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Behavior of Setback Steel Moment Resisting Frame with Soil Structure Interaction

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***Abstract*: In India, as majority of the existing reinforced concrete structures in the seismic region are primarily designed for gravity loads only, they do not meet the current seismic requirements. The building to be fixed at its bases is assumed in common design practice for dynamic loading. The effect of soil structure interaction should be considered in the buildings which are located in the earthquake prone areas. The effect of soil structure interaction on structures during earthquake is not considered mostly, although structures are supported on soils. When a structure is subjected to an earthquake excitation, it interacts with the foundation and soil, and thus changes the motion of the ground. Supporting soil medium allows movement of the whole ground. Structural system is influenced by the type of soil as well as the type of structure. Setback affects the mass, strength, stiffness, centre of mass and centre of stiffness of setback building. Dynamic characteristics of such buildings differ from the regular building due to changes in geometrical and structural property. Design codes are not clear about the definition of building height for computation of fundamental period. The bay wise variation of height in setback building makes it difficult to compute natural period of such buildings. With this background it is found essential to study the effect of setbacks on the fundamental period of buildings. Present study focuses on study of steel setback structure subjected to dynamic loads with soil structure interactions (SSI). SSI has been considered for hard, medium and soft soil. Overall performance of the structure has been found out and results indicates that, SSI is necessary for the analysis of steel setback frames with respect the overall stability of the structure.**

Key Words: Setback Steel, Time history analysis, Equivalent static analysis

1. Introduction

In India, where the larger part of existing seismic strengthened solid structures are planned principally for gravity loads, they don't meet the current seismic requirements. The structure to be fixed at its bases is assumed in the usual design practice for dynamic loading. The impact of soil structure cooperation ought to be considered in the structures situated in the earthquake inclined territories. The impact of soil structure communication on structures amid the seismic tremor is generally not considered, despite the fact that structures are supported on soils. When a structure is presented to earthquake excitation, it interfaces with the establishment and the ground, changing the development of the dirt. Supporting soil medium permits the development of the whole soil. The structural system is impacted by the sort of soil and also the kind of structure. With a level of parallel powers because of earthquakes, the building can withstand direct hardened soil and firm ground, yet a similar building can't withstand the little seismic earthquake on delicate ground.

The SETBACK influences the mass, strength, rigidity, center of mass and center of rigidity of the retrogressive development. The dynamic qualities of such structures contrast from the customary building because of changes in geometric and structural property. The design codes are not clear about the meaning of development height for the figuring of the fundamental time period. The insightful variety of height in the invert development makes it hard to figure the common time of such structures. With this foundation, it is basic to examine the impact of setbacks in the fundamental time of the structures. Likewise, the execution of the exact condition given in Indian Standard IS 1893: 2002 for the estimation of the fundamental time of force structures involves worry for basic architects. This is the main primary inspiration hidden the present investigation.

Soil-structure connection is an interdisciplinary field of Endeavour. It is situated at the crossing point of soil and basic mechanics, soil and basic flow, seismic designing, geophysics and geo mechanics, materials science, computational and numerical strategies, and numerous other specialized controls. Going back to the late nineteenth century, it step by step created and developed in the next decades and the primary portion of the twentieth century, and the second 50% of the year was fortified basically by the request of atomic power and marine industry. The PC programming and stimulation apparatuses and the want to enhance seismic earthquake security. The impact of soil on the basic reaction relies upon the idea of the dirt, the structure and the idea of the excitation. You can utilize Fourier examination or different techniques to straightforwardly answer the reaction. The procedure of soil reaction influencing structural development is called soil-structure Interaction (SSI). This document is IJRESM template. Any queries on paper preparation & guidelines, please contact us via e-mail.

2. Literature Review

Nagarjuna and Shivakumar B Patil (2015): Studied the impact of changes in the tallness of underlying columns amid earthquakes and the impact of shear walls in various areas. There are two kinds of structures laying on level ground. Seismic investigation was performed by linear static analysis, and response spectrum analysis was performed as per IS: 1893 (Part 1):2002. At last, the outcomes demonstrate that the short columns are more influenced amid the earthquake. Investigation demonstrates that for structures based on grass,

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the working's back setting is proper, while the building's corner is set with shear walls.

Ravikumar et al. (2012): It tackles numerous sorts of structure that have irregular structures in floor plan and elevation maps that are ruinous in future earthquakes. For this situation, it decides the fundamental execution of new and existing structures to withstand disasters. This paper looks at two kinds of irregularities in this structure, namely planning irregularities with diaphragms and geometric discontinuities, as well as vertical irregularities with sloping ground and retreat. This irregularity is built as per IS 1893 (Part 1), class 7.1 code. In recognizing the most defenceless structures, linear and non-linear seismic requirements are considered to decide the different examination techniques performed. Different lateral loads were tested on different irregular buildings and a pushover analysis was carried out. At last, the outcomes demonstrate that the building limit might be extraordinary, however the seismic requirements are distinctive as far as design. Without a double system, the eccentricity between the rigid center and the quality centre is unique. This examination created consciousness of seismic vulnerability in down to practical building.

Sarkar et al. (2010): Another technique for evaluating irregularities in a stepped structure framework is proposed, which clarifies the dynamic qualities, ie mass and stiffness. This article talks about a portion of the key issues identified with the analysis and design of a stepped building. They proposed another strategy to evaluate the irregularities in a stair-type building. It demonstrates the related traits there are mass and stiffness appropriations in the frame. It has been found that this method performs better than the existing measures that quantify irregularities. Based on the analysis of the free vibration of irregularity and height variation of 78 step frames, this study gives a correction factor for the empirical formula of the basic cycle so that it can be applied to ladder-type buildings. They proposed a vertical irregularity measurement technique called "regularity index", taking the adjustment in stiffness and mass as a proportion of the tallness of a building. Is the first mode participation factor considering the participation factor of the first mode, utilized for a comparative customary building structure without steps IS 1893:2002 code.

Haldar and Singh (2009): The significance of fittingness of the different determination conditions was analyzed and tested by assessing the normal execution of an arrangement of code-designed structures. The FEMA-440 and HAZUS techniques are utilized to assess seismic execution and vulnerability. The outcomes demonstrate that the design of the special flexural frame (SMRF) as per the present design controls of the Indian Standard has a higher likelihood of harm than the design of the ordinary flexural frame as a result of as far as higher drift permitted. It likewise demonstrates that a deterministic structure for execution based seismic outline does not give a far reaching comprehension of the normal execution and related dangers of plan structures.

3. Modelling and Analysis

Initially a 30 story rectangular steel moment resisting frame is considered, having overall dimension 36 m x 20 m in X and Y direction. Bay size is 4 m uniform along both the direction. Modelling and analysis is carried out using SAP 2000 ver. 19. Built up columns and ISHB beams are considered for the modelling the steel structure. And steel deck is modelled as floor element. At every 10 m height, column sections are reduced. Three soils of types are considered for the analysis i.e., Hard, Medium and soft soil. The effect of considering fixed base condition (FB) & soil structure interaction (SSI) condition has been studied for all the 3 types of soil. Equivalent static and dynamic time history analysis has been carried out.

Here are the types of model shown for the easy assessment.

1. Model-1: Set back Steel MRF with fixed base (Hard Soil-Gravel soil)
2. Model-2: Set back Steel MRF with fixed base (Medium Soil- Silty soil)
3. Model-3: Set back Steel MRF with fixed base (Soft Soil-Clayey soil)
4. Model-4: Set back Steel MRF with soil structure interaction (Hard Soil)
5. Model-5: Set back Steel MRF with soil structure interaction (Medium Soil)
6. Model-6: Set back Steel MRF with soil structure interaction (Soft Soil)

A. *Defining Material Properties*

The material property is an important aspect to be defined while modelling a structure. Both the steel and concrete are having some property, which has to be specified as listed below:

Young's modulus (Steel), Es = 2.1 X 10^5 MPa
Young's modulus (concrete), EC = 2.5 X 10^4 MPa
Compressive strength of concrete, F_{ck}= 25 MPa
Yield stress for reinforcing steel, Fy = 500 MPa

B. *Defining Frame Sections*

The beam and column form the frame. The frame members have to be defined, as listed below.

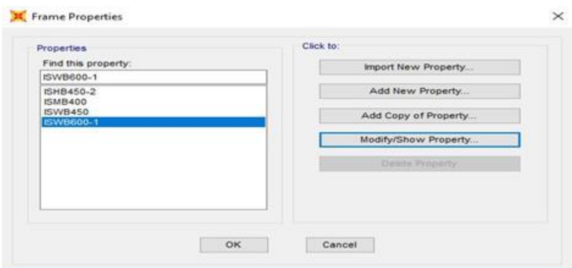

Fig. 1. Frame property

C. *Defining Loads*

The different types of loads are defined under this option, here we can define,

1. Dead load
2. Live Load
3. Super dead Load
4. Glazing Load

Further the load combinations are automatically generated in the SAP2000.

1) 1.5 (DL+LL)

2) 1.2 (DL+LL+EL)
3) 1.5 (DL+EL)
4) 0.9DL * 1.5EL

D. Dynamic Time History Analysis

For the Dynamic time history analysis BHUJ and ELCENTRO time history data was chosen and are defined in SAP 2000 as below.

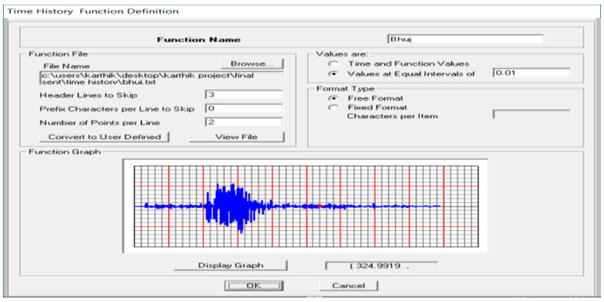

Fig. 2. BHUJ time history data

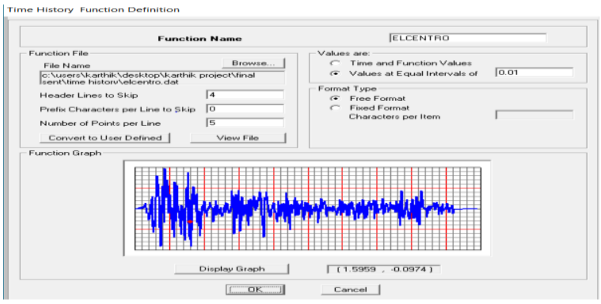

Fig. 3. EL CENTRO time history data

E. Building Information

Table-1
Design data for the example buildings

Structure		Steel Structure
Plan Dimension		36m X 20m in X and Y direction
Grid spacing		4m both along X & Y direction
No. of storey		G+30 Storey
Storey height	First storey	3m
	Upper storey	3m
Building type		Commercial
Type of foundation		Isolated foundation / Raft
Frame sections Beams and Columns		ISHB 450-2,ISMB 400 ISWB 450,ISWB 600-1
Area sections		Steel deck slab 4mm
Types of soils		Hard, Medium, Soft
Assumed DL Intensities		
Roof finishes		1.50 kN/m²
Floor finishes		1.50 kN/m²
Glazing load		1 kN/m²
LL Intensities		
Roof/ Floor		4.0 kN/m²

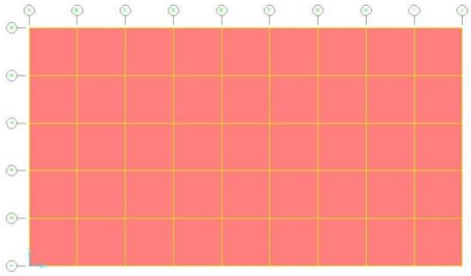

Fig. 4. Plan view

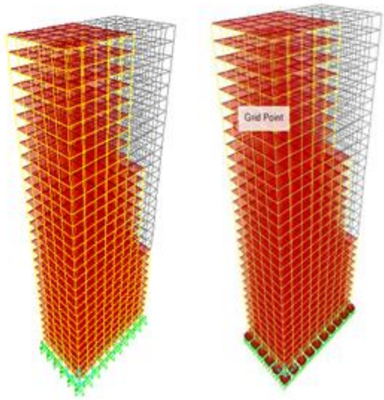

Fig. 5. 3D view

The standard models are prepared. The similar models are created based on the different type of shear wall and flat slab arrangement.

4. Results

Results from Time history analysis for ELCENTRO and BHUJ are extracted and important results like peak acceleration, displacements, and base force are presented in the form of response plots graphs.

A. Dynamic Time History Analysis (ELCENTRO EQ)

1. Maximum Base shear

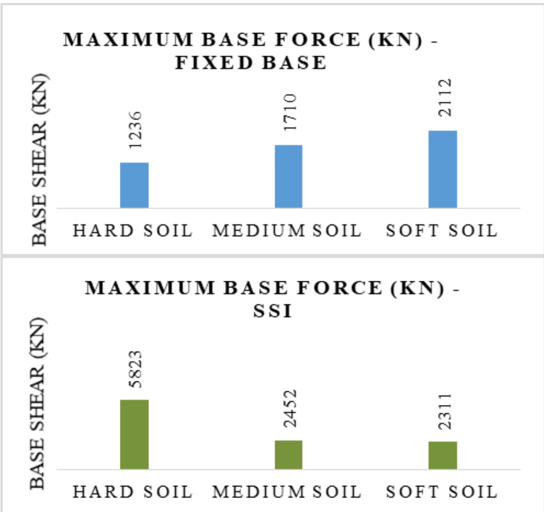

Fig. 6. Maximum base shear - X Dir.

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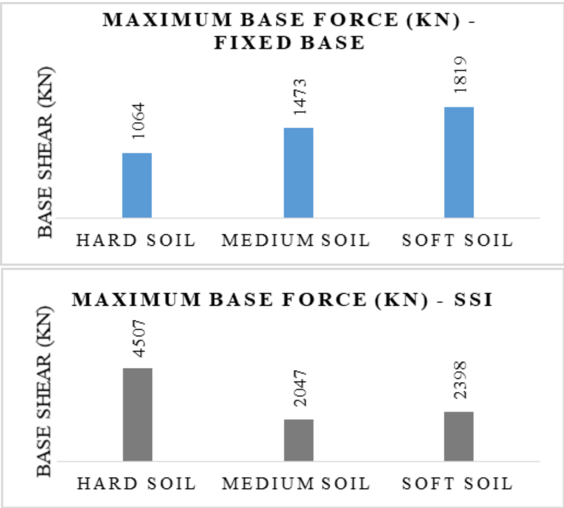

Fig. 7. Maximum base shear - Y Dir.

2. *Time history responses - Peak displacement*

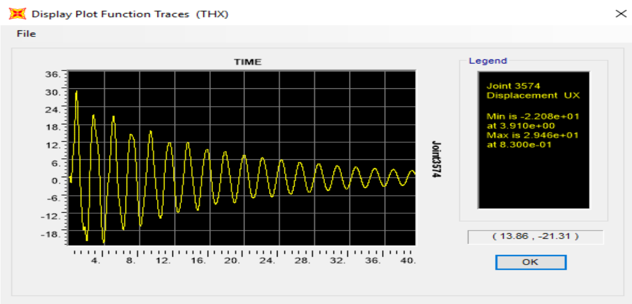

Fig. 8. Peak displacement response - Hard soil FB - X Dir.

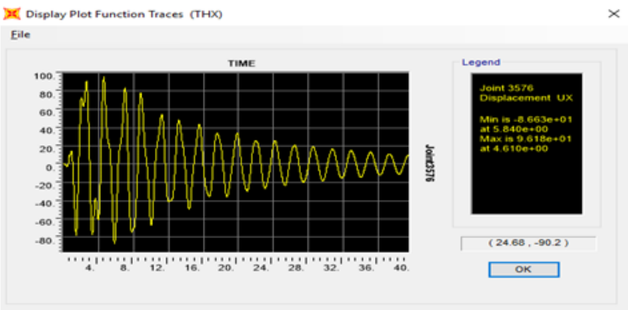

Fig. 9. Peak displacement response - Hard soil-SSI - X Dir.

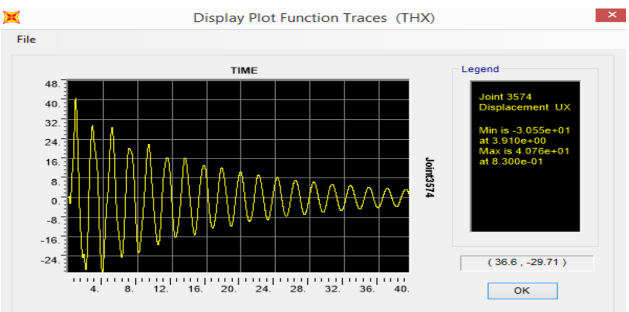

Fig. 10. Peak displacement response - Medium soil-FB - X Dir.

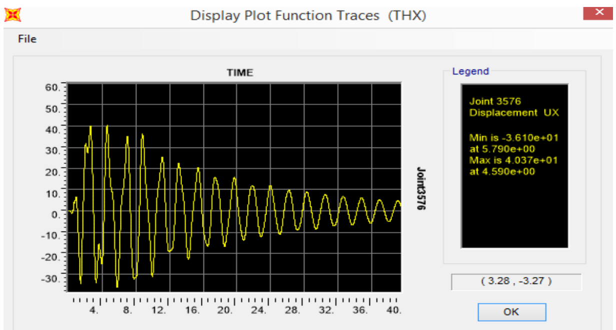

Fig. 11. Peak displacement response - Medium soil – SSI - X Dir.

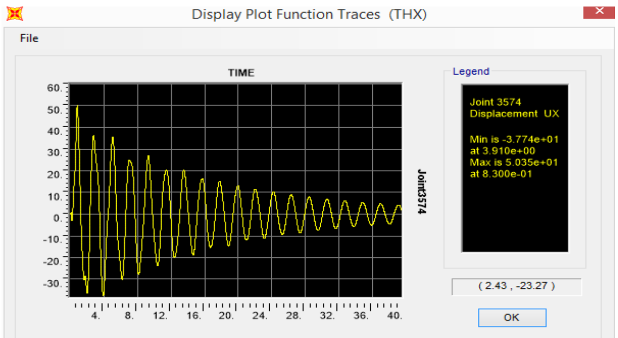

Fig. 12. Peak displacement response - Soft soil – FB - X Dir.

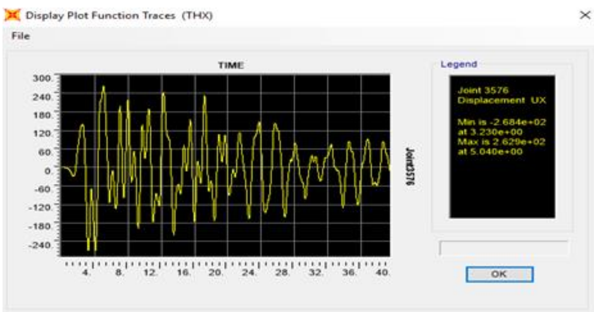

Fig. 13. Peak displacement response - Soft soil – SSI - X Dir.

The below Table-2 is the summary of the maximum base force, peak acceleration and peak displacements.

Table-2
Time History response summary chart - ELCENTRO

Models	Base Force (kN)		Peak Acceleration (m/s^2)		Peak Displacements (mm)	
	X Dir	Y Dir	X Dir	Y Dir	X Dir	Y Dir
FB – Hard Soil	1236	1064	6.03	5.83	29.46	33.9
FB – Medium Soil	1710	1473	8.34	8.04	40.76	46.9
FB – Soft Soil	2112	1819	10.31	9.84	50.35	58.04
SSI– Hard Soil	5823	4507	4.56	4.30	96.18	117.1
SSI– Medium Soil	2452	2047	2.06	1.88	40.37	51.15
SSI– Soft Soil	2311	2112	8.93	10.12	268	598

From Table-2 it can be observed that, base force is found to be more i.e., 5823 kN in case of SSI – hard soil condition in X-direction & 4507 kN in Y direction compared to all other types of structure. Peak acceleration is found to increase with decrease in SBC of the soil from 6.03 m/sec^2 to 10.31 m/sec^2 in X direction and 5.83m/sec^2 to 9.84m/sec^2 in Y direction fixed base condition. About 70% increase is found with respect to hard soil to soft soil. In case of the soil structure interaction also there is a significant increase in the peak acceleration 4.56 m/sec^2 to 8.93m/sec^2 in X direction and 4.30m/sec^2 to 10.12m/sec^2 in Y direction. Peak displacement is found to be crossing the limitations as per the code in soft soil with soil structure interaction case.

B. Dynamic Time History Analysis (BHUJ EQ)

1. Base force

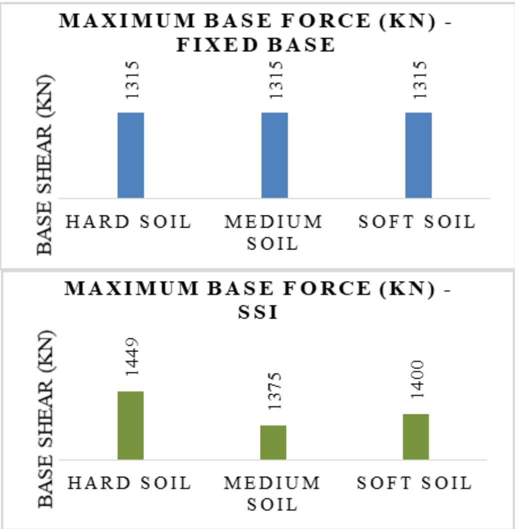

Fig. 14. Maximum base shear - X Dir.

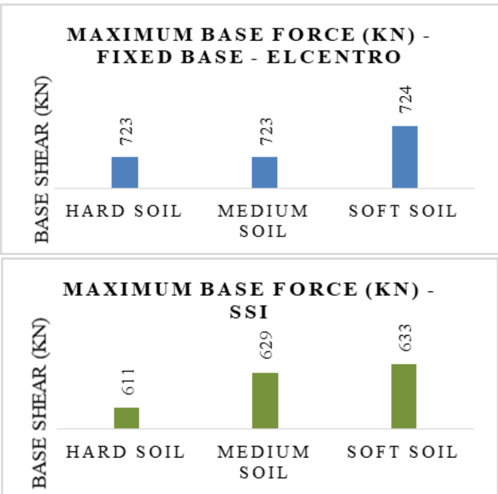

Fig. 15. Maximum base shear - Y Dir.

2. Time history responses - Peak displacement

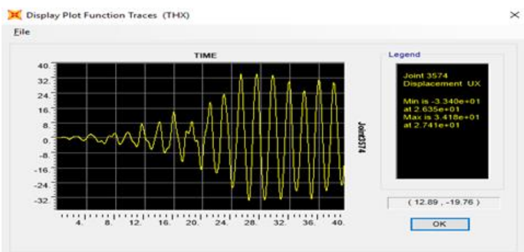

Fig. 16. Peak displacement response - Hard soil-FB - X Dir.

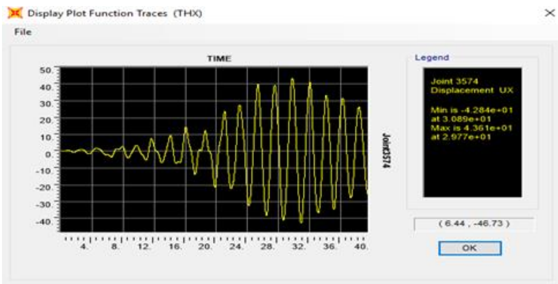

Fig. 17. Peak displacement response - Hard soil-SSI - X Dir.

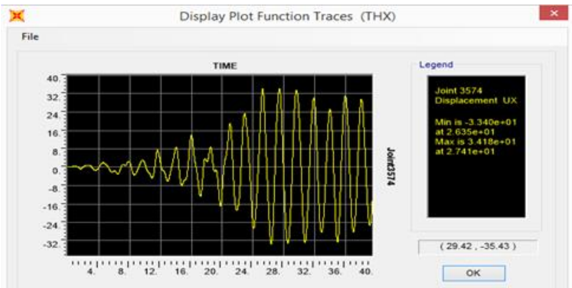

Fig. 18. Peak displacement response - Medium soil-FB - X Dir.

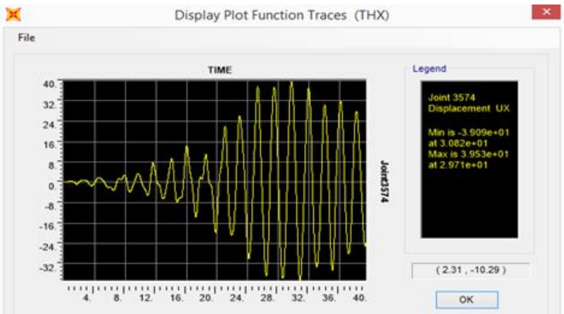

Fig. 19. Peak displacement response - Medium soil-SSI - X Dir.

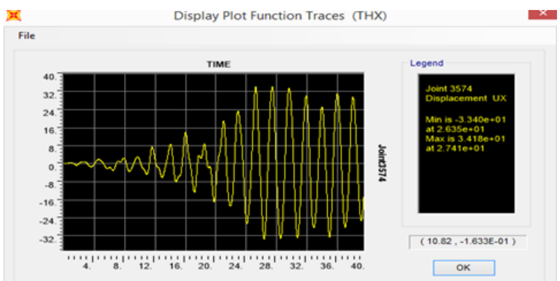

Fig. 20. Peak displacement response - Soft soil-FB - X Dir.

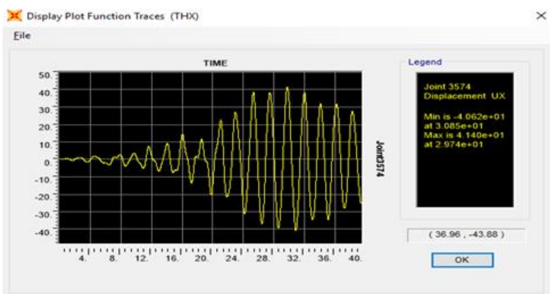

Fig. 21. Peak displacement response - Soft soil-SSI - X Dir.

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The below Table-3 is the summary of the maximum base force, peak acceleration and peak displacements.

Table-3
Time History response summary chart -BHUJ

Models	Base Force (kN)		Peak Acceleration (m/s^2)		Peak Displacements (mm)	
	X Dir	Y Dir	X Dir	Y Dir	X Dir	Y Dir
FB – Hard Soil	1315	723	0.360	0.31	34.18	23.54
FB – Medium Soil	1315	724	0.361	0.31	34.18	23.61
FB – Soft Soil	1315	724	0.361	0.31	34.18	23.61
SSI– Hard Soil	1449	611	0.38	0.32	43.61	27.49
SSI– Medium Soil	1375	629	0.39	0.31	39.5	27.47
SSI– Soft Soil	1400	633	0.39	0.33	41.4	27.5

From Table-3 it can be observed that, base force is found to be more i.e., 1449 kN in case of SSI – hard soil condition in X-direction & 724 kN in case of FB- hard, medium soil condition in Y direction. Peak acceleration is found to be 0.36 m/sec^2 in X direction and 0.31 m/sec^2 in Y direction for fixed base and in case of the soil structure interaction peak acceleration is found to be 0.39 m/sec^2 in X direction and 0.33 m/sec ^{2} in Y direction. Peak displacement is found to be 21% and 16.8% along X and Y direction for soft soil case with SSI respectively. The responses are found to be shown less variation compared to ELCENTRO dynamic input. The impact of soil structure interaction is found to be considerable where the variation is found to be 10% for base force along X direction and along Y direction which are less than that of in FB condition. Peak acceleration is found to be very less compare ELCENTRO input.

C. Equivalent static analysis

1. Time period and frequency

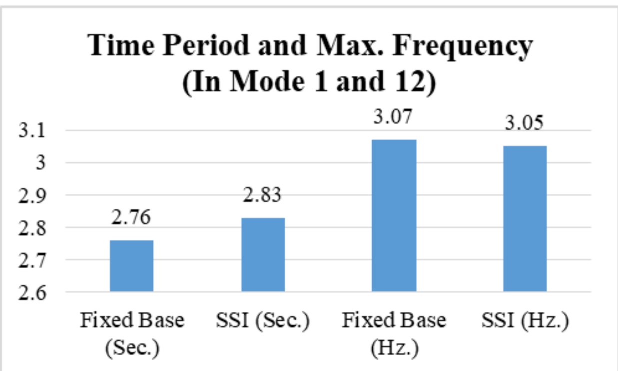

Fig. 22. Time period and frequency

The Fig. 22 represents the time period and maximum frequency of fixed base and soil structure interaction models. From the results it can be observed that building with SSI has effect about time period of 7% & max frequency of 2% variation with respect to fixed base.

2. Storey shear

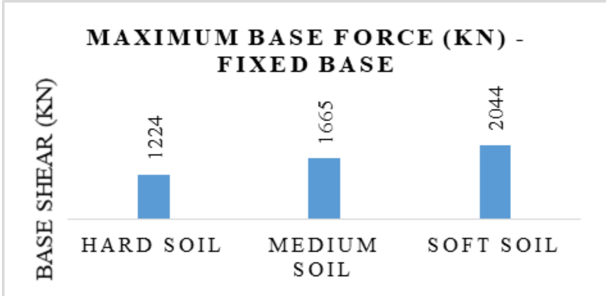

Fig. 23. Storey shear - FB

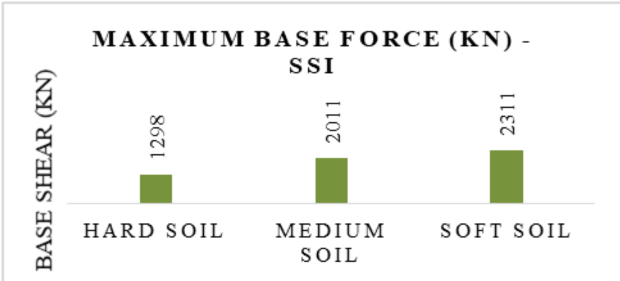

Fig. 24. Storey shear - SSI

From Fig. 23 and Fig. 24 it is clear that, story shears has a considerable increase in the SSI models with respect to the fixed base for all types of soils. And it is found to be 6%, 20% and 13% for hard, medium and soft soil respectively.

3. Storey displacement

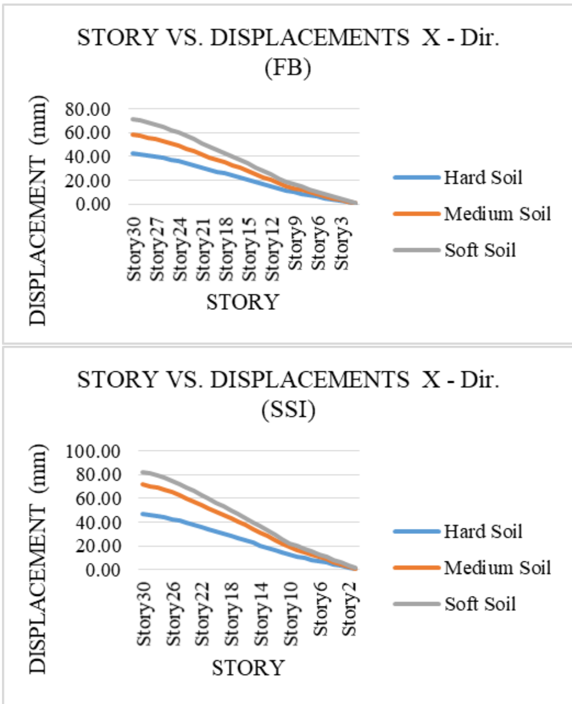

Fig. 25. Storey displacement - X Dir.

The Fig. 25, it can be observed that, displacements are found to be more in the structures with soil structure interaction. Maximum displacement is found to be more in structure resting on soft soil and it is found to be 15.8% along X direction.

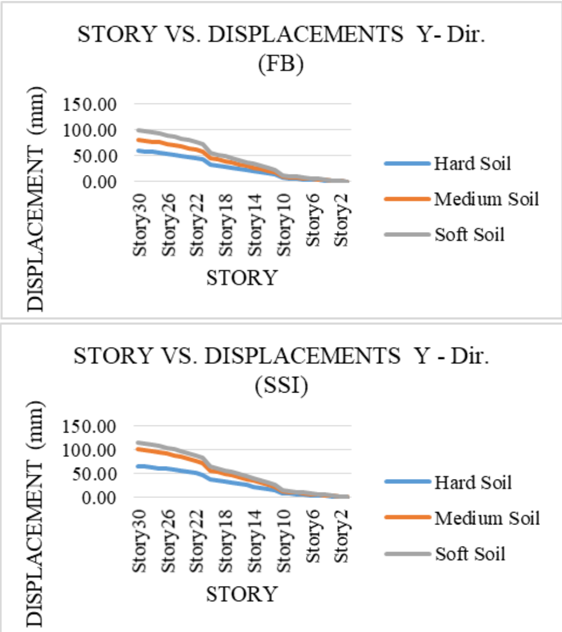

Fig. 26. Storey displacement- Y Dir.

The Fig. 26, it can be observed that, displacements are found to be more in the structures with soil structure interaction. Maximum displacement is found to be more in structure resting on soft soil and it is found to be 23.6% along Y direction.

Also along Y direction it is found that, displacements are higher than the X directions about 40%. From Fig. 24 and 25 the displacements at vertical setbacks are found to be increasing drastically about 90% i.e., for all types of soil. With the introduction of soil structure interaction displacements are increasing up to 40% in comparison with fixed base.

4. Storey drift

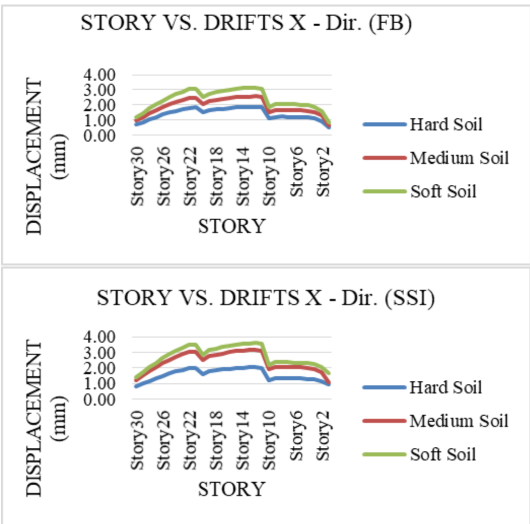

Fig. 27. Storey drift- X Dir.

From Fig. 27, it is clear that along X direction the maximum story drifts is found to be 3.16 mm in fixed base and 3.60 mm in SSI structure which is found to be 13.9% for soft soil.

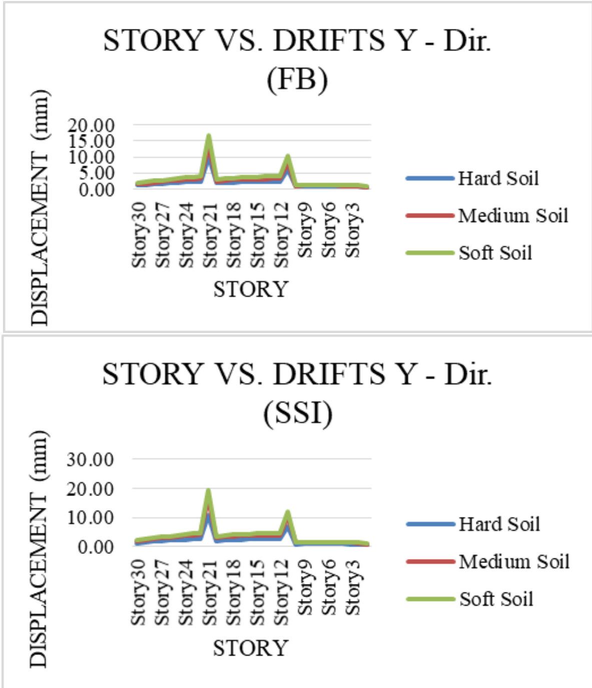

Fig. 28. Storey Drift - Y Dir.

From Fig. 28, it is clear that along Y direction also maximum story drifts is found to 16.70 mm in fixed base and 19.24 mm in SSI structure which is found to be 15.2% for soft soil. And also story drifts are found to be considerably more along Y direction in comparison with X direction. Also at vertical setbacks the story drifts is found to be increasing sharply about an average of 22%.

5. Conclusion

From dynamic time history and pushover analysis following conclusions are made.

1. Variation of time period and frequency has less effect on FB and SSI cases, hence time history analysis is required for further understand the behavior of the of soil structure interaction.
2. From equivalent static analysis it can be concluded that, the soil structure interaction effect is considerable since the displacements or drifts are more compared to fixed base case. Also structure resting on soft soil has to be designed carefully with soil treatment, since displacements and drifts are more compared to hard and medium soil.
3. From the variation of story drifts with respect to height, it can be concluded that, providing offset i.e., setback buildings contribute more drifts at the setback location and hence certain measures has to be taken like adding the bracings or dampers to control the drifts particularly along Y direction. And also story drifts are found to be more if SSI is considered for the analysis.

4. From time history analysis it can be concluded that, the dynamic responses like peak acceleration, displacement and base force depends on the intensity of loading, type of soil and direction. Also time history analysis with SSI has noteworthy effect on overall response of the structure.
5. And finally it can be concluded that, particularly for vertical irregular buildings like setback steel moment resisting frames, considering SSI effect has an important role in understanding the behavior of the overall performance.

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