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Soil Structure Interaction and Seismic Response of Base Isolated Steel Frame with BRB Damping Systems

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ABSTRACT:
This paper SSI refers to the process in which the reaction of the soil affects the motion of the structure and the motion of the structure affects the response of the soil. In this instance, neither structural nor ground displacements are independent from one another. The term "soil-structure interaction" refers to the effect of the behaviour of the soil immediately under and surrounding the foundation on the reaction of the soil-structure to static or dynamic loads. A foundation is the interaction between a superstructure and the underlying soil or rock. Typically, in static circumstances, only vertical loads must be transferred to supporting rock. In a seismic setting, the stresses exerted on a foundation by a structure subjected to seismic excitation might substantially surpass the static vertical loads and potentially cause uplift; in addition, there will be horizontal forces and possible foundation level displacement. The properties of the soil and rock at the location may considerably magnify incoming earthquake movements travelling from the earthquake source. A study is undertaken to determine the influence of SSI on the seismic Response of a multi-story steel frame with BRB Damping System. To compare research parameters such as story drift, base shear, displacement, and vertical settlement with those obtained from seismic analysis of a steel frame. As the tale length lowers, the deformation value falls as well. As the tale progresses, the Story drift value increases. As the height of the story drops, the base shear value likewise increases. Silty soil undergoes less deformation than sand and clay. Silty soil has less story drift than sand and clay. Silty soil has a greater base shear than sand and clay.
Keywords: *Soil Structure Interaction, Seismic Response, BRB, Damping Systems*

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I. INTRODUCTION

1.1 Opening Remarks

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 SSI. In this case neither the structural displacements nor the ground displacements are independent from each other.

The phrase 'soil-structure interaction' may be defined as influence of the behaviour 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.

SSI effects become prominent and must be regarded for structures where P delta effects play a significant role structures with massive or deep seated foundations, slender tall structures and structures supported on very soft soils with average shear velocity less than 100 m/s.

1.2 Composite structure:

A composite member is constructed by combining concrete member and steel member so that they act as a single unit. As we know that concrete is strong in compression and weak in tension on the other side steel is strong in tension and weak in compression. The strength of concrete in compression is complemented by strength of steel in tension which results in an efficient section. By the concept of this composite member the concrete and steel are utilized in a well-organized manner. The structural elements which are comprised in a composite construction are given below.

1. Composite deck slab
2. Composite beam
3. Composite column
4. Shear connector

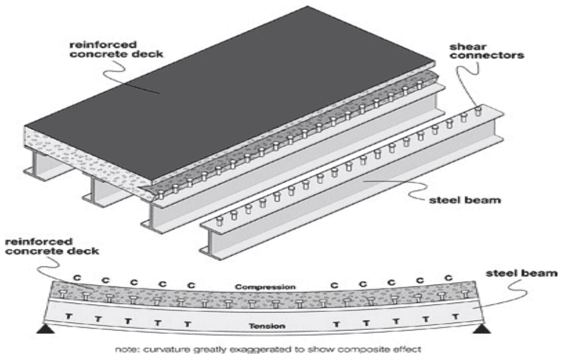


Figure 1: Composite deck slab and beams

1. Composite deck slab:

Composite floor system comprises of steel beams, metal deck and concrete slab. In general a steel beam for example I section is coupled with steel deck over which a concrete slab is laid. The metal deck rests between two steel sections which also serve as operational stand for concrete work. This composite floor system acts as a diaphragm due to which the composite floor system produces a rigid horizontal diaphragm, providing solidity to the structure in addition to that it distributes wind loads and earthquake loads to the composite frame system.

2. Composite beam:

A composite beam is produced by placing a concrete slab over steel beams mostly I section. When loads are applied on this member these rudiments have a tendency to perform in a self-regulating way which results in occurrence of slip among them. This relative slip can be eliminated when we provide an appropriate connection between steel beam and concrete slab, by providing connections the steel beam and concrete slab is made to act as a single unit. The steel which is weak in compression buckles under compression loads and concrete which is weak in tension develops cracks due to tensile loads. By providing above mentioned arrangement concrete and steel elements act together in order to resist both tensile and compression loads in an efficient way. Due to higher stiffness than steel members composite members deflect less than them. For same loading, employing composite beam results in thin, effective and economic cross sections than RCC structures. The composite deck slab and composite beams are shown in fig

3. Composite columns:

A compression member consisting of both steel and concrete elements can be termed as steel concrete composite columns. There are two types of composite columns
1. Concrete section with embedded steel section
2. A hallow steel section with concrete infill

Figure 2: Types of composite columns

Friction and bond are the two parameters which makes both steel and concrete elements to act as a single unit in composite columns. The general process of construction of composite column includes erection of hallow steel section or I section which takes the initial construction loads then it is filled with concrete or concrete is casted around I beam. Lateral deflections and buckling of steel members are prevented by concrete member. In addition to that composite columns have less cross sectional area and light weight when compared with RCC columns. Due to this the usable floor area increases in composite structures and foundation cost is also decreased

4. Shear connectors:

This is the main component which is responsible for the development of composite action between concrete slab and steel beam by shear transfer. This helps the composite system to take up large amounts of flexural stresses and to transfer horizontal loads to the lateral load resisting system. The purpose of shear connectors is to avoid partition of concrete slab and steel beam and to transmit the lateral shear at the concrete and steel interface. There are many types of shear connectors which can be employed based on their suitability.

1.3 Damping

On a global basis of resisting earthquake loads, shear walls are commonly used in RC framed buildings, whereas, steel damping is most often used in steel structures. In the last two decades, a number of reports have also indicated the effective use of steel damping in RC frames. The damping methods adopted fall into two main categories, namely:

1. External damping
2. Internal damping

In the external damping system, existing buildings are retrofitted by attaching a local or global steel damping system to the exterior frames. Architectural concerns and difficulties in providing appropriate connections between the steel damping and RC frames are two of the shortcomings of this method. In the internal damping method, the buildings are retrofitted by incorporating a damping system inside the individual units or panels of the RC frames. The damping may be attached to the Steel frame either indirectly or directly.

There are two types of damping systems

1. Concentric Damping System
2. Eccentric Damping System

The concentric damping's increase the lateral stiffness of the frame, thus increasing the natural frequency and also usually decreasing the lateral drift. However, increase in the stiffness may attract a larger inertia force due to earthquake. Eccentric Damping's reduce the lateral stiffness of the system and improve the energy dissipation capacity. Due to eccentric connection of the braces to beams, the lateral stiffness of the system depends upon the flexural stiffness of the beams and columns, thus reducing the lateral stiffness of the frame.

Concentric Damping's Eccentric Damping's

Figure 4: Type of damping

1.4 OBJECTIVE

- To estimate the effect of SSI on the seismic Response of multistore isolated steel frame with BRB Damping System.
- To study the parameter such as story drift, Base Shear, Displacement, Vertical Settlement are compare along with parameters which is obtain from seismic analysis of steel frame.
- To evaluate effectiveness of damping system considering SSI structural improvement of earthquake resisting structure.
- To conduct experimental investigation with shake table on base isolated steel frame with BRB damping System.
- To suggest appropriate measures for improve the stability of structure against seismic response. & SSI.

II. LITERATURE REVIEW

2.1 Opening Remarks

The literature surveys including some previous research papers regarding the study of Damping is efficient because the diagonals work in axial stress and therefore call for minimum member sizes in providing stiffness and strength against horizontal shear. A damping system improves the seismic performance of the frame by increasing its lateral stiffness and capacity. Steel-braced frames are efficient structural systems for buildings subjected to seismic or wind lateral loadings. Therefore, the use of steel-damping systems for retrofitting reinforced-concrete frames with inadequate lateral resistance is attractive.

The foundation designer must consider the behaviour of both structure and soil and their interaction with each other. The interaction problem is of importance to many civil engineering situations and it covers a

wide spectrum of problems. These include the study of shallow and deep foundation, floating structure, retaining wall-soil system, tunnel lining, earth structure etc:

2.2 Literatures Reviewed

Hendrik Wijaya et.al. (2019) studied using the premise of this paper is to investigate the effect of the uncertainty associated with the hysteretic damper design parameters on the probabilistic seismic performance of steel buildings. Two steel buildings which are designed in accordance with the European Standard design code are evaluated. The uncertainties associated with the damper design parameters are incorporated using the Optimised Latin Hypercube sampling method for different confidence levels. The building response is obtained by conducting nonlinear time history analyses in OpenSEES. The annual frequency of exceeding a damage limit state, which is quantified by integrating the seismic fragility curves and hazard curves, is computed for the steel buildings with and without consideration of the design parameter uncertainties. The application of hysteretic damper has gained major attention in seismic resistant design of buildings. It provides an efficient and cost-effective solution to reduce the level of damage induced on the building due to seismic excitations. The efficiency of the damper is influenced by parameters such as yield strength, yield displacement and brace-damper assembly system stiffness.

Seyed Ali Seyed Razzaghi et. al. (2019) In this study, the performance of Buckling Restrained Environmental Braces (BRB) in high-rise buildings were evaluated applying nonlinear time-history dynamics analysis with three pairs of acceleration and compared with conventional concentrically braced frame (CBF). The studied structures are 20, 40, and 60 stories building which braces were utilized peripherally. The acquired results reveal that the application of Buckling Restrained Brace Frames (BRB) instead of conventional braces frame (CBF) in high-rise steel buildings ameliorates hysteresis behavior of the braces and reduces lateral displacements and increase the capacity of base shear as well. In recent years, seismic design of structures has been undergoing significant changes as a result of increasing demand for optimization and minimizing the level of damage and reducing the cost of structural repairs, the development of analytical methods and the remarkable improvements of computer performance have been among the factors which influenced the design of structures. A lot of research has been conducted on the development of better braces with perfect elastoplastic behavior. The inventions and development of buckling restrained braces have been the results of these researches.

Héctor Guerrero et. al. (2017) this paper presents the experimental measurements of damping on structures equipped with Buckling-Restrained Braces (BRBs) working within their linear-elastic range. For comparison purposes, tests were also conducted on bare structures (without BRBs) and on a structure fitted with a conventional brace. All the experiments were conducted on a shaking table. The results show that, while the test with conventional brace did not show increase of the damping ratio, BRBs significantly did. This happened even when both, the main structure and the BRBs, exhibited linear-elastic response. A model is proposed to account for the dissipative forces observed on the experiments. The findings of this study are significant as they show that BRBs start dissipating energy at low levels of displacement; and this energy dissipation must be taken into account in the context of performance-based seismic design, so that the dynamic response demands on such structures are estimated properly. It has been widely recognised that the source of damping on structures is not viscous. However, an equivalent viscous damping, that generates similar dynamic response of structures, is used for simplification purposes. Under such consideration.

III. METHODOLOGY

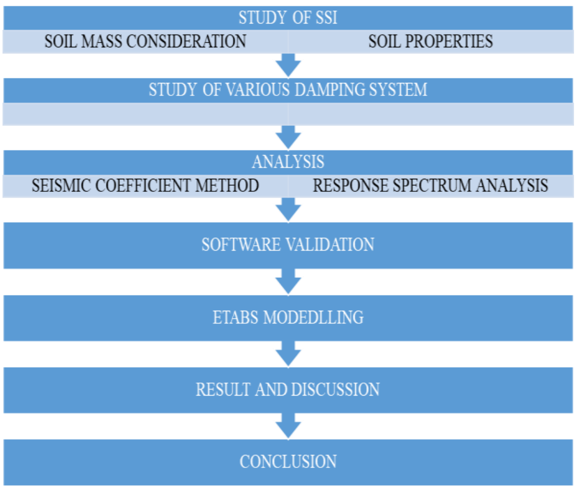


Figure 5: Layout of the Project

Soil – structure interaction plays an important role in the behaviour of foundations. For structures like beams, piles, mat foundation and box cells it is very essential for consider the deformation characteristics of soil and flexural properties of foundations. It can be seen that when interaction is taken into account, the true design values arrived-at may be quite different from those worked out without considering interaction. In general, in most of the case interaction causes reduction in critical design values of the shear and moments etc. However, there may be quite a few locations where the values show an increase. Because of these possibilities have their own roles to play in economy and safety of structure.

Several studies have indicated that the maximum bending moment in a foundation raft or beam could be substantially affected by interaction with superstructure. Reduction as high as 80% is reported in certain cases. The rigidity of foundation raft relative to soil is of extremely high values of bending moments in relative rigid rafts as compared to those in flexible rafts. An elastic-plastic analysis also indicates similar trend, although to a much lesser degree. An equal settlement is the severest cause for cracking and even failure of superstructures. On the other hand, rigidity of superstructure helps in reducing differential settlements. Of course to realize this, only interactive analysis has to be carried out.

***3.1* Soil Foundation Interaction Problem**

The study of the interaction between foundation and supporting soil media is of fundamental importance to both geotechnical and structure engineers. Results of such study can be used in the structural design of the foundation and in the analysis of the stresses and deformations with the supporting soil medium.

In-situ soils are commonly anisotropic and non-homogeneous and display markedly non-linear, irreversible and time dependant characteristics. The behaviour of such soils is expected to be influenced by following factors.

(i) The shape, sizes and mechanical properties of the individual soil particles.
(ii) The configuration of the soil structure.
(iii) The inter-granular stresses and stress history
(iv)The presence of soil moisture, the degree of saturation and the soil permeability

The solution of any interaction problem on the basis of all above factors is very difficult, laborious and impracticable, realistic and purposeful solutions can have achieved by idealizing the behaviour of the soil by considering specific aspects of its behaviour. The simplest idealization of response naturally occurring soils assumes linear elastic behaviours of the supporting soil medium. This idealization also assumes the surface of the soil medium to form the soil-foundation interface and the soil medium is represented by elastic medium occupying a half-space region. Though these assumptions are not always satisfied by in-situ soils, these considerably simplifying the solution and provide useful information to number of practicable problems in geotechnical engineering. Various idealization soil behaviour models will be introduced afterwards.

The flexural behaviour of foundation can be adequately described by modelling appropriately foundations as beam and plates, and using the convenient respective theories of beams and plates. The theories may be modified by incorporating the effects of shearing deformations or by taking in to account the three dimensional state of stress. It may be noted that the time dependant behaviour of the foundation itself can have a significant influence on the modelling and the end results of a soil foundation interaction analysis.

3.2 Behaviour of Interface:

The complete solution of the interaction problem necessitates prior assignment of a particular type of mechanical behaviour to the soil-foundation interface. The interface conditions associated with the elastic continuum behaviour of the soil medium are assumed to range from the completely smooth to the completely frictional interfaces. The factors which are expected to significantly affect the conditions at the soil foundation interface are:

1. The presence of pore water which can alter the magnitude and distribution of the frictional forces throughout the consolidation process.
2. The distribution and character of the external loads on the foundation.
3. The relative flexibility and type of the foundation, and
4. The time dependant effects.

Frictional effects at the interface are expected to acquire importance when dealing with the interaction of highly flexible foundations resting on compressible soil media. It is suggested that proper interface conditions be formulated only after obtaining adequate data from field observations. In the absence of such data interface may be assumed as smooth and such assumption can serve as a usual first approximation. The assumption of the smooth contact considerably simplifies the analysis of the interaction by retaining only the normal component of the contact stress.

3.3 Methods of soil modelling

The generalized stress-strain relations for soils, don’t represent even the gross physical properties of a soil mass, the idealized models are observed to provide a useful description of certain features of soil media under limited

boundary conditions. The idealized soil behaviour particularly reduces the analytical rigor spent in the solution of complex problems in geotechnical engineering.
The idealization will depend on a variety of factors such as:
1. The type of soil.
2. The soil conditions,
3. The type of foundation,
4. The nature of external loading,
5. The method of construction,
6. The purpose and life span of the structure and
7. The economic considerations.

Some important idealized models of soil-foundation interaction are briefly presented in following articles. The character of each model is typified by the surface deflection it experiences under the action of a system of forces, and these surface deflection in-general represent the displacement characteristics of the soil-foundation interface, and form a significant part of the soil foundation interaction analysis.

IV. MODELING

4.1 General:

The objective of this study is to develop efficient building models by using combination of braced frames. Four types of multi storied braced frame models are developed in seismic zone and evaluated its structural performance with respect to member strength, ductility and inter storey drift. Equivalent static method used for seismic analysis and the results are verified by software. The results of all four models are analysed and selected an efficient structural model for design of eight storied commercial building.

The steel concrete composite building used in this study is ten storied (G+9). building have same floor plan with5 bays having 4m distance along longitudinal direction and 3 bays having 5m distance along transverse direction as shown in figure.

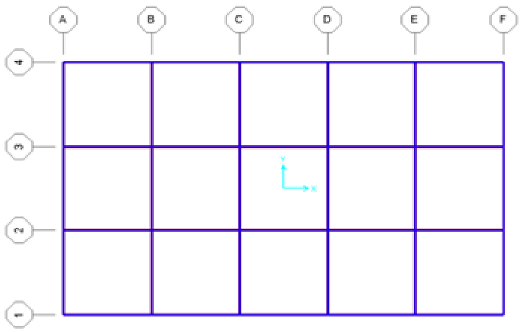


Fig 6: Building Plan

4.2 DESIGN DATA

Model 1- Composite floors are designed based on limit state design philosophy. Since IS 456:2000 is also based on limit state methods, the same has been followed wherever it is applicable. The design should ensure an adequate degree of safety and serviceability of structure. The structure should therefore be checked for ultimate and serviceability limit states.

(a) Design data

Model: G+9
Seismic zone: III
Zone factor: 0.16
Importance factor: 1
Height of building: 31.5 m
Floor height: 3.00m
Depth of foundation: 1.5 m
Plan size: 20 m X 15 m
Type of soil: Medium
Slab depth: 120 mm thick for R.C.C.
Wall thickness: 230 mm.

(b) Material Properties

Unit weight of masonry: 20kN/m^3
Unit weight of R.C.C.: 25kN/m^3
Unit weight of steel: 79kN/m^3

Grade of concrete: M20 for R.C.C and Steel.
Grade of steel: HYSD bars for reinforcement Fe 415
Modulus of Elasticity for R.C.C.: 5000 X $\sqrt{f_{ck}}$ N/mm^2
Modulus of Elasticity for Steel: 2.1 x 10^5 N/mm^2

Prepare Model in ETABS: -

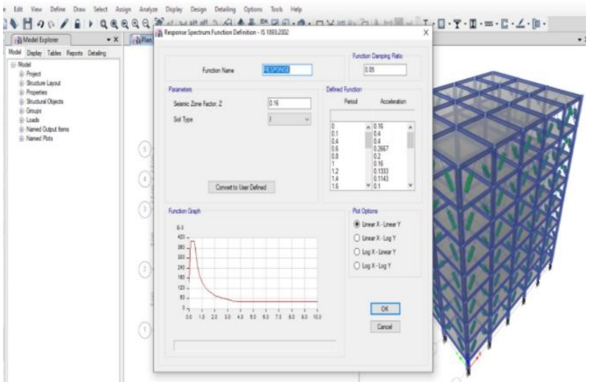


Fig 7- Define soil property and zone factors.

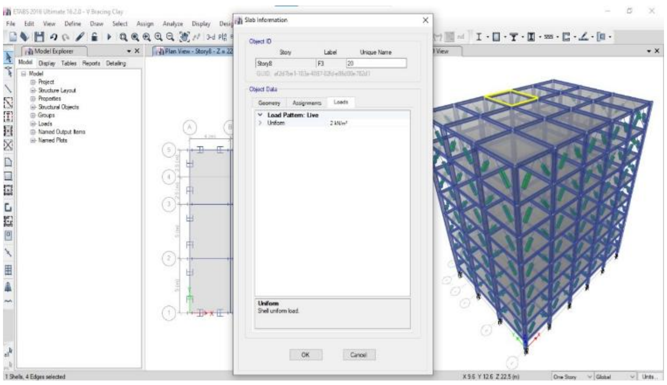


Fig 8: Assign Live and dead loads.

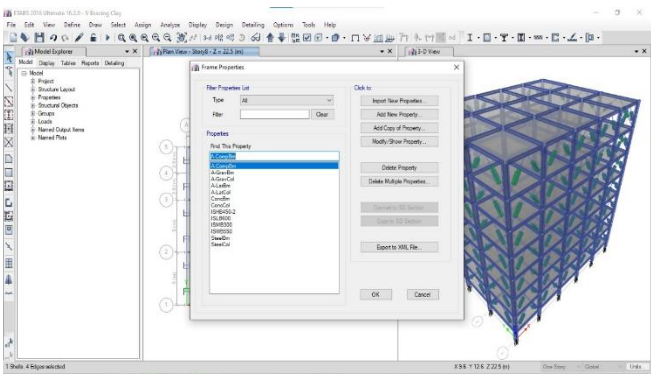


Fig 9: Define Member properties

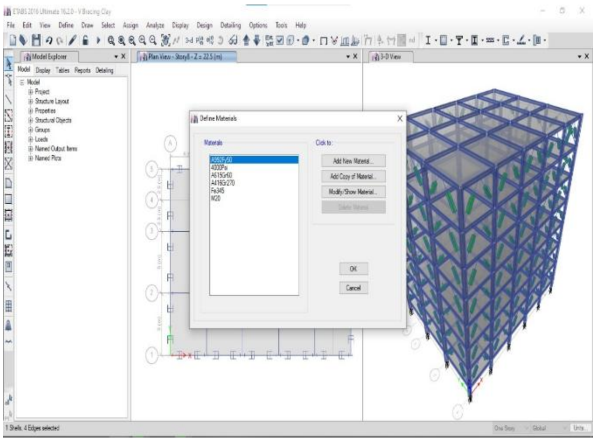


Fig 10: Define material property

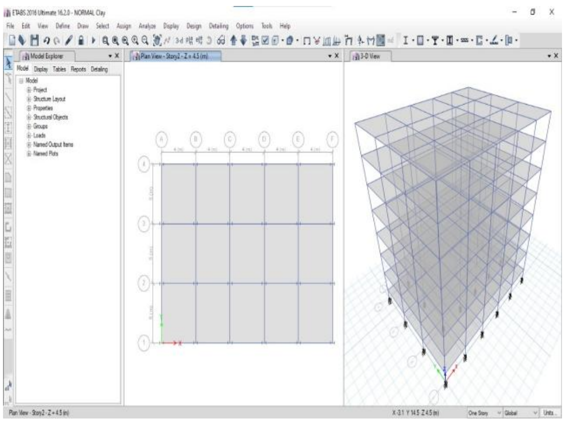
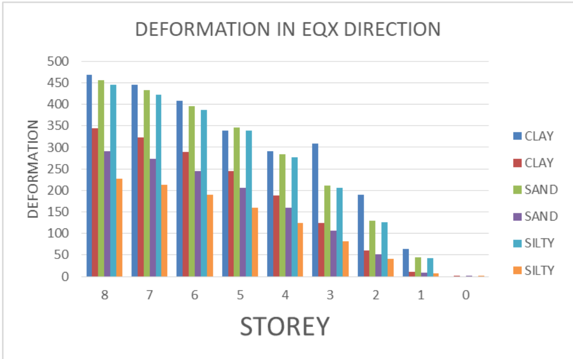


Fig No 11: Prepare modeling in ETABS

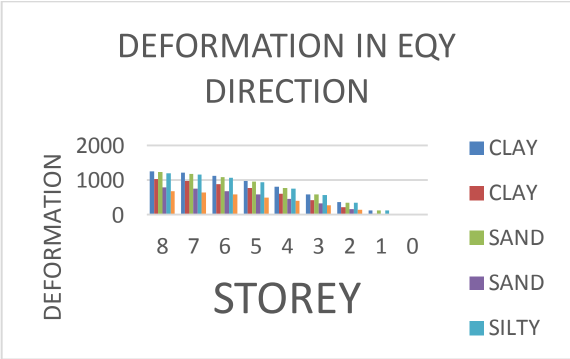
VI. RESULT AND DISCUSSION

COMPARISON OF CLAY, SANDY AND SILTY SOIL FOR WITH AND WITHOUT SSI



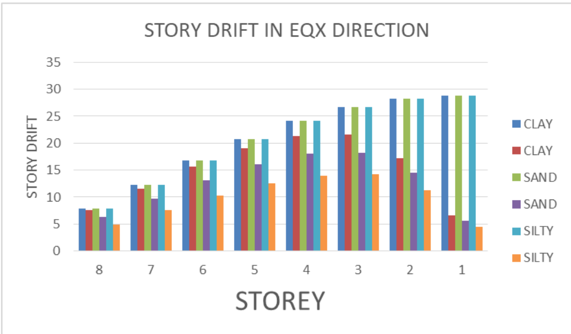
Graph no 1- Total Deformation in EQX Direction

The above graphs show total deformation in EQX direction for clay, sandy and silty soil for with and without SSI structure. In clay with SSI has lower deformation that the without SSI structure by 26.39%. In sandy soil with SSI has lower deformation that the without SSI structure by 36.06 %. In silty soil with SSI has lower deformation that the without SSI structure by 49.04%. And silty soil has the lowest deformation.



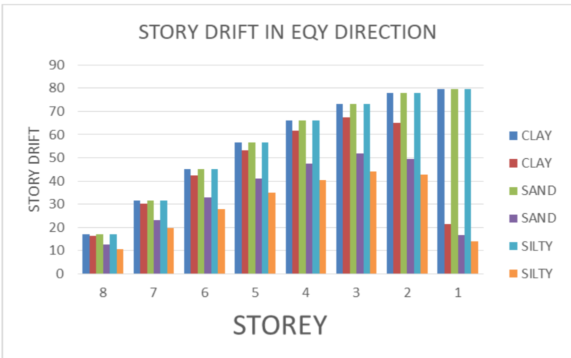
Graph no 2- Total Deformation in EQY Direction

The above graphs show total deformation in EQY direction for clay, sandy and silty soil for with and without SSI structure. In clay with SSI has lower deformation that the without SSI structure by 18.78%. In sandy soil with SSI has lower deformation that the without SSI structure by 35.69 %. In silty soil with SSI has lower deformation that the without SSI structure by 44.05 %. And silty soil has the lowest deformation.



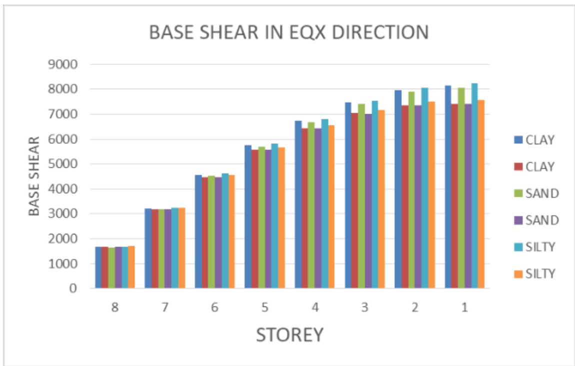
Graph no 3- Story Drift in EQX Direction

The above graphs show total story drift in EQX direction for clay, sandy and silty soil for with and without SSI structure. In clay with SSI has lower story drift that the without SSI structure by 4.48 %. In sandy soil with SSI has lower story drift that the without SSI structure by 19.76 %. In silty soil with SSI has lower story drift that the without SSI structure by 37.17 %. And silty soil has the lowest story drift.



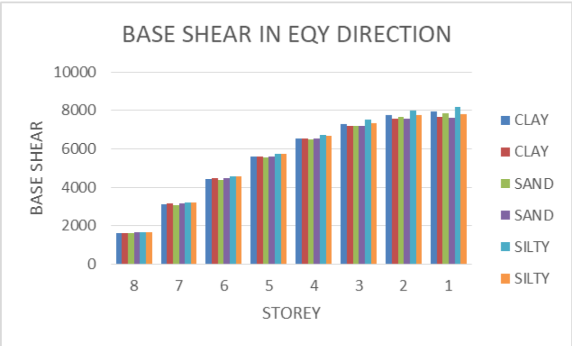
Graph no 4- Story Drift in EQY Direction

The above graphs show total story drift in EQY direction for clay, sandy and silty soil for with and without SSI structure. In clay with SSI has lower story drift that the without SSI structure by 4.58 %. In sandy soil with SSI has lower story drift that the without SSI structure by 25.73%. In silty soil with SSI has lower story drift that the without SSI structure by 37.23%. And silty soil has the lowest story drift.



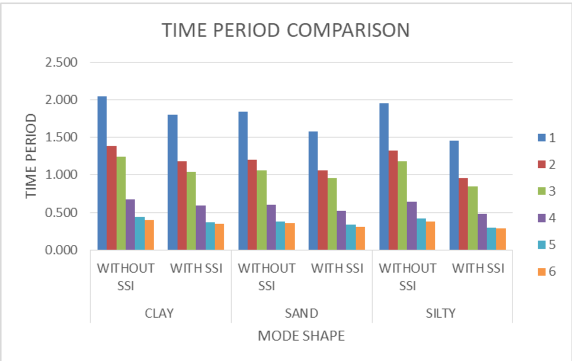
Graph no 5- Base Shear in EQX Direction

The above graphs show base shear in EQX direction for clay, sandy and silty soil for with and without SSI structure. In clay with SSI has lower base shear that the without SSI structure by 0.366 %. In sandy soil with SSI has lower base shear that the without SSI structure by 1.19 % In silty soil with SSI has lower base shear that the without SSI structure by 1.10 %. And silty soil has the highest value of base shear.



Graph no 6- Base Shear in EQY Direction

The above graphs show base shear in EQY direction for clay, sandy and silty soil for with and without SSI structure. In clay with SSI has lower base shear that the without SSI structure by 1.613%. In sandy soil with SSI has lower base shear that the without SSI structure by 2.699 % In silty soil with SSI has lower base shear. that the without SSI structure by 0.567 %. And silty soil has the highest value of base shear.



Graph 7- Time Period

The above graphs show time period for clay, sandy and silty soil for with and without SSI structure. In clay with SSI has lower time period that the without SSI structure by 12.048 %. In sandy soil with SSI has lower time period. that the without SSI structure by 14.309 % In silty soil with SSI has lower time period. that the without SSI structure by 25.15 %. And silty soil has the lowest time period.

VII. CONCLUSION

5.1 Opening Remarks

The objective of this research was to analyse oblique columns and Y-shaped columns for high-rise structure. The study has indicated that objectives of oblique columns and Y-shaped columns will achieve by proper planning and realistically.

The following summarizes the results and conclusions.

5.2 Conclusion of the Project

- Displacement for X bracing is lesser than the without, Y and V bracing in each soil.
- In X, Y and V bracing X bracing has the lesser deformation than the other two.
- As the story decreases, deformation value is also decreasing.
- Story drift for X bracing is lesser than the normal, Y and V bracing.
- In X, Y and V bracing X bracing has the lower Story drift than the other two.
- As the story decreases, Story drift value is also increasing.
- Base shear for X bracing is greater than the normal, Y and V bracing.
- In X, Y and V bracing X bracing has the higher Base shear than the other two.
- As the story decreases, Base shear value is also increasing.
- Deformation for silty soil is lesser than the sand and clay.
- Story drift for silty soil is lesser than the sand and clay.
- Base shear for silty soil is higher than the sand and clay.

Total deformation in EQY direction for clay, sandy and silty soil for with and without SSI structure. In clay with SSI has lower deformation that the without SSI structure by 18.78%. In sandy soil with SSI has lower deformation that the without SSI structure by 35.69 %. In silty soil with SSI has lower deformation that the without SSI structure by 44.05 %. And silty soil has the lowest deformation.

Total deformation in EQY direction for clay, sandy and silty soil for with and without SSI structure. In clay with SSI has lower deformation that the without SSI structure by 18.78%. In sandy soil with SSI has lower deformation that the without SSI structure by 35.69 %. In silty soil with SSI has lower deformation that the without SSI structure by 44.05 %. And silty soil has the lowest deformation.

Total story drift in EQX direction for clay, sandy and silty soil for with and without SSI structure. In clay with SSI has lower story drift that the without SSI structure by 4.48 %. In sandy soil with SSI has lower story drift that the without SSI structure by 19.76 %. In silty soil with SSI has lower story drift that the without SSI structure by 37.17 %. And silty soil has the lowest story drift.

Total story drift in EQY direction for clay, sandy and silty soil for with and without SSI structure. In clay with SSI has lower story drift that the without SSI structure by 4.58 %. In sandy soil with SSI has lower story drift that the without SSI structure by 25.73%. In silty soil with SSI has lower story drift that the without SSI structure by 37.23%. And silty soil has the lowest story drift.

Base shear in EQX direction for clay, sandy and silty soil for with and without SSI structure. In clay with SSI has lower base shear that the without SSI structure by 0.366 %. In sandy soil with SSI has lower base shear that the without SSI structure by 1.19 % In silty soil with SSI has lower base shear that the without SSI structure by 1.10 %. And silty soil has the highest value of base shear

Base shear in EQY direction for clay, sandy and silty soil for with and without SSI structure. In clay with SSI has lower base shear that the without SSI structure by 1.613%. In sandy soil with SSI has lower base shear that the without SSI structure by 2.699 % In silty soil with SSI has lower base shear. that the without SSI structure by 0.567 %. And silty soil has the highest value of base shear.

Time period for clay, sandy and silty soil for with and without SSI structure. In clay with SSI has lower time period that the without SSI structure by 12.048 %. In sandy soil with SSI has lower time period. that the without SSI structure by 14.309 % In silty soil with SSI has lower time period. that the without SSI structure by 25.15 %. And silty soil has the lowest time period.

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