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Evaluation of Seismic Behavior of Tube in Tube Braced Structural System Considering Soil-Structure Interaction

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Abstract:- The tube in tube structures is the innovative and fresh concept in the tubular structures. The tube in tube structures is especially suitable for all tall buildings. Bracing and shear wall are best concepts in a structure analysis of seismic force-resisting systems. Bracing and shear wall provide as additional lateral resistance against the lateral force. In the proposed study, tube structures of different heights have been considered. Bracing has been installed at corner along the structure's height and without bracing also meanwhile, shear wall provides in central core. Soil structure interaction (SSI) has also been taken into account. The parameters, such as maximum Story displacement, base shear, story drift, and story shear have also been studied. A tube-in-tube structure has been modelled in ETABS 2018.

Keywords: *Tube structure system, Bracing, Shear wall, ETABS.*

I. INTRODUCTION

Modern high-rise structures are typically constructed using the tube idea, which positions the lateral-load resisting elements on the outside perimeter for structural efficiency. These structures typically have a service core that houses elevators, emergency stairways, electrical and mechanical infrastructure, and other amenities. The core's walls are frequently engineered to provide additional rigidity to the structure, acting as a second tube within the exterior tube. These structures are known as "tube-in-tube" structures.

A finite element analysis is expensive and time demanding because these buildings are usually tall building have many structural elements. It is not cost-effective to use finite element analysis in the early stages of a design. As a result, approximate techniques that forecast the structure's global behavior are sought.

Tubular constructions are commonly employed in tall structures. The effect of lateral load increases as the height of the structure increases. Frame tube structures, braced tube structures, bundled tube structures, and tube in tube structures are examples of different structural structures.

The columns in tube structures are placed at 2 to 5 m intervals and are connected to heavy beams with outer side moment resisting frames. For buildings with a height of 40 to 100 stories, tube structures are preferable. Shear lag occurs in tube buildings, so to alleviate this problem, bracing is added to the building's exterior edge, resulting in braced tube structures. The shear lag effect is eliminated using bracings, and the distance between the columns and the depth of the girders can be reduced, allowing for larger windows. The gravitational force is carried by the internal tube of a braced tube structure, while the lateral stresses are resisted by the outside tube diagonal members. Bundled tube constructions are made up of tubes arranged in a bundle to create a significant amount of floor space. The outer tube of a tube construction is made up of thick columns, whereas the inner tube is made up of shear walls.

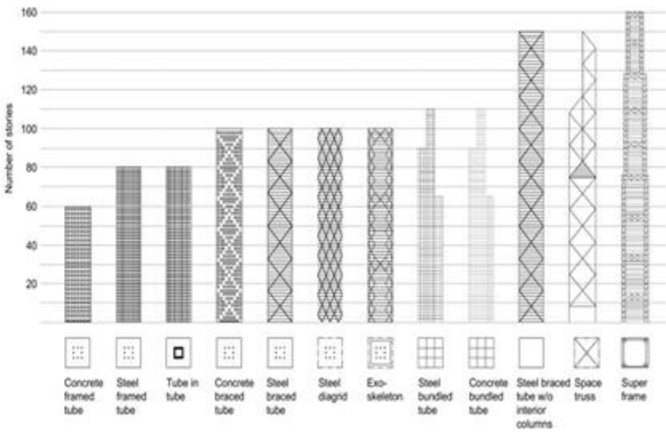

Fig. 1. Different Structural System

II. TYPES OF TUBE STRUCTURE

The Tube systems consist of three types such as,

- Frame tube system,
- Tube in Tube system
- Bundled-tube system

The efficiency of this system is derived from the great number of rigid joints acting along the periphery, creating a large tube. Exterior tube carries all the lateral loading. The reduction of material makes the buildings economically much more efficient.

III. TUBE IN TUBE STRUCTURE

This system is also known as 'hull and core' and consists of a core tube inside the structure which holds services such as utilities and lifts, as well as the usual tube system on the exterior which takes the majority of the gravity and lateral loads. The inner and outer tubes interact horizontally as the shear and flexural components of a wall-frame structure. They have the advantage of increased lateral stiffness.

An outer framed tube together with an internal elevator and service core. The outer and inner tubes act jointly in resisting both gravity and lateral loading in steel-framed buildings. - The bending and transverse shears are supported three- dimensionally at the flange and web surface in the structure.

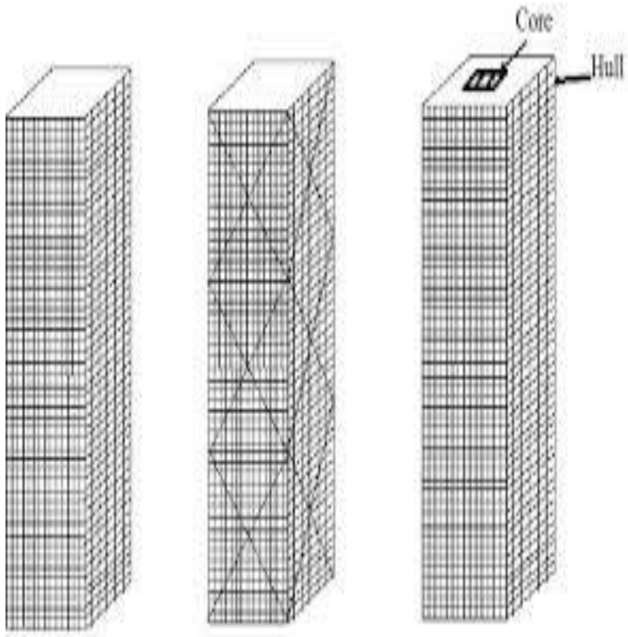

Fig. 2. Tube in tube Structure

IV. SOIL STRUCTURE INTERACTION

Ground–structure interaction (SSI) consists of the interaction between soil (ground) and a structure built upon it. 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).

In the regard of the rapid increase in population and constructions, one is compelled to construct the structures in medium soil and soft soil instead of hard soil which is having less resistance to earthquake forces. Construction of structure in the medium and soft soil leads to consideration of stiffness properties and relative mass of soil. Thus, the physical property of the foundation medium is an important factor in the earthquake response of structures supported on it. Also, structures need to overcome the forces occurs at the foundation level. This will call the attention of designers to understand the dynamic behaviour of such kind of structures considering SSI.

Many researchers have proposed different methods to evaluate the effect of soil structure interaction from time to time. The soil medium as a system of identical but mutually independent, closely spaced, discrete, linearly elastic springs. [1]

V. EFFECT OF SOIL TO THE FOUNDATIONS UNDER EARTHQUAKE LOADING

Under earthquake, piles may be subjected to significant additional lateral forces as a result of the soil mass attempting to move past the pile group. Settlement due to earthquake excitation may also occur in loose dry no cohesive soils. The possibility of liquefaction under earthquake motion should be investigated for no cohesive soils underlie such as loose saturated sands. This is because this type of soil may lose their strength due to liquefaction under the cyclic effect of earthquake motions. It will result in serious foundation failure. Friction piles may lose their bearing capacity and slender end bearing piles may become laterally unstable. There are some measures such as dynamic compaction or grouting, ground replacement may be used. [2]

VI. SOIL STRUCTURE INTERACTION IN LAYERED SOIL

As shown in figure 1.9, when the body waves travel through layered soil strata, it results in scattering, diffraction, reflection, and refraction of the seismic waves. As the Primary waves are much faster, its effect on the structure is not predominant. However, as the shear waves are much slower and causing the effect in the perpendicular direction of motion may damage the structures below the grade.

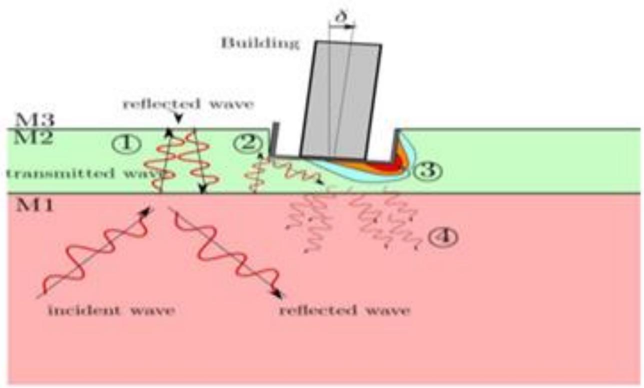

Fig. 4. Soil Structure Interaction in layered soil

As shown in Fig. 4, the soil is modelled using finite elements along the boundary of the foundation, interface elements are defined between the foundation and the soil. However, this complicate mode will cause a computational difficulty, especially when the system is geometrically complex or contains significant nonlinearities in the soil or structural materials. [2]

Represent the stiffness and damping at the soil foundation interface, using springs and dashpots (or more complex nonlinear elements).

Response analysis of the combined structure spring/dashpot system with the foundation input motion applied.

VII. IDEALIZATION OF SOIL IN THE PRESENT STUDY

Flexibility of soil medium below foundation may appreciably alter the natural periods of any building. It usually causes to elongate time period of structure.

The flexibility of soil is usually modeled by inserting springs between the foundation member and soil medium.

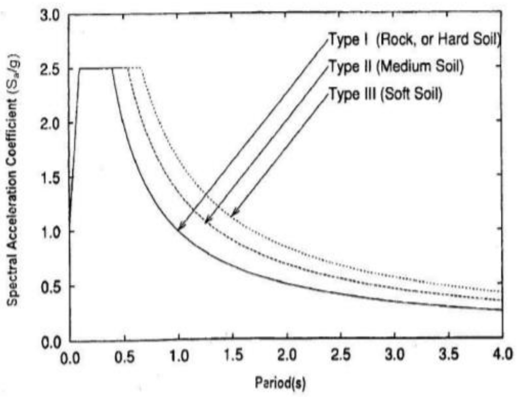

Fig. 5 Response spectra for rock and soil sites for 5% damping (IS1893)

Three tran.slation springs along two horizontal and one vertical axis, together with three rotational springs about those mutually perpendicular axes, have been attached to simulate the effect of soil flexibility.

In present study, out of different methods of soil modeling study has been carried out by considering spring model using gazetas equation (given in FEMA 356) or Richart and Lysmer.

VIII. NEED OF STUDY

- Tube-in-Tube Building generally consists of an inner tube to aid vertical transportation demand and an outer tube which comprises of dense columns and beams. It is used in structural system for high-rise building.
- In the huge height of building different structural system are very useful against the lateral forces.
- In tall building vital role is played by soil structure interaction.
- Bracing and shear wall are ability to yield both in tension and compression without buckling during the lateral force are acting in higher earth quake zone area.

IX. OBJECTIVE OF STUDY

- To study the behavior tube in tube braced structural system in different soil condition such as soft soil, medium soil and hard soil.
- To Study the Different Model using different types Foundation.
- To study the verities of model with or without bracing

X. METHODOLOGY ETABS 2018

- *Model Initialization*

The Model initialization is the first phase. Select Indian Standard Codes for Steel and Concrete Design for IS 800:2007 and IS 456:2000 respectively.

- *Define Sectional Properties*

In this area simply define the different size of column, different size of beam and different size of slab or else as per requirements.

- *Define Load Combination*

Define the load combinations to be evaluated for the structure or automatic generated by ETABS 2018.

- *Load Assignment*

In figure3.10 shows previous step as we discussed all structure component draw. Now here assign the load all types of loads like dead load, live load, wind load, earthquake load, in all different component as per calculation.

- Check Model & Run Analysis

In this step model will be checked and analysis is obtained.

XI. SOIL PROPERTIES

Table 1. Soil properties

Type of soil	S.B.C of soil (kN/m2)	Young’s modulus(E) (kN/m2)	Poisson’s ratio(υ)	Shear Modulus(G) (kN/m2)
Soft	100	12000	0.45	4137.93
Medium	150	35000	0.4	10714.28
Hard	250	200000	0.3	76923.08

Degrees of Freedom	Stiffness of equivalent soil spring
Vertical	[2GL/(1-ν)] (0.73+1.54χ0.75) with χ =Ab/4L2
Horizontal (Lateral direction)	[2GL/(2-ν)] (2+2.50χ0.85) with χ = Ab/4L2
Horizontal (Longitudinal direction)	[2GL/(2-ν)] (2+2.50χ0.85)-[0.2/(0.75-ν)]GL[1-(B/L)] with χ = Ab /4 L2
Rocking	[G/(1-ν)] Ibx

(About longitudinal)	0.75(L/B)0.25[2.4+0.5(B/L)]
Rocking (About lateral)	[G/(1-ν)] Iby 0.75(L/B)0.15
Torsion	3.5G Ibz 0.75(B/L)0.4(Ibz/B4)0.2

Ab= Area of the foundation considered;
B and L=Half-width and half-length of a rectangular foundation, respectively;

Ibx, Iby, and Ibz = Moment of inertia of the foundation area with respect to longitudinal, lateral and length.

To make a spring in ETABS, enter the above equation and assign the spring to the foundation. Assign spring behaviour such as soli structure interaction.

XII. GEOMETRIC PROPERTIES OF BUILDING

Table 2. Geometric properties of building

Component	Description	Modelling Data
Frame	Plan dimension	26.1x21.6 m
	No. of Story	G+39
	No of grid in X Direction	7
	No of grid in Y Direction	7
	Frame height	3m
	Thickness of Slab	150 mm
	Size of column	800x800 mm
	Size of Beam	600x600 mm
Loads on frame	Self-weight	-
	Live load (Typical floors)	3 kN/m2
	Floor Finish	1.5 kn/m2
Earthquake zone	Zone	V
Factor	Response reduction factor	5
	Importance factor	1
	Damping ratio	0.05(5%)
Rebar and Steel	Yield strength of Rebar	500 N/mm2
	Yield strength of Steel (Bracing)	250 N/mm2
Concrete	Compressive Strength	M40
Type of bracing	X bracing (Corner &Without)	ISMC 175

XIII. RAFT AND PILE FOUNDATION BUILDING

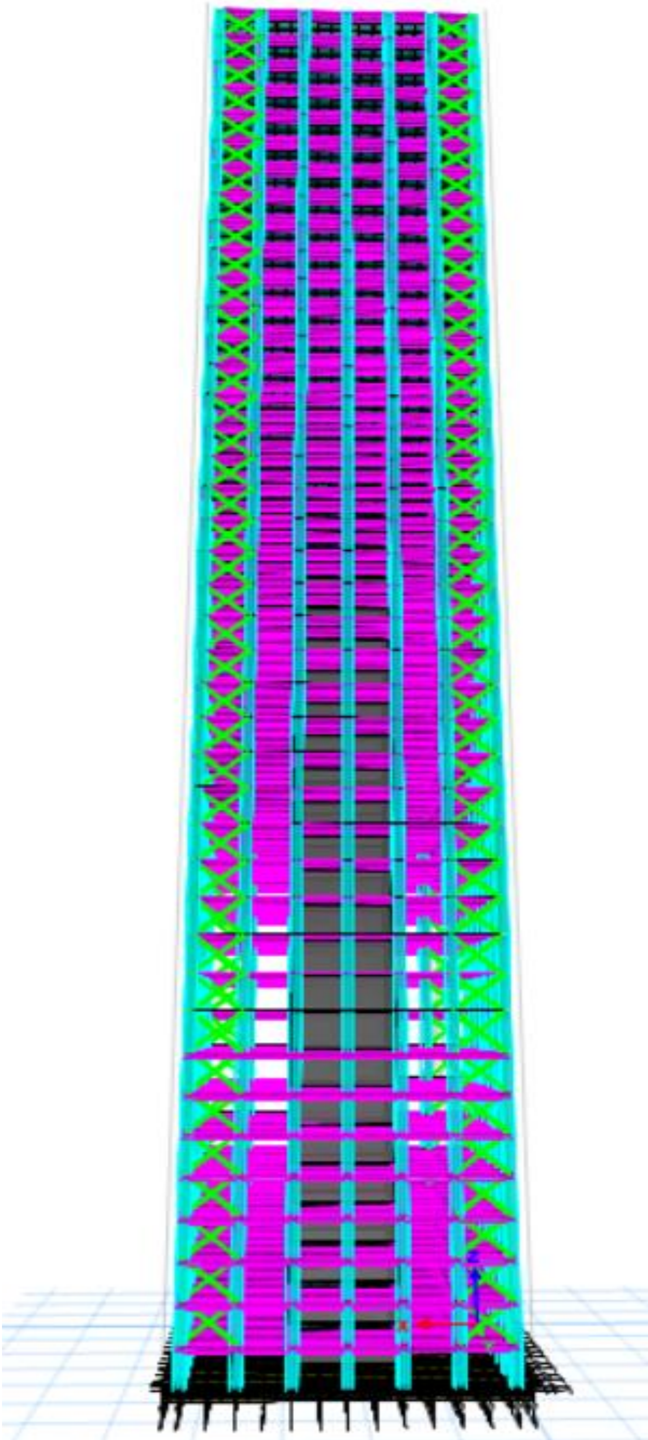

Fig. 6. Modelling of building(Raft)

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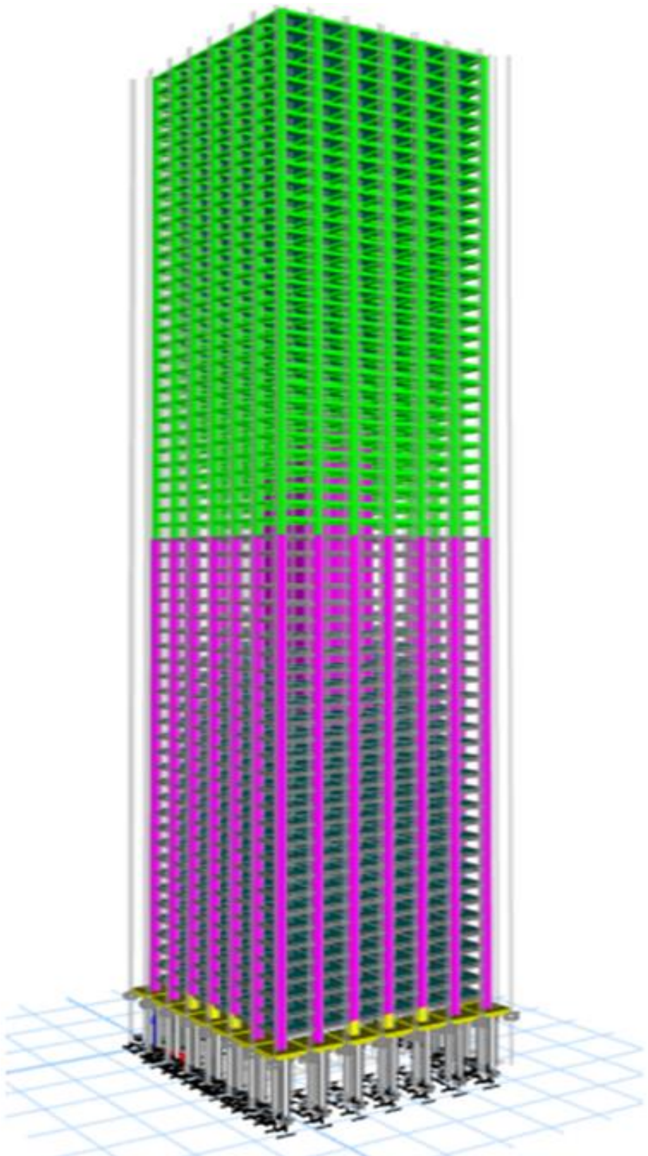
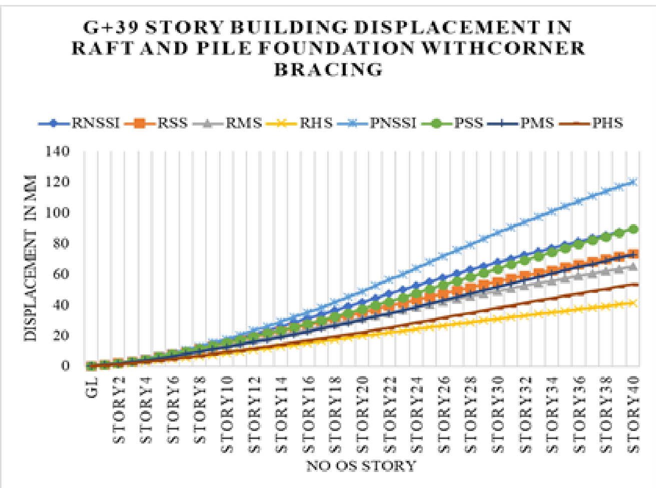
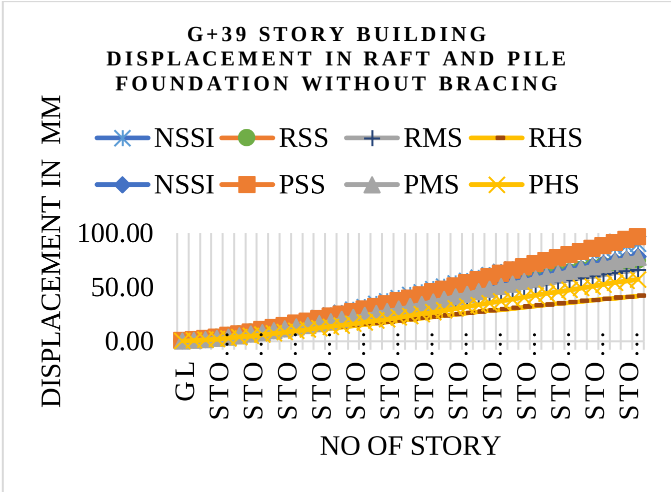


Fig. 7. Modelling of building (Pile)

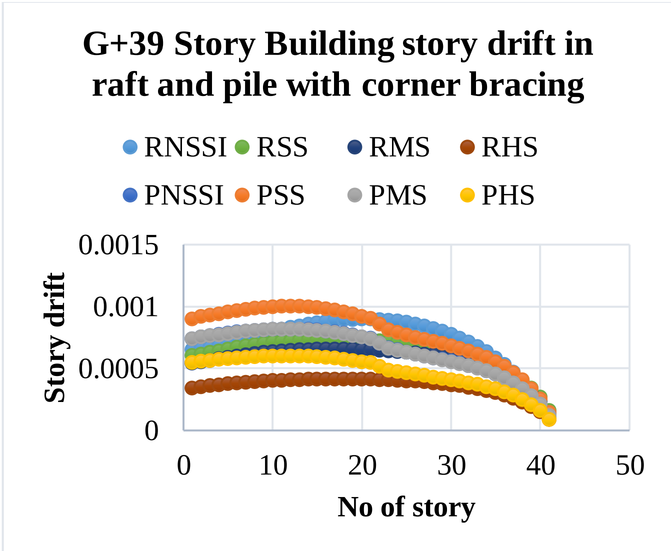
XIV. ANALYSIS, RESULTS AND DISCUSSION



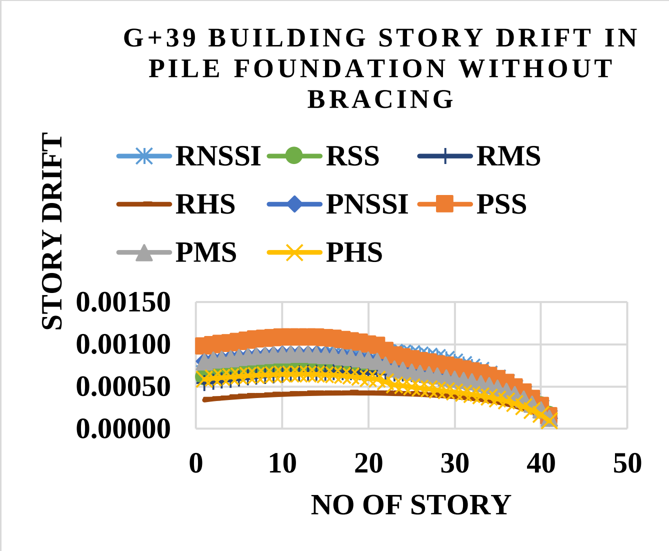
As can be seen from the above graph that highest displacement observed in PNSSI is 120.102 mm at 40th story. The maximum story displacement in top story is 89.292 in RNSSI, 73.314 mm in RSS, 65.174 in RMS, 41.14 in RHS, whereas 120.102 in PNSSI, 89.564 in PSS, 72.82 in PMS, and 53.557 in PHS.



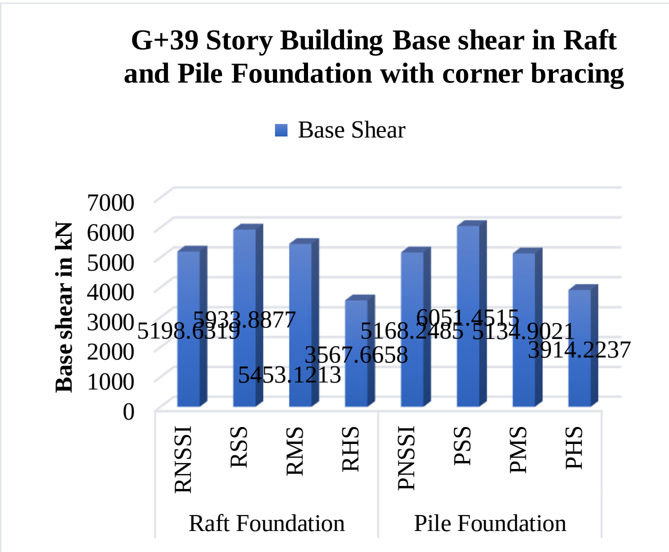
According to the above graphs that highest displacement observed in PSS is 96.25 mm at 40th story. The maximum story displacement in top story is 90.57 in RNSSI, 74.46 mm in RSS, 66.20 in RMS, 41.79 in RHS, whereas 78.44 in PNSSI, 96.25 in PSS, 78.12 in PMS, and 57.46 in PHS.



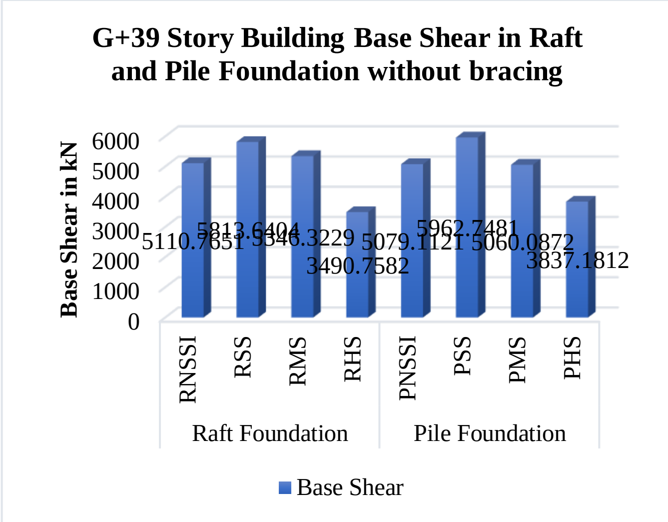
As can be seen from the chart 5.3 that the highest story drift observed between story 21 to 26 is 0.000896 in RNSSI, 0.000735 in RSS, 0.000655 in RMS, 0.000414 in RHS Meanwhile, the highest story drift observed between 29 to 33 is 0.000817 in PNSSI, 0.001001 in PSS, 0.000815 in PMS, and0.000599 in PHS.



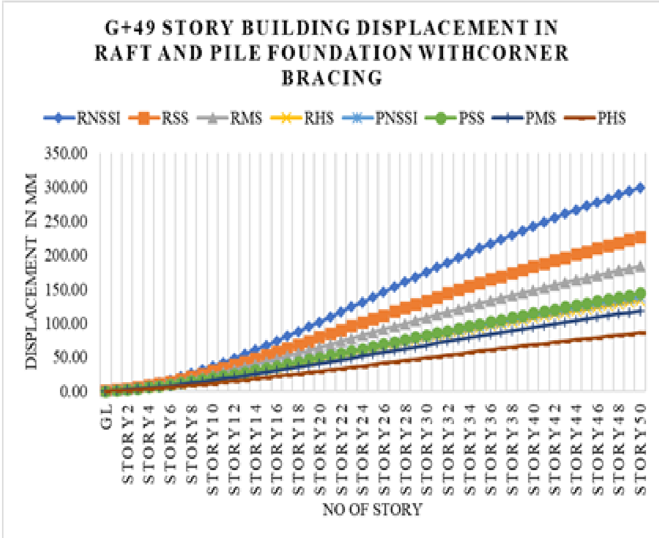
As can be seen from the chart 5.4 that the highest story drift observed between story 21 to 25 is 0.000911 in RNSSI, 0.000746 in RSS, 0.000665 in RMS, 0.000421 in RHS Meanwhile, the highest story drift observed between 29 to 33 is 0.000879 in PNSSI, 0.001079 in PSS, 0.000877 in PMS, and0.000645 in PHS.

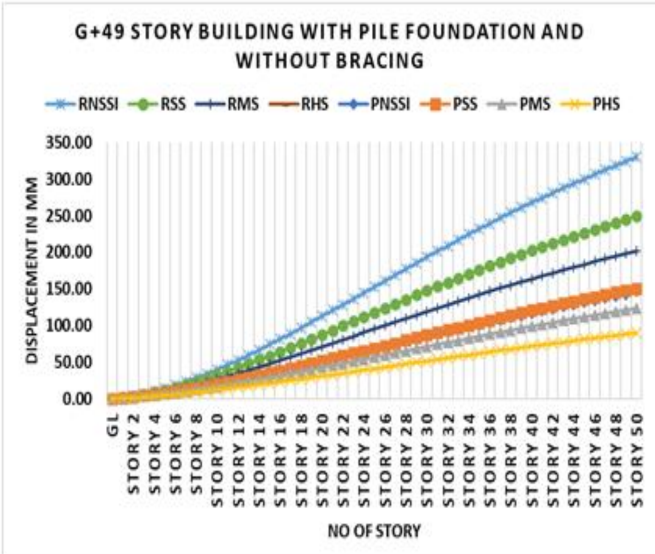


It is apparent from the chart 5.5 that highest base shear observed in PSS is 6051.4515kN at Base. The maximum base shear in base is 5198.6319 kN in RNSSI, 5933.887 kN in RSS (Raft foundation with soft soil), 5453.1213 kN in RMS (Raft foundation with medium soil), 3567.6658 kN in RHS (Raft foundation with hard soil), whereas 5168.2485 kN in PNSSI (Pile foundation with No Soil Structure Interaction), 6051.4515 kN in PSS (Pile foundation with soft soil), 5134.9021 kN in PMS (Pile foundation with Medium Soil), and 3914.2237 kN in PHS (Pile foundation with hard soil)



G+49 Storey Building





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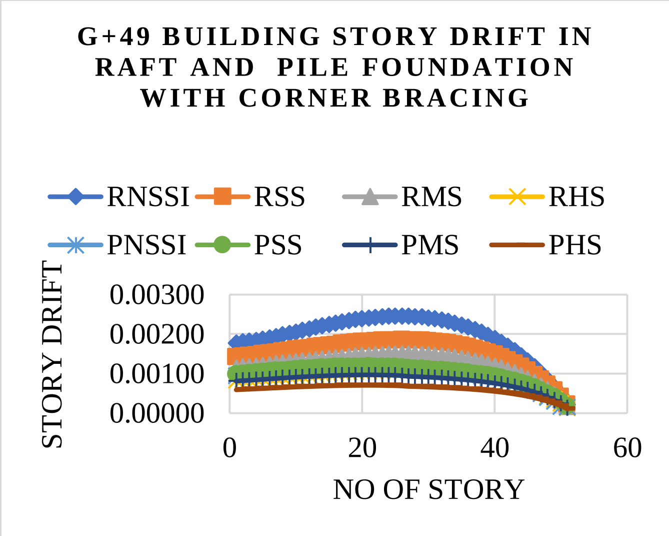
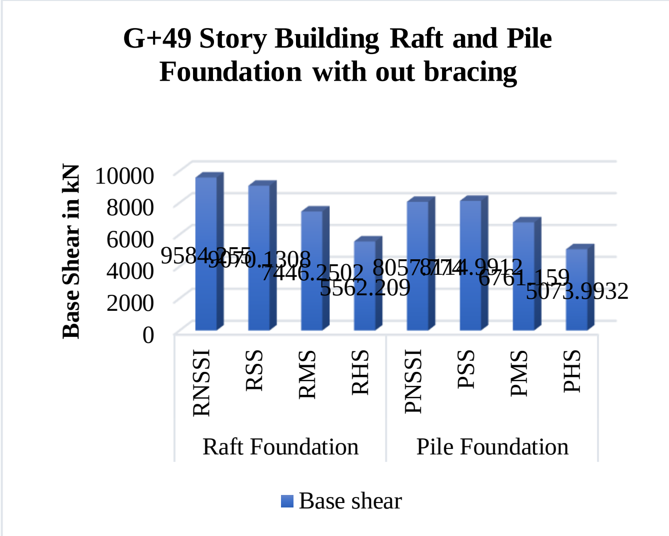
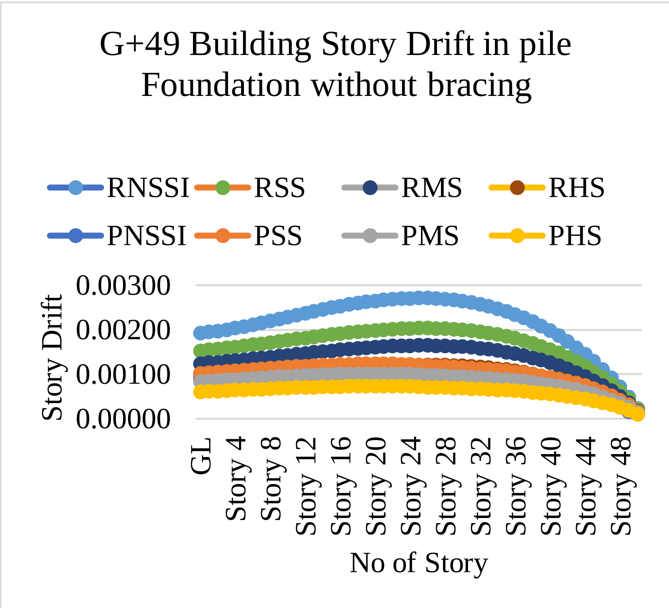
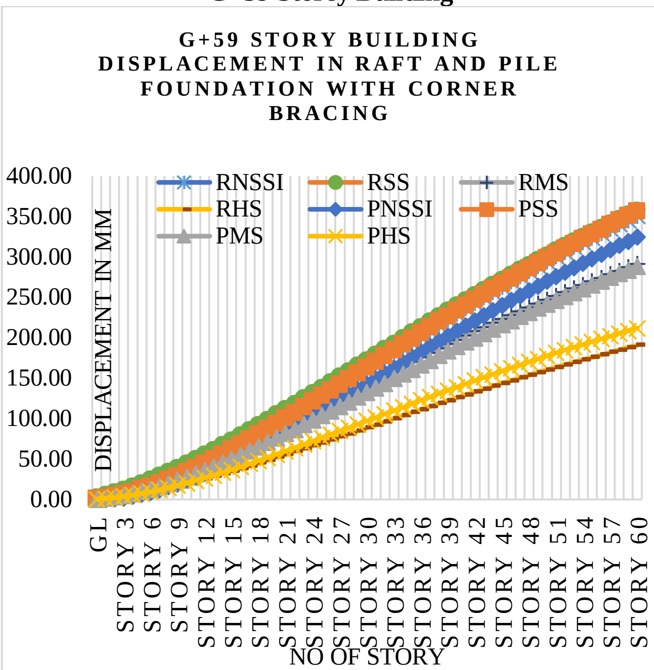
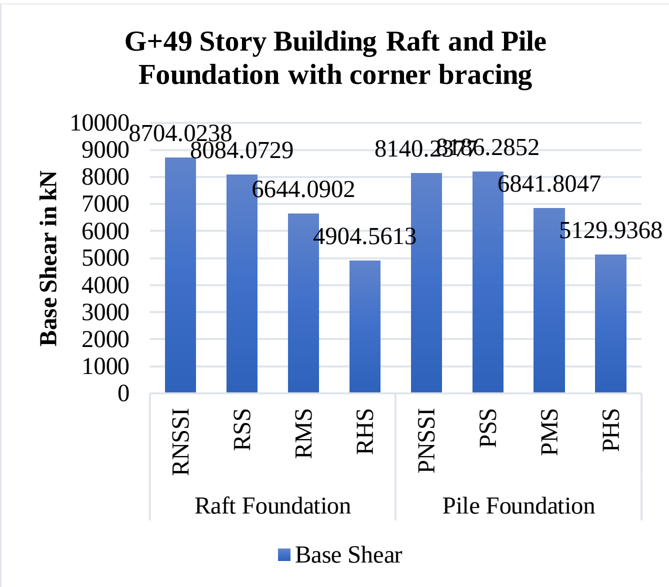


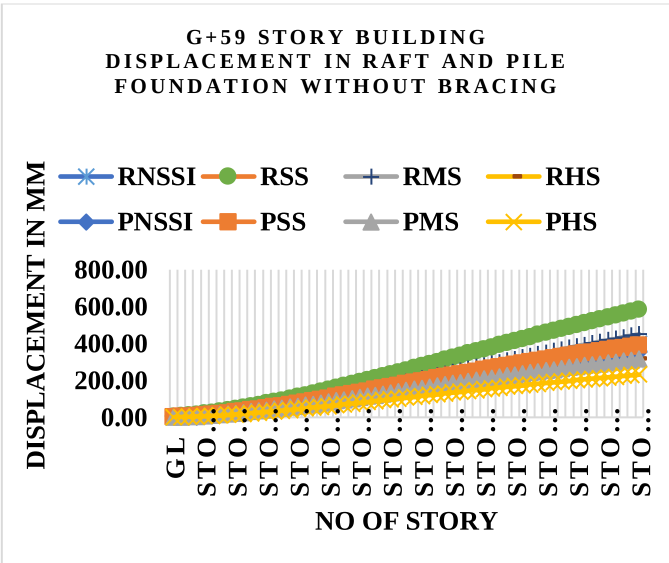


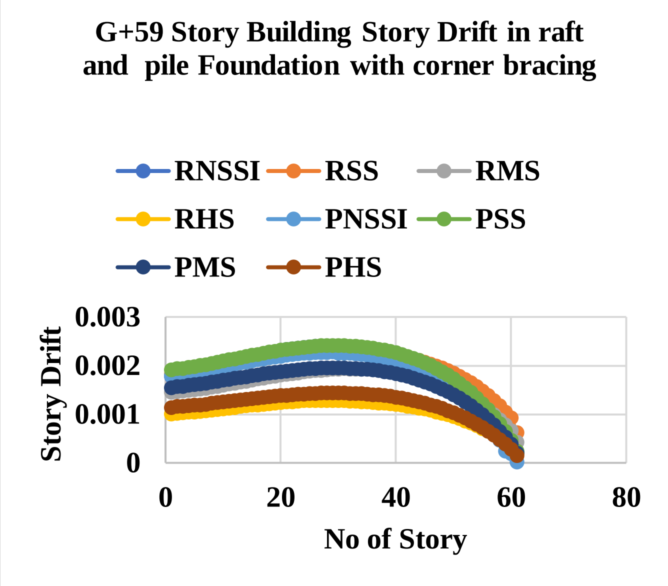


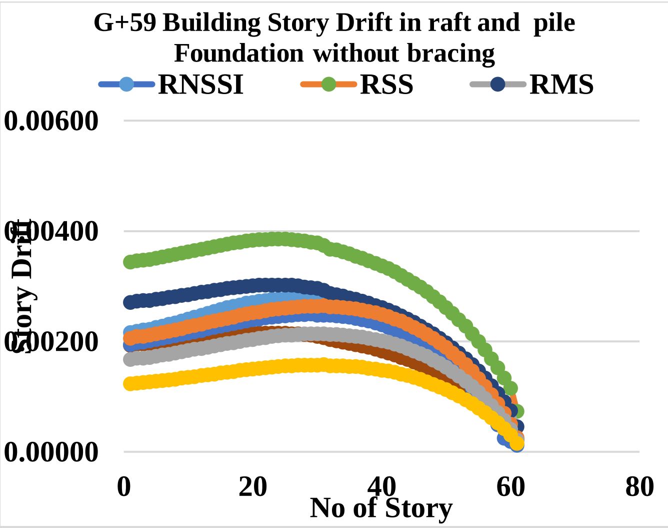
G+59 Storey Building

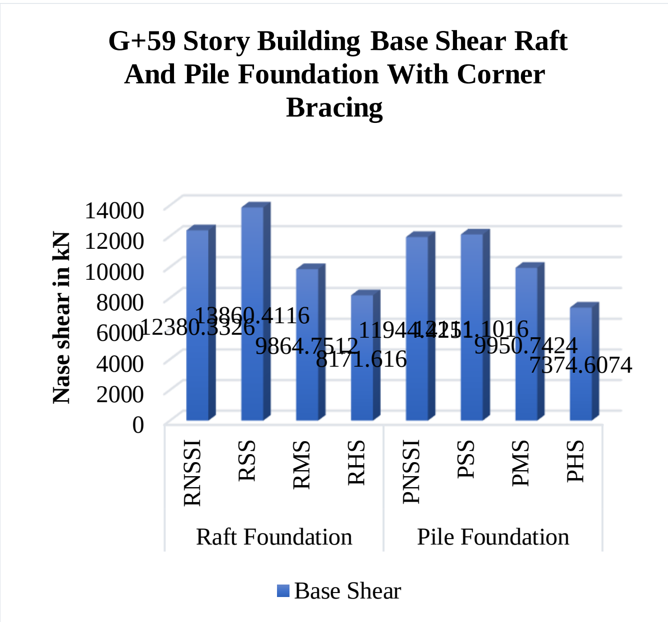


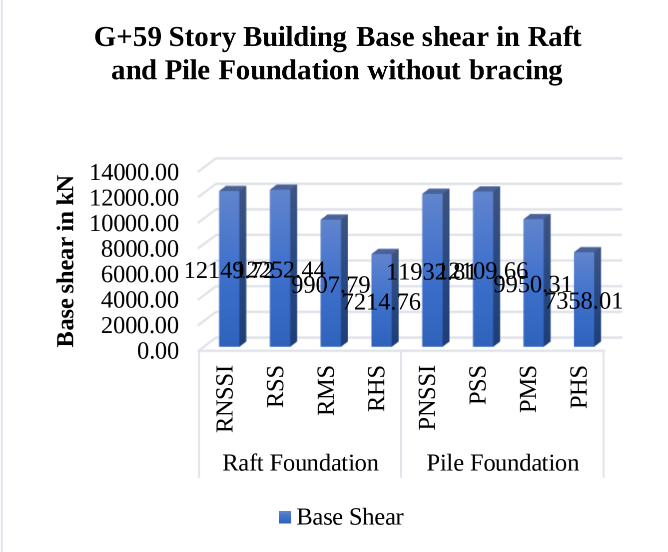












XVII. CONCLUSION

The present work attempts to study the effect of soil structure interaction under seismic loading for G+39, G+49 and G+59 story R C building with raft foundation and pile foundation including bracing and without bracing. Also, an attempt is made to study effect of the soil structure interaction on building with seismic zones V. This study has been mainly carried out to determine the change in various seismic response quantities due to consideration of flexibility of soil and the effect of seismic zones. Following conclusions were drawn from the present study and eventually results obtain in the form of displacement, story drift, story shear and base shear.

➤ *Displacement*

In g+39 story building the highest displacement observed in PNSSI. There is a significant decline in the displacement in soft soil, medium soil, and hard soil respectively when building resting on the raft foundation. There is a gradual fall in the displacement in soft soil, medium soil, and hard soil respectively when building resting on the pile foundation. Although same trend not seen, when building does not have bracing.

In g+39 story building the displacement is reduced by 4.51 percentage, when building is incorporating with PSS to RSS.

In g+39 story building the displacement is reduced by 8.52 percentage, when building is incorporating with PMS to RMS.

In g+39 story building the displacement is reduced by 3.31 percentage, when building is incorporating with PHS to RHS.

In g+49 story building the highest displacement observed in RNSSI. There is a significant decline in the displacement in soft soil, medium soil, and hard soil respectively when building resting on the raft foundation. There is a gradual fall in the displacement in soft soil, medium soil, and hard soil

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respectively when building resting on the pile foundation. Although, same trend not seen, when building does not have bracing.

In g+49 story building the displacement is reduced by 0.84 percentage, when building is incorporating with RNSSI to PNSSI.

In g+49 story building the displacement is reduced by 1.70 percentage, when building is incorporating with RSS to PSS.

In g+49 story building the displacement is reduced by 1.80 percentage, when building is incorporating with RMS to PMS.

In g+49 story building the displacement is reduced by 1.79 percentage, when building is incorporating with RHS to PHS.

In g+59 story building the highest displacement observed in RSS. There is a significant decline in the displacement in soft soil, medium soil, and hard soil respectively when building resting on the raft foundation. There is a gradual fall in the displacement in soft soil, medium soil, and hard soil respectively when building resting on the pile foundation. Although same trend not seen, when building does not have bracing.

In g+59 story building the displacement is reduced by 12.29 percentage, when building is incorporating with RSS to PSS.

In g+59 story building the displacement is reduced by 8.96 percentage, when building is incorporating with RHS to PHS.

➢ *Story Drift*

In g+39 story building the highest story drift observed in PNSSI. There is a gradual fall in the story drift in soft soil, medium soil, and hard soil respectively when building resting on the raft foundation. There is a significant decline in the story drift in soft soil, medium soil, and hard soil respectively when building resting on the pile foundation. Although same trend not seen, when building does not have bracing.

In g+39 story building the Story drift is reduced by 10.34 percentage, when building is incorporating with PNSSI to RNSSI, whereas, 2.76%,4.09%,2.23% in PSS to RSS, PMS to RMS and PHS to RHS respectively.

In g+49 story building the highest story drift observed in RNSSI. There is a gradual fall in the story drift in soft soil, medium soil, and hard soil respectively when building resting on the raft foundation. There is a Steady decline in the story drift in soft soil, medium soil, and hard soil respectively when building resting on the pile foundation. Although same trend not seen, when building does not have bracing.

In g+49 story building the Story drift is reduced by 0.86 percentage, when building is incorporating with RNSSI to PNSSI, whereas, 1.77%,1.84%,1.88% in RSS to PSS, RMS to PMS and RHS to PHS respectively.

In g+59 story building the highest story drift observed in PSS. There is a gradual fall in the story drift in soft soil, medium soil, and hard soil respectively when building resting on the raft foundation. There is a Steady decline in the story drift in soft soil, medium soil, and hard soil respectively when building resting on the pile foundation. Although same trend not seen, when building does not have bracing.

In g+59 story building the Story drift is reduced by 17.70 percentage, when building is incorporating with RNSSI to PNSSI, whereas,27.37%,8.38% in, RMS to PMS and RHS to PHS respectively.

➢ *Base Shear*

In g+39 story building the highest base shear observed in PSS. There is a Steady decline in the base shear in soft soil, medium soil, and hard soil respectively when building resting on the raft foundation. There is a Steady decline in the base shear in soft soil, medium soil, and hard soil respectively when building resting on the pile foundation. Although same trend seen, when building does not have bracing.

In g+49 story building the highest base shear observed in RNSSI. There is a Steady decline in the base shear in soft soil, medium soil, and hard soil respectively when building resting on the raft foundation. There is a went down in the base shear in soft soil, medium soil, and hard soil respectively when building resting on the pile foundation. Although same trend seen, when building does not have bracing.

In g+59 story building the highest base shear observed in RSS. There is a Steady decline in the base shear in soft soil, medium soil, and hard soil respectively when building resting on the raft foundation. There is a Steady decline in the base shear in soft soil, medium soil, and hard soil respectively when building resting on the pile foundation. Although same trend seen, when building does not have bracing.

In the closing it is evident that, for tall building hard soil is most preferable as compare to medium and soft soil.

REFERENCES

[1]. Y. Naga Satyesh, K. Shyam Chamberlin, “SEISMIC RESPONSE OF PLANE FRAMES WITH EFFECT OF BAY SPACING AND NUMBER OF STORIES CONSIDERING SOIL-STRUCTURE INTERACTION,” International Journal of Civil Engineering and Technology (IJCIET), January 2017.

[2]. “Design and Analysis of Tall and Complex Structures,” in Design and Analysis of Tall and Complex Structures, Elsevier Ltd., 2018.

[3]. B. S. Hamid Reza Tabatabaiefar, “Seismic Behavior of Building Frames Considering Dynamic Soil-Structure Interaction,” INTERNATIONAL JOURNAL OF GEOMECHANICS © ASCE, JULY/AUGUST 2013 .

[4]. M. M. Shehata E. Abdel Raheem, "Evaluation of soil–foundation–structure interaction effects on seismic response demands of multi-story MRF buildings on raft foundations," Int J Adv Struct Eng, Vols. DOI 10.1007/s40091-014-0078-x, no. Springer, (2015).
[5]. M. M. Shehata E. Abdel Raheem, "SOIL-STRUCTURE INTERACTION EFFECTS ON SEISMIC RESPONSE OF MULTI-STORY BUILDINGS ON RAFT FOUNDATION," in Journal of Engineering Sciences Assiut University Faculty of Engineering , Egypt, 2014.
[6]. J. C. S., R. V. RAMA RAO1, "Soil-structure interaction effects on seismic response of open ground," Indian Academy of Sciences, 24 April 2021.
[7]. H. F. Xiaofeng Zhang, "Effects of dynamic soil structure interaction on seismic behaviour of high rise buildings," Bulletin of Earthquake Engineering (Springer), no. Springer, 6 july 2021.
[8]. B. K. Joy P. V.1, "Pushover Analysis of Buildings Considering Soil-Structure Interaction," Applied Mechanics and Materials, vol. Vol. 857, 2019.
[9]. N. A. M. Jenifer Priyanka, "Studies on Soil Structure Interaction of Multi Storyed Buildings with Rigid and Flexible Foundation," International Journal of Emerging Technology and Advanced Engineering, vol. 2, ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 2, Issue 12, December 2012.
[10]. W. A.,. M. U. Ravi Kant, "Study on seismic performance of reinforced concrete multi-Story building considering soil-structure interaction effect," Science Direct (ELSEVIER), 2021 Elsevier Ltd..
[11]. S. A. Jaime A. Mercado, M. Luis G. Arboleda-Monsalve and a. V. Terzic, "Seismic Soil-Structure Interaction Response of Tall Buildings," Geo-Congress, vol. GSP 308, no. (ASCE) (American Society of Civil Engineers.), 2019.
[12]. R. K. M. Maikesh Chouha, "Dynamic Analysis of Multi-Storyed Frame-Shear Wall Building Considering SSI," International Journal of Engineering Research and Applications, Vols. Vol. 6,, no. Issue 8, August 2016.
[13]. B. M. Dhiraj Raj, "n the seismic response of steel buckling-restrained braced structures including soil-structure interaction," Proceedings of Indian Geotechnical Conference (IITRoorkee), 2013.
[14]. G. A. P. Antonios K. Flogeras, "On the seismic response of steel buckling-restrained braced structures including soil-structure interaction," Earthquakes and Structures (Techno-Press, Ltd), vol. 2017, no. no.4, 2017.
[15]. G. N. K. V. Haneef, "Influence of Soil Structure Interaction on Multi-Story Building with Raft Foundation," Journal of Information and Computational Science, vol. Volume 9 , no. Issue 12, 2019.
[16]. D. R. A. K. Jasvir Singh, "Study of Soil Structure Interaction for Framed Structures with Raft(Shallow) Foundations," International Journal of Advanced Scientific Research and Management, vol. Vol. 3, no. Issue 12, Dec. 2018.
[17]. P. S. Shreya Sitakant Shetgaonkar1, "Seismic Response of Multistoried Building with Different Foundations Considering Interaction Effects," © 2018 Trans Tech Publications, Switzerland ,Applied Mechanics and Materials, Vols. ISSN: 1662-7482, Vol. 877, pp 276-281, 2015.
[18]. K.S. Halkude S.A.Ȧ, "Seismic Response of R.C. Frames with Raft Footing Considering Soil Structure Interaction," International Journal of Current Engineering and Technology , Vols. Vol.4, , no. 3, 2014.
[19]. S. S. Lavanya.T, "DYNAMIC ANALYSIS OF TUBE-IN-TUBE TALL BUILDINGS," International Research Journal of Engineering and Technology (IRJET), vol. Volume: 04, no. Issue: 04, Apr -2017.
[20]. M.E. Stavroulaki, "Application of response spectrum analysis in historical buildings," Transactions on the Built Environmen, vol. 15, 1995 WIT press.
[21]. A. L. Ryan A. Kersting, "Seismic Design of Steel BucklingRestrained Braced Frames," Gaithersburg, U.S. Department of Commerce National Institute of Standards and Technology Engineering Laboratory, September 2015, p. 34.
[22]. M. Deiranlou, "Evaluation of Seismic Behavior in Building Tube Structures System with Respect to Dense Soil-Structure Interaction Effect," Scientific Research Publishing (Open Journal of Civil Engineering), 2015.

- IS 16700 for Tall Building.
- IS 800:2007 General Construction in Steel
- IS 1893:2016 General Criteria for earthquake resistant design of structure
- IS 2911:2010 Design and Construction of Pile Foundation.
- IS 456:2000 Plain and Reinforced Concrete
- FEMA 356:2000