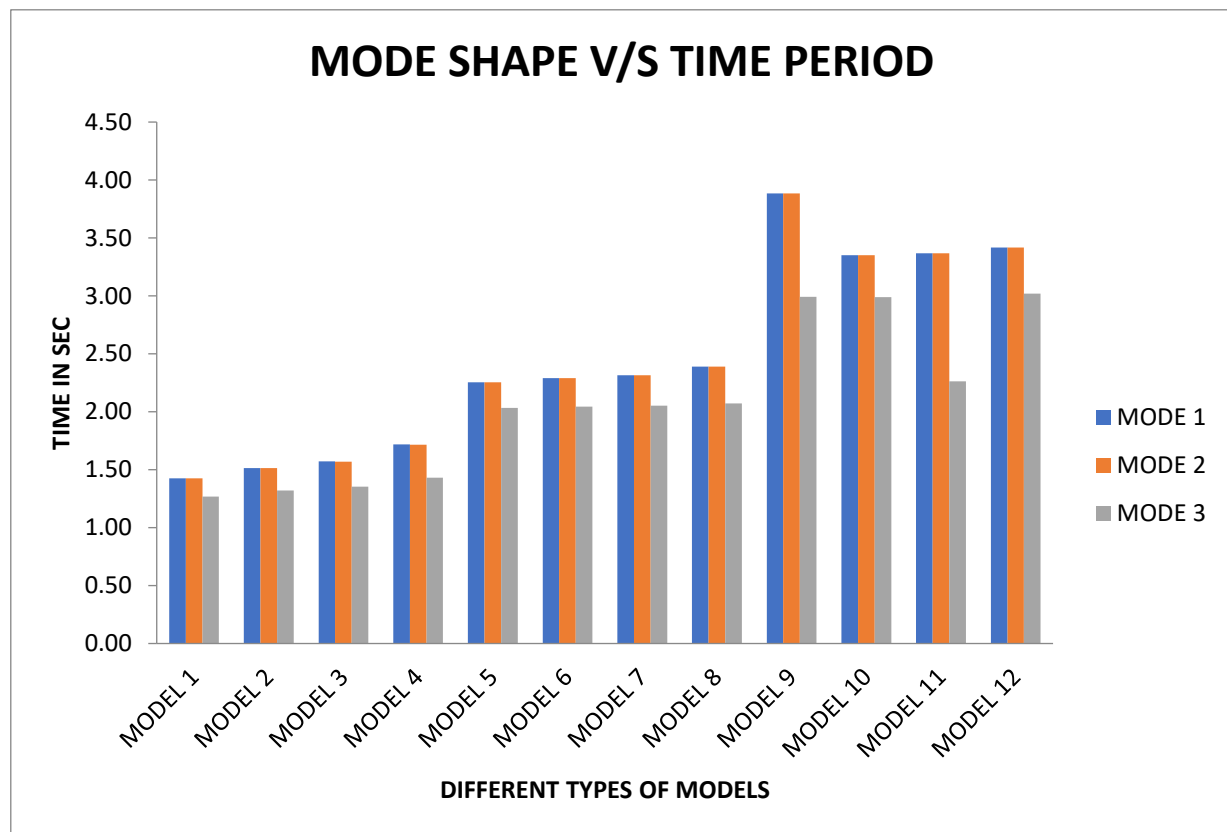


MODEL – 10, 11,& 12 with different properties of soil with Friction Sliding Isolator

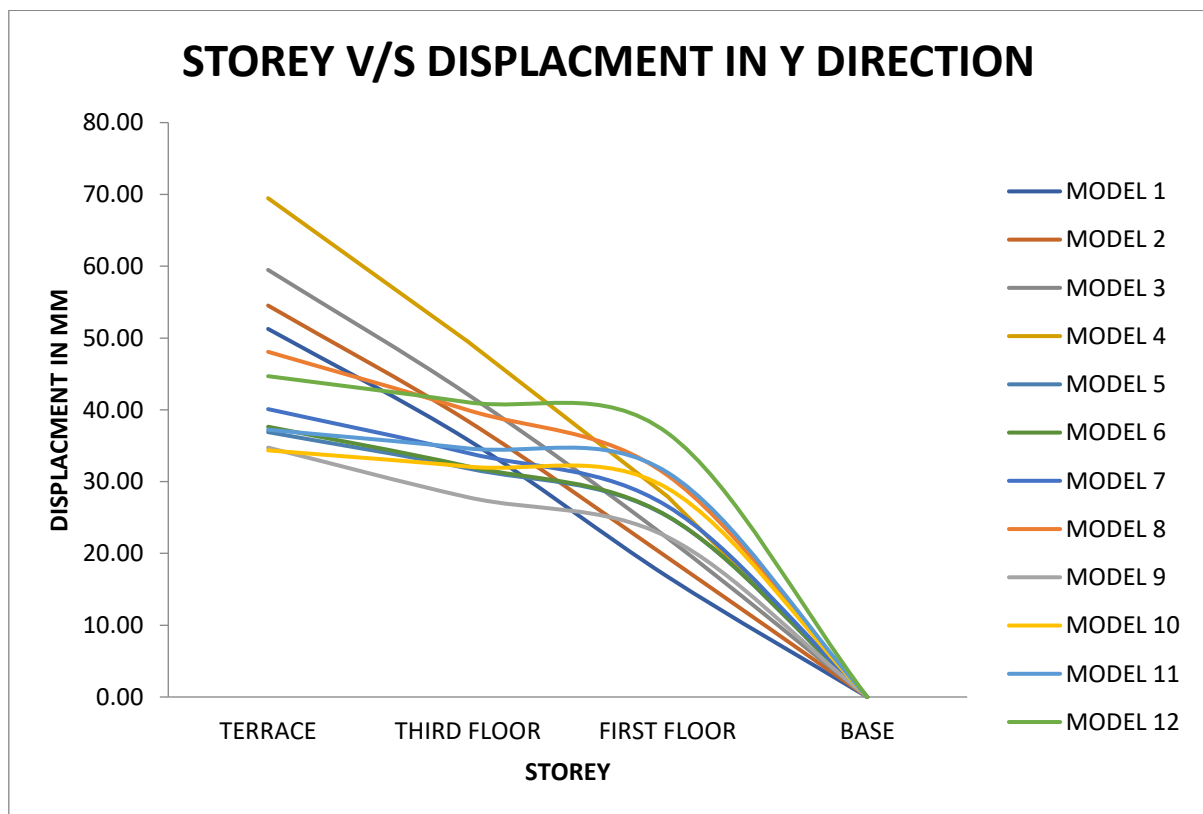
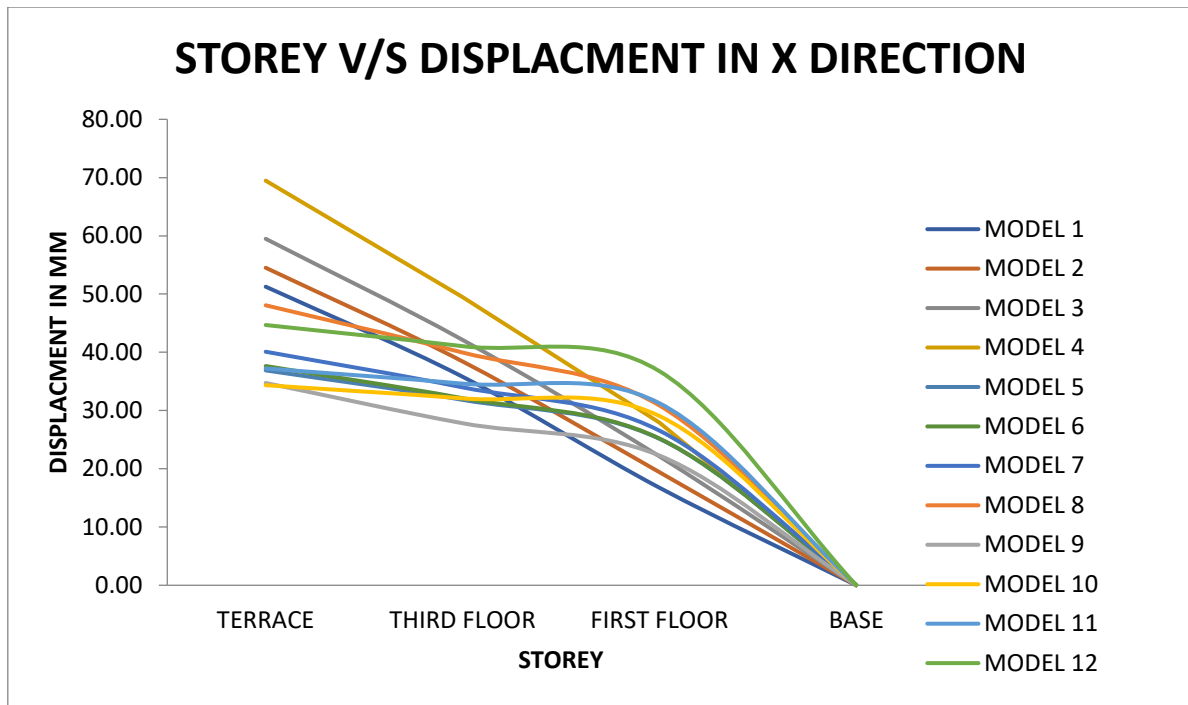


4. Results –

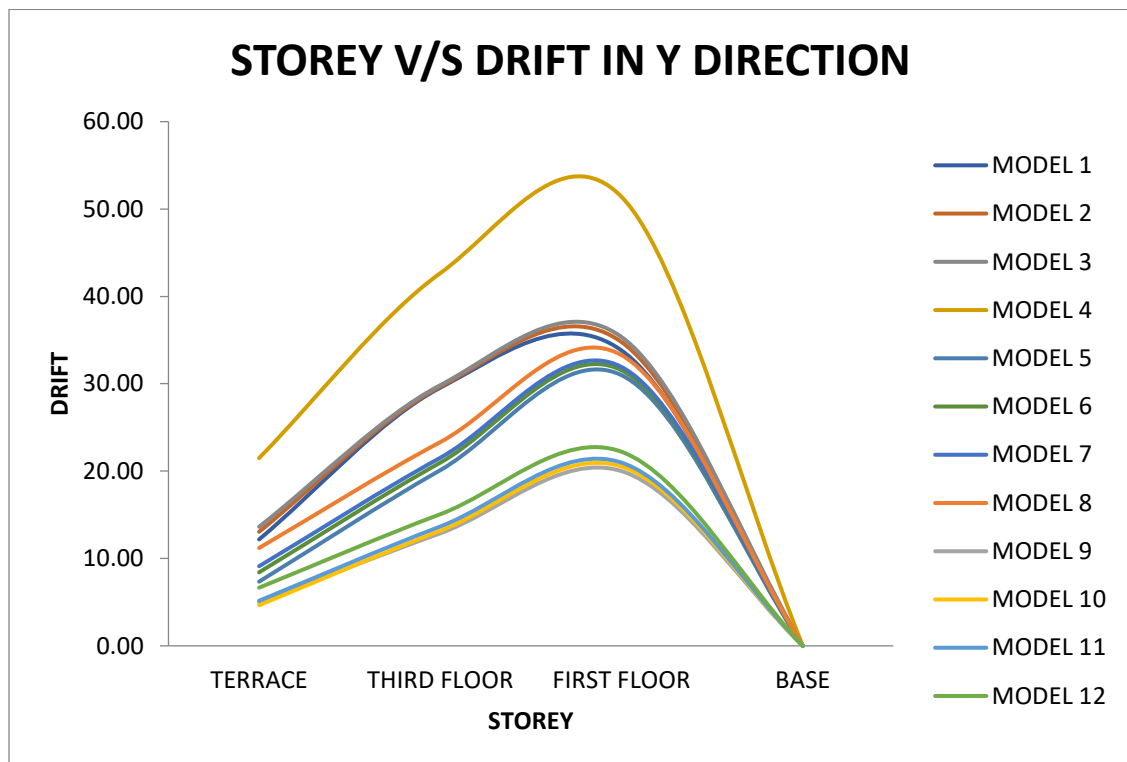
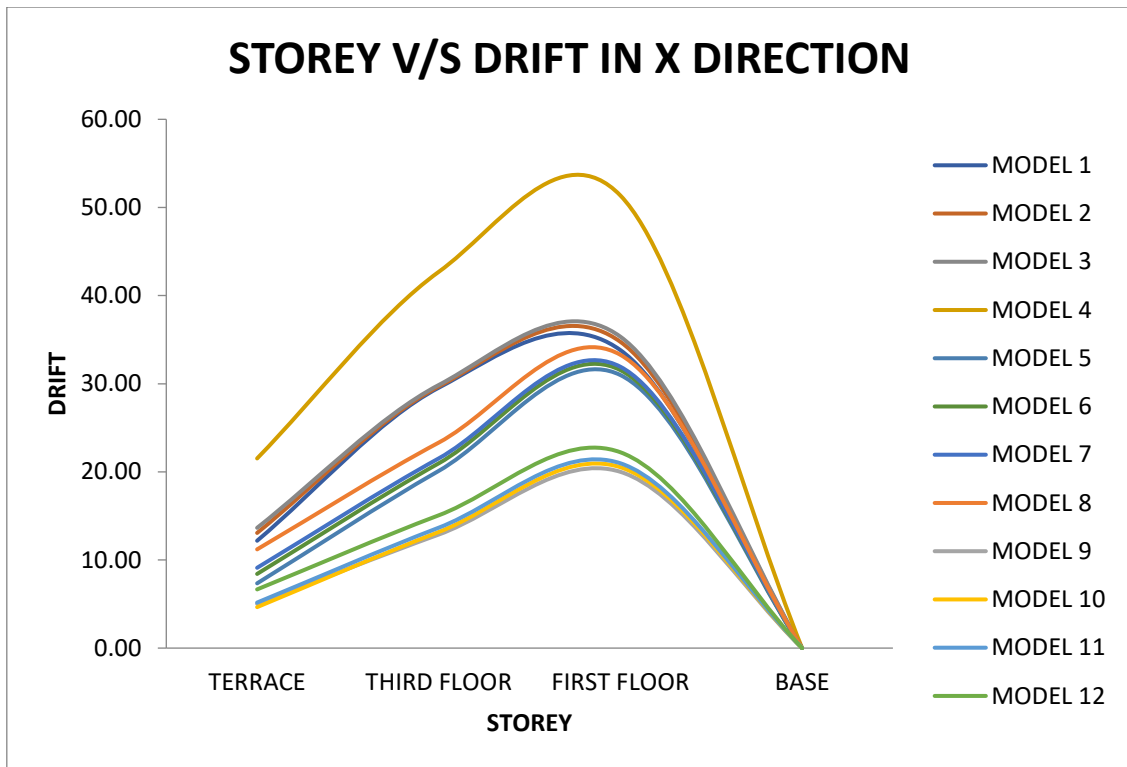
NATURAL TIME PERIOD –The time taken (in seconds) for complete cycle of oscillation is called Fundamental Natural Period of the building.



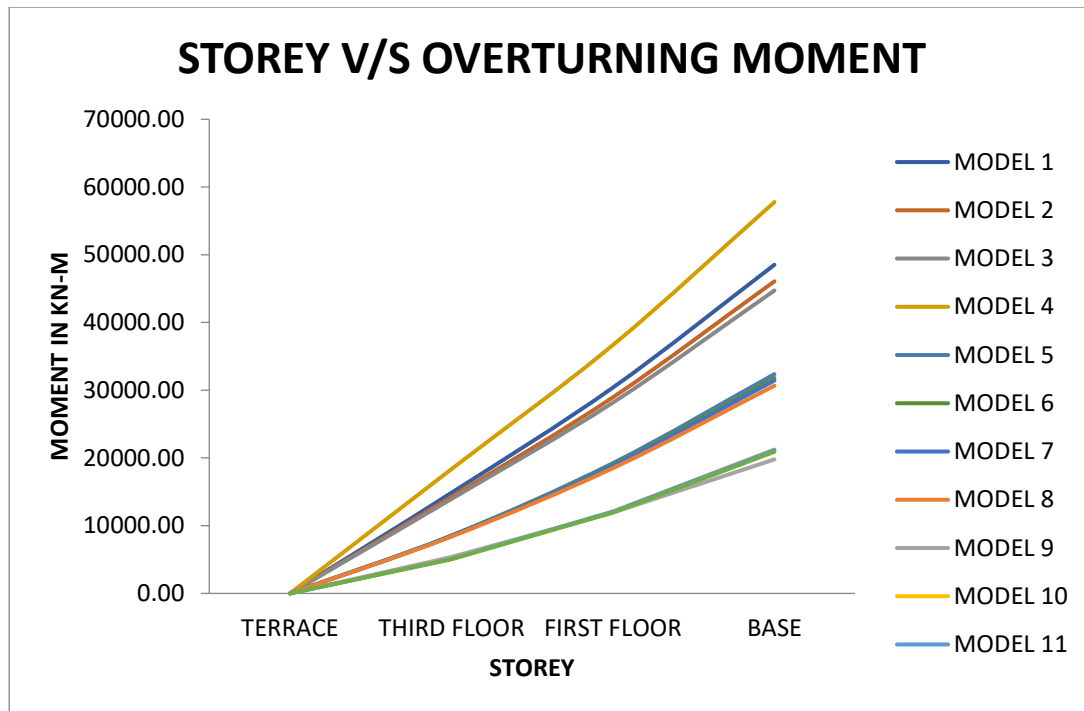
Displacement - The storey displacements of all the models are depicted in Figure below. It shows an increase in storey displacement along the height of the structure.



Drift - Below figures compares the drift of all the models along both X and Y directions. The drift values exceed the permitted drift range which is suggested by IS 1893:2016 Cl 7.11.1[3]. The code recommends a maximum permitted drift value of $0.004H$ where H is the storey height ($H=3.6m$) and the permissible drift.

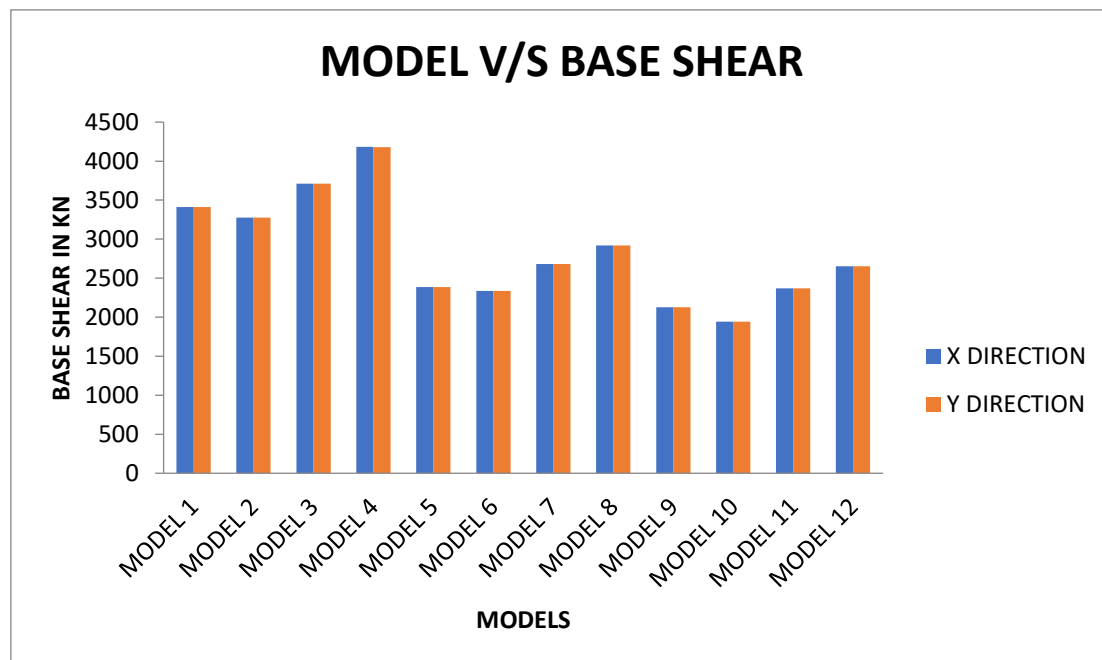


Overturning Moment - The overturning of a structure refers to the monolithic rotation of the structure with respect to an arbitrary point until its total collapses.



Base Shear – Base shear is an estimate of the maximum expected lateral force on the base of the structure due to seismic activity. It is calculated using the seismic zone, soil material, and building code lateral force equations.

Value of Base Shear for Different Type of Models –



5. Conclusion –

This chapter addresses the conclusions derived from the conducted analysis. The subsequent discourse pertains to the prospective scope of work. The aforementioned study has led to the conclusion that,

1. The base shear of a structure equipped with base isolation is reduced by 30% compared to that of a structure lacking base isolation.
2. The base shear of a structure rises by 20% on soft soil, by 8% on medium soil, and diminishes by 5% on hard soil when compared to a base with solid support.

3. The natural time period of the building rises by 60% with Lead Rubber Bearing base isolation and triples with friction sliding base isolation, resulting in a lower natural frequency of the structure, which is advantageous since higher frequencies lead to greater displacement of components, causing increased fatigue damage.
4. The displacement in both directions utilizing friction sliding base isolation diminishes by up to 30% for each soil type, as it results in reduced structural movement due to the support's rigidity.
5. The displacement of a structure with spring characteristics on soft soil is 5% greater than that of a building with a fixed base feature.
6. The lateral displacement in both directions utilizing friction sliding base isolation diminishes by up to 60% for every soil type. Furthermore, owing to the characteristic of base isolation, primarily the base experiences greater displacement, resulting in a diminished ratio of displacement between the upper and lower levels.
7. The story drift of a permanent support structure is 10% lower than that of a building with soft soil spring characteristics at its foundation.
8. The overturning moment utilizing friction sliding base isolation diminishes by as much as 50% across all soil types.
9. The overturning moment of the FEM Support structure is 5% greater than that of the building with a fixed base property.

Suggestion - The conceptualization of soil support through springs is a rough estimation. This does not demonstrate the adaptability with great accuracy. Consequently, it produces results of diminished accuracy. The pragmatic idealization of supporting soil can solely be achieved by the Finite Element method. This will yield more accurate data than the spring model. The research additionally indicates a disparity between the outcomes of soil spring data and fixed support. The spring model fails to accurately assess the values. The implementation of Friction Base Isolation is highly advantageous in regions prone to intense earthquakes, since it demonstrates a superior response to seismic forces.

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