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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* —Bracing, ETABS2018, Shear wall, Tube in tube structure system**

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.

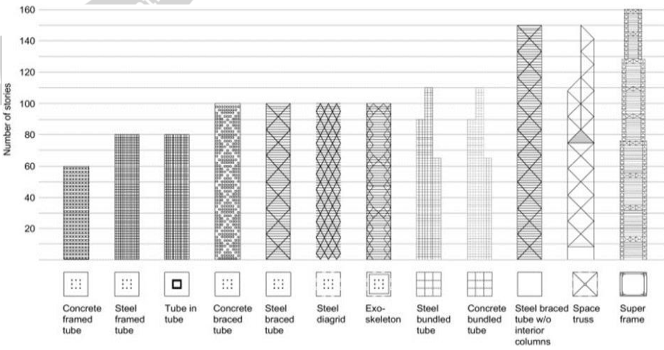

Fig. 1. Different Structural System

II. 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

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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.

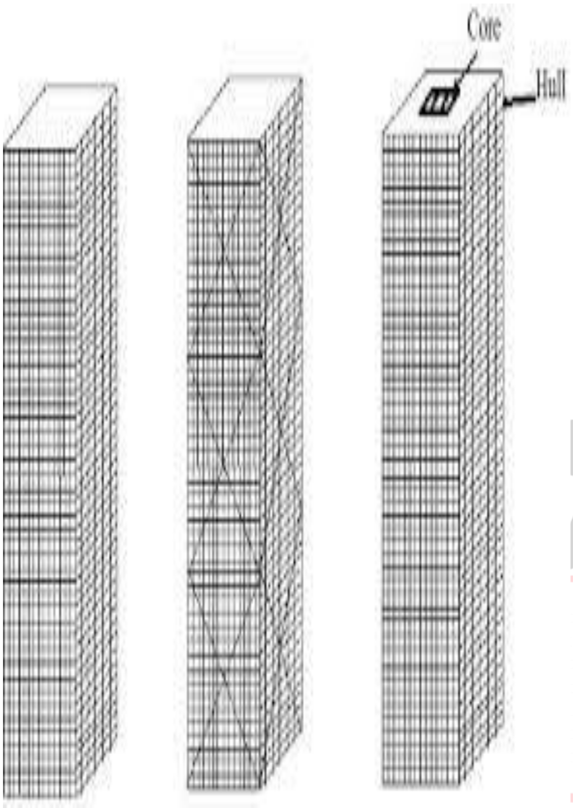

Fig. 2. Tube in tube Structure

III. 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]

IV. 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.

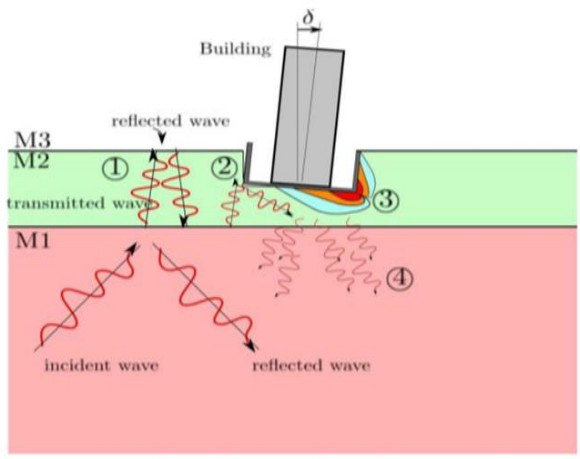

Fig. 3. Soil Structure Interaction in layered soil

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.

V. 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.

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

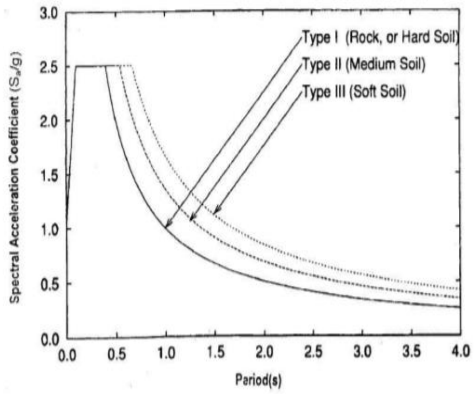

Fig. 4 Response spectra for rock and soil sites for 5% damping (IS1893)

Three translation 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.

VI. 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.

VII. 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

VIII. 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.

IX. 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

Table 2. Soil Spring Equation

Degrees of Freedom	Stiffness of equivalent soil spring
Vertical	[2GL/(1-v)] (0.73+1.54χ0.75) with χ =Ab/4L2
Horizontal (Lateral direction)	[2GL/(2-v)] (2+2.50χ0.85) with χ = Ab/4L2
Horizontal (Longitudinal direction)	[2GL/(2-v)] (2+2.50χ0.85)-[0.2/(0.75-v)]GL[1-(B/L)] with χ = Ab /4 L2
Rocking (About longitudinal)	[G/(1-v)] Ibx 0.75(L/B)0.25[2.4+0.5(B/L)]
Rocking (About lateral)	[G/(1-v)] 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.

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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

X. GEOMETRIC PROPERTIES OF BULDING

Table 3. 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

XI. RAFT AND PILE FOUNDATION BUILDING MODELLING

Fig. 5. Modelling of building (Raft)

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Above figure 5 is shows the information about modelling of building with raft foundation and soil structure interaction.

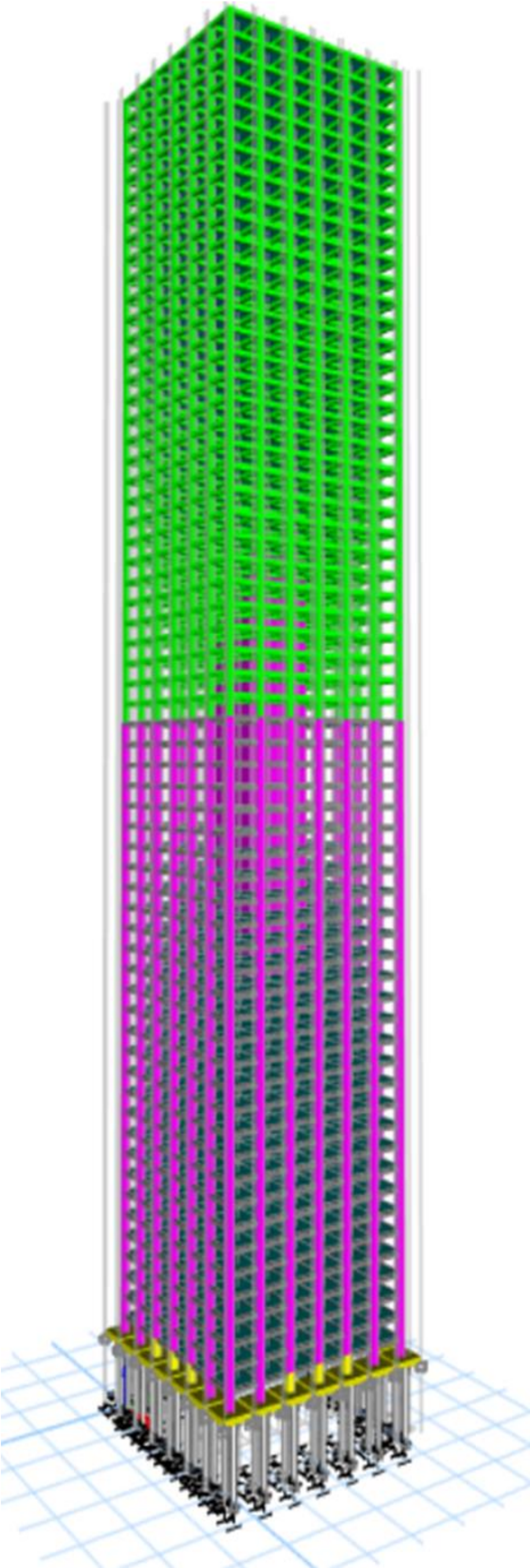

Fig. 6. Modelling of building (Pile)

Above figure 6 is shows the information about modelling of building with pile foundation and soil structure interaction.

XII. ANALYSIS, RESULTS AND DISCUSSION

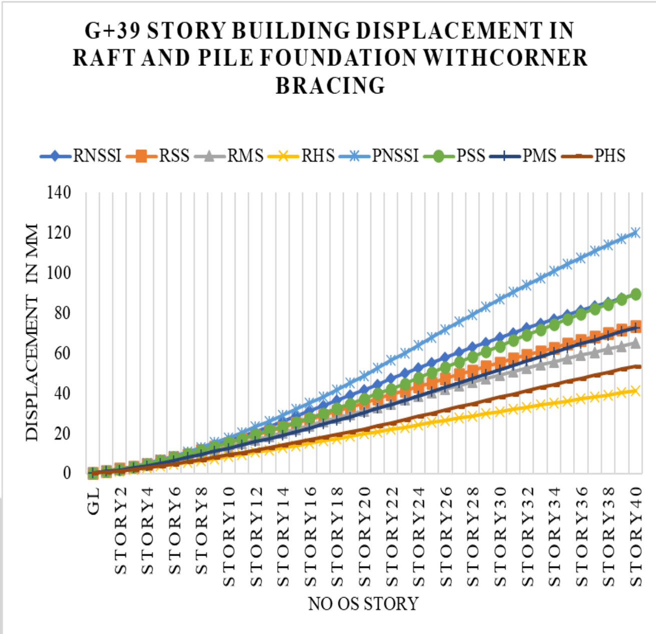

Chart 1 G+39 Story building displacement

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.

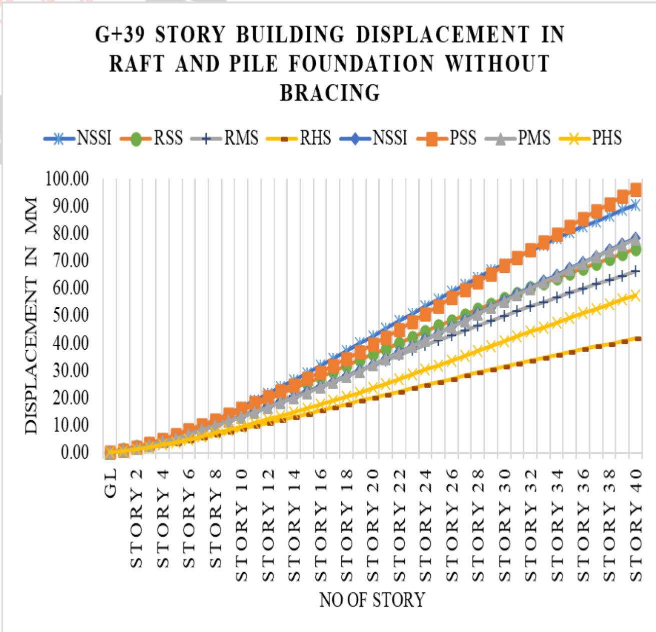

Chart 2 G+39 Story building displacement

According to the above graphs that highest displacement observed in PSS is 96.25 mm at 40th story. The maximum

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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.

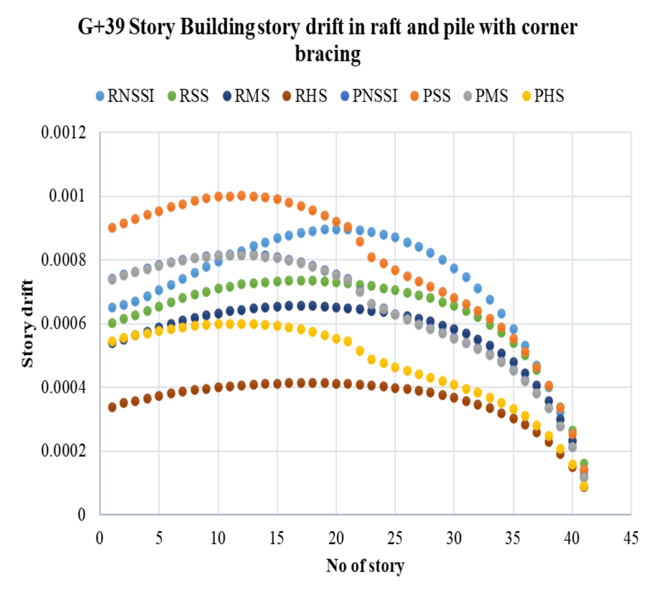

Chart 3 G+39 Story building Story drift

As can be seen from the chart 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.

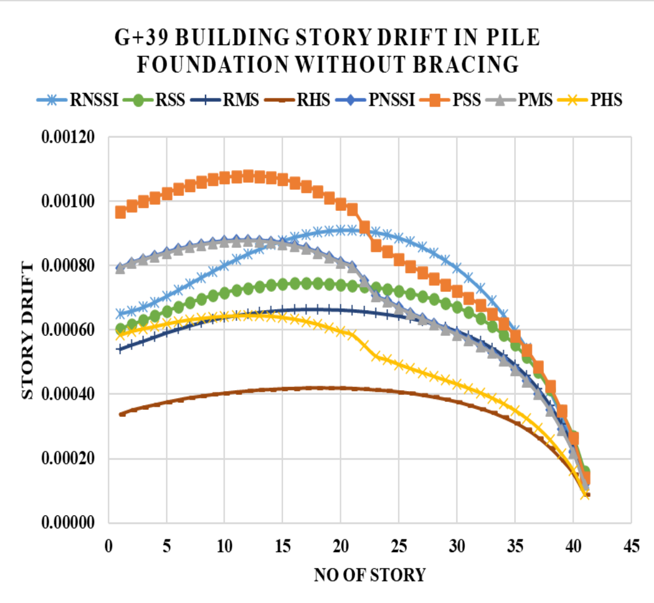

Chart 4 G+39 Story building story drift

As can be seen from the chart 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.

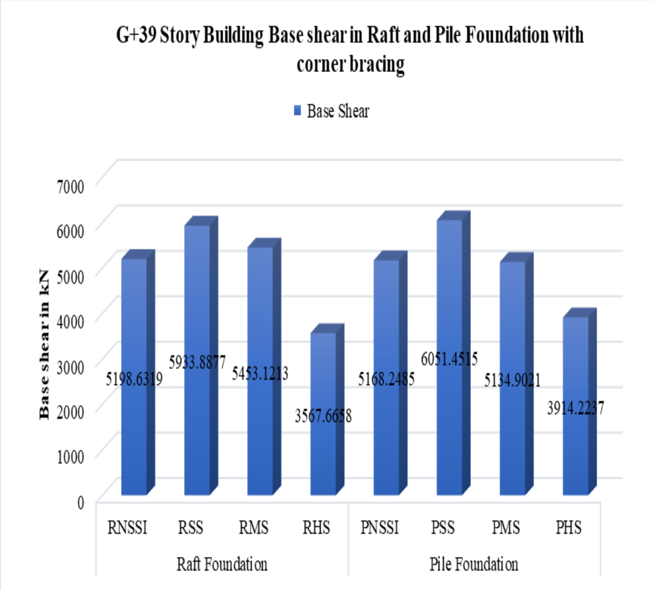

Chart 5 G+39 Story building base shear

It is apparent from the chart 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)

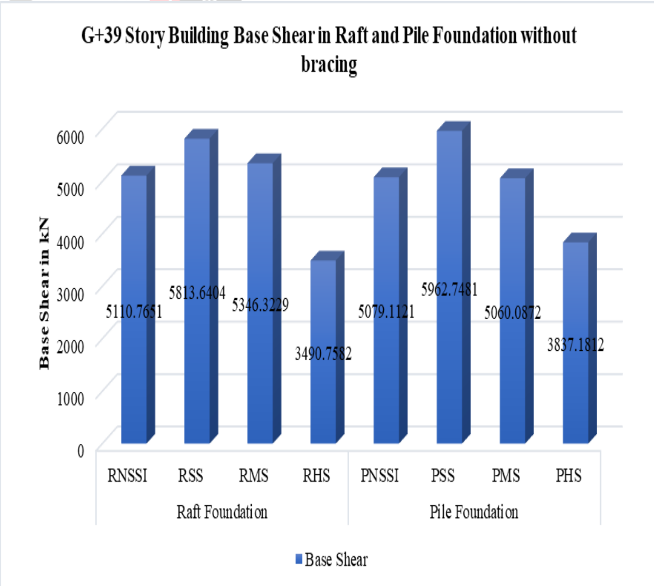

Chart 6 G+39 Story building base shear

It is apparent from the chart 6 that highest base shear observed in PSS is 5962.7481 kN at Base. The maximum base shear in base is 5110.7651 kN in RNSSI, 5813.6404 kN in RSS (Raft foundation with soft soil), 5346.3229 kN in RMS (Raft foundation with medium soil), 3490.7582 kN in RHS (Raft foundation with hard soil), whereas 5079.1121 kN in PNSSI (Pile foundation with No Soil

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Structure Interaction), 5962.7481 kN in PSS (Pile foundation with soft soil), 5060.0872 kN in PMS (Pile foundation with Medium Soil), and 3837.1812 kN in PHS. (Pile foundation with hard soil)

G+49 Storey Building

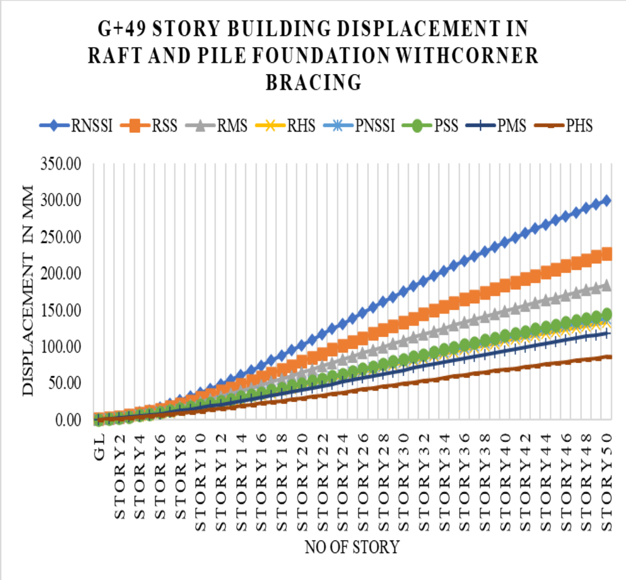

Chart 7 G+49 Story building displacement

It can be seen from the chart 7 that highest displacement observed in RNSSI (Raft with No Soil Structure Interaction) is 299.31 mm at 50th story. The maximum story displacement in top story is 299.31 in RNSSI, 226.67 mm in RSS (Raft foundation with soft soil), 183.54 in RMS (Raft foundation with medium soil), 132.53 in RHS (Raft foundation with hard soil), whereas 137.26 in PNSSI (Pile foundation with No Soil Structure Interaction), 143.77 in PSS (Pile foundation with soft soil), 118.00 in PMS (Pile foundation with Medium Soil), and 85.61 in PHS (Pile foundation with hard soil)

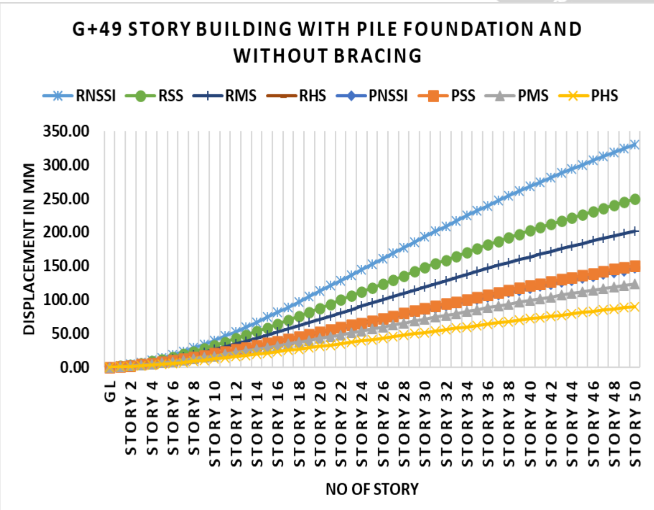

Chart 8 G+49 Story building displacement

It can be seen from the chart 8 that highest displacement observed in RNSSI (Raft with no Soil Structure Interaction) is 330.04 mm at 50th story. The maximum story displacement in top story is 330.04 in RNSSI, 249.76 mm in RSS (Raft foundation with soft soil), 202.23 in RMS (Raft foundation with medium soil), 148.73 in RHS (Raft foundation with hard soil), whereas 147.54 in PNSSI (Pile foundation with No Soil Structure Interaction), 151.03 in PSS (Pile foundation with soft soil), 123.06 in PMS (Pile foundation with Medium Soil), and 89.94 in PHS (Pile foundation with hard soil)

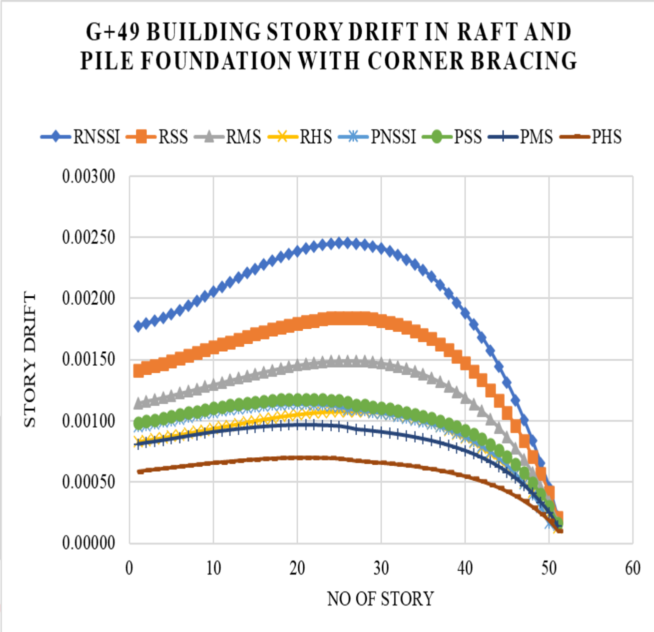

Chart 9 G+49 Story building story drift

As can be seen from the chart 5.9 that the highest story drift observed between story 23 to 26 is 0.002453 in RNSSI, 0.001845 in RSS, 0.001494 in RMS, 0.001078 in RHS Meanwhile, the highest story drift observed between 30 to 33 is 0.001135 in PNSSI, 0.001179 in PSS, 0.000968 in PMS, and0.000704 in PHS.

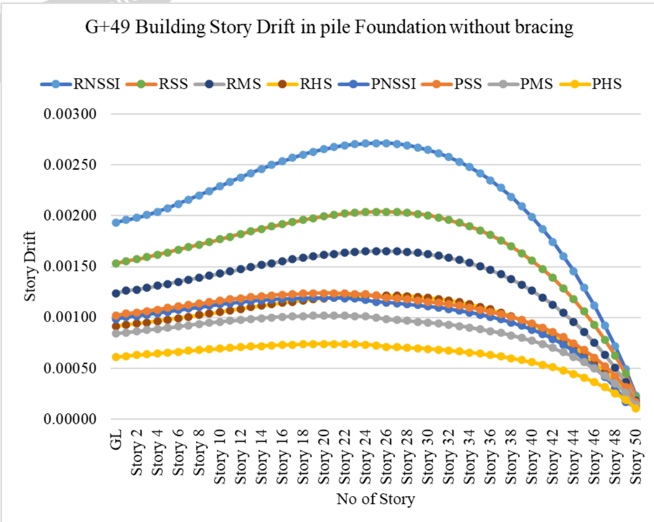

Chart 10 G+49 Story building story drift

As can be seen from the chart 5.10 that the highest story drift observed between story 21 to 26 is 0.002716 in RNSSI, 0.00204 in RSS, 0.001652 in RMS, 0.001215 in

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RHS Meanwhile, the highest story drift observed between 29 to 35 is 0.001193 in PNSSI, 0.001238 in PSS, 0.001017 in PMS, and0.000739 in PHS.

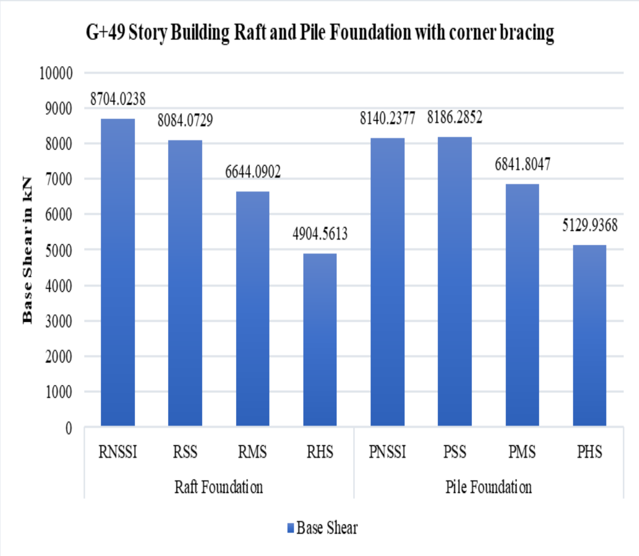

Chart 11 G+49 Story building base shear

It is apparent from the chart 11 that highest base shear observed in RNSSI is 8704.0238 kN at Base. The maximum base shear in base is 8704.0238 kN in RNSSI, 8084.0729 kN in RSS (Raft foundation with soft soil), 6644.0902 kN in RMS (Raft foundation with medium soil), 4904.5613 kN in RHS (Raft foundation with hard soil), whereas 8140.2377 kN in PNSSI (Pile foundation with No Soil Structure Interaction), 8186.2852 kN in PSS (Pile foundation with soft soil), 6841.8047 kN in PMS (Pile foundation with Medium Soil), and 5129.9368 kN in PHS (Pile foundation with hard soil)

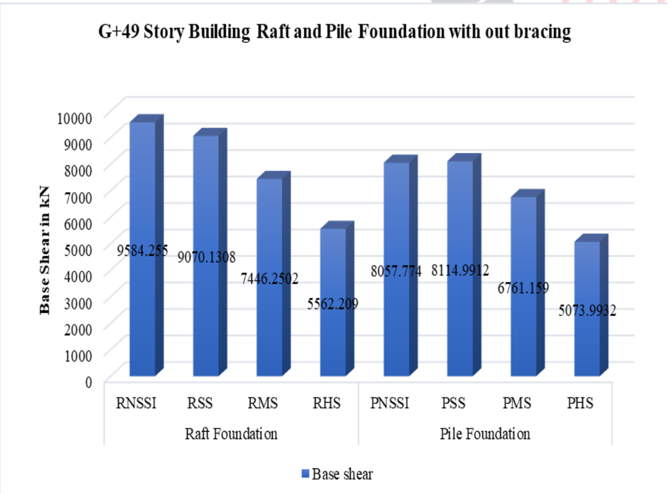

Chart 12 G+49 Story building base shear

It is apparent from the chart 12 that highest base shear observed in RNSSI is 9584.255 kN at Base. The maximum base shear in base is 9584.25 kN in RNSSI, 9070.1308 kN in RSS (Raft foundation with soft soil), 7446.2502 kN in RMS (Raft foundation with medium soil), 5562.209 kN in RHS (Raft foundation with hard soil), whereas 8057.774 kN in PNSSI (Pile foundation with No Soil Structure Interaction), 8114.9912 kN in PSS (Pile foundation with soft soil), 6761.159 kN in PMS (Pile foundation with Medium Soil), and 507309932 kN in PHS (Pile foundation with hard soil)

G+59 Storey Building

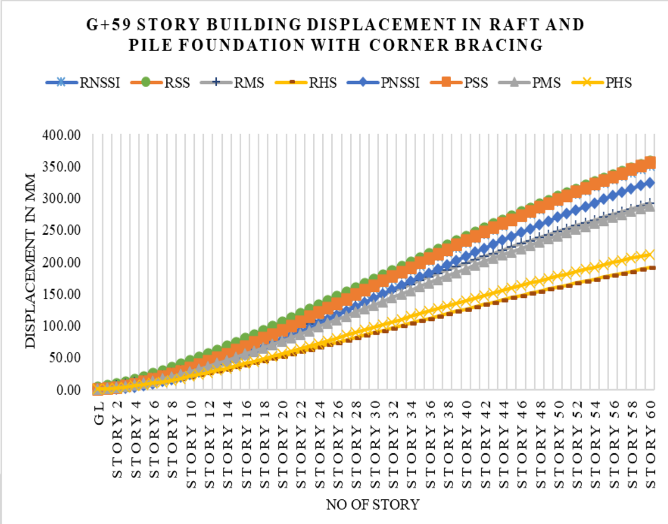

Chart 13 G+59 Story building displacement

It can be seen from the chart 13 that highest displacement observed in RSS is 357.39 mm at 60th story. The maximum story displacement in top story is 351.02 in RNSSI, 357.39 mm in RSS (Raft foundation with soft soil), 291.23 in RMS (Raft foundation with medium soil), 190.69 in RHS (Raft foundation with hard soil), whereas 324.62 in PNSSI (Pile foundation with No Soil Structure Interaction), 356.09 in PSS (Pile foundation with soft soil), 288.26 in PMS (Pile foundation with Medium Soil), and 211.95 in PHS. (Pile foundation with hard soil)

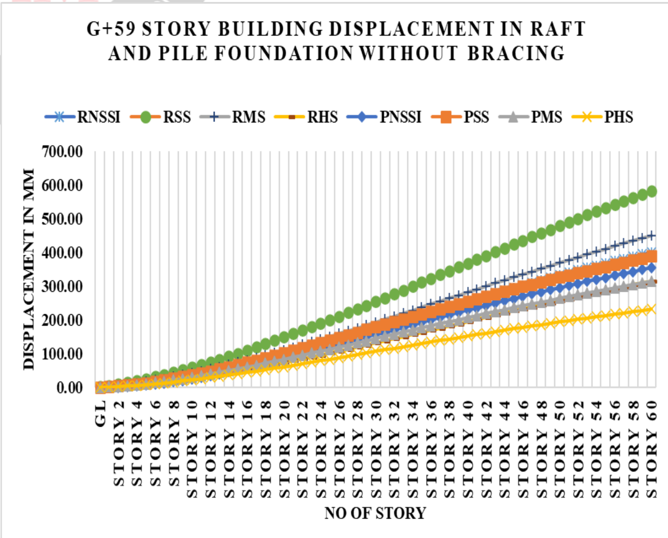

Chart 14 G+59 Story building displacement

It can be seen from the chart 14 that highest displacement observed in RSS is 582.75 mm at 60th story. The maximum story displacement in top story is 400.23 in RNSSI, 582.75

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mm in RSS (Raft foundation with soft soil), 450.41 in RMS (Raft foundation with medium soil), 314.94 in RHS (Raft foundation with hard soil), whereas 354.70 in PNSSI (Pile foundation with No Soil Structure Interaction), 388.52 in PSS (Pile foundation with soft soil), 314.51 in PMS (Pile foundation with Medium Soil), and 231.25 in PHS (Pile foundation with hard soil).

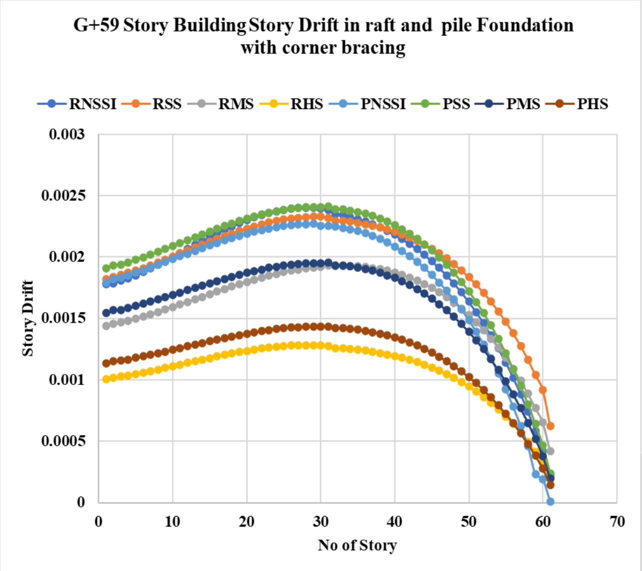

Chart 15 G+59 Story building story drift

As can be seen from the chart 15 that the highest story drift observed between story 31 to 36 is 0.002401 in RNSSI, 0.002328 in RSS, 0.001934 in RMS, 0.001238 in RHS Meanwhile, the highest story drift observed between 29 to 35 is 0.002273 in PNSSI, **0.002413 in PSS**, 0.001953 in PMS, and0.001436 in PHS.

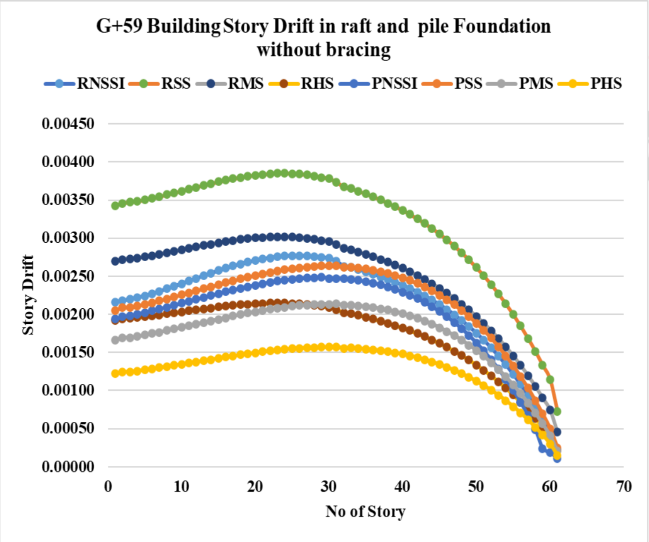

Chart 16 G+59 Story building displacement

It is evident from the chart 16 that the highest story drift observed between story 31 to 36 is 0.002769 in RNSSI, 0.003851 in RSS, 0.003019 in RMS, 0.002148 in RHS Meanwhile, the highest story drift observed between 31 to 35 is 0.002491 in PNSSI, 0.002643 in PSS, 0.002139 in PMS, and0.001573 in PHS.

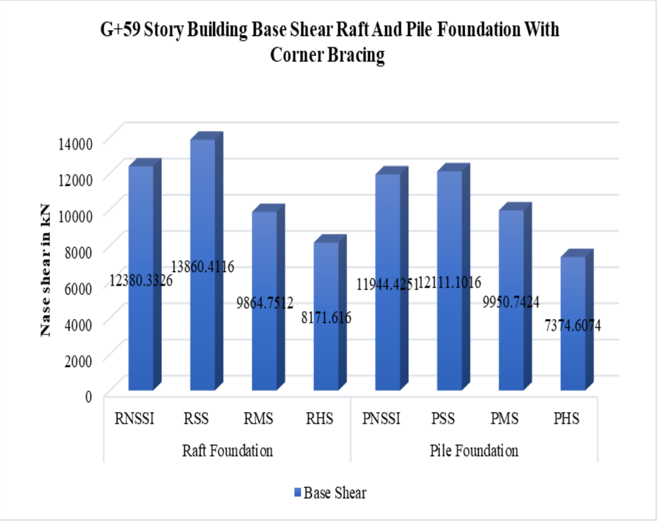

Chart 17 G+59 Story building base shear

It is apparent from the chart 17 that highest base shear observed in RSS is 13860.4116 kN at Base. The maximum base shear in base is 12380.3326 kN in RNSSI, 13860.4116 kN in RSS (Raft foundation with soft soil), 9864.7512 kN in RMS (Raft foundation with medium soil), 8171.616 kN in RHS (Raft foundation with hard soil), whereas 11944.4251 kN in PNSSI (Pile foundation with No Soil Structure Interaction), 12111.1016 kN in PSS (Pile foundation with soft soil), 9950.7424 kN in PMS (Pile foundation with Medium Soil), and 7374.6074 kN in PHS. (Pile foundation with hard soil)

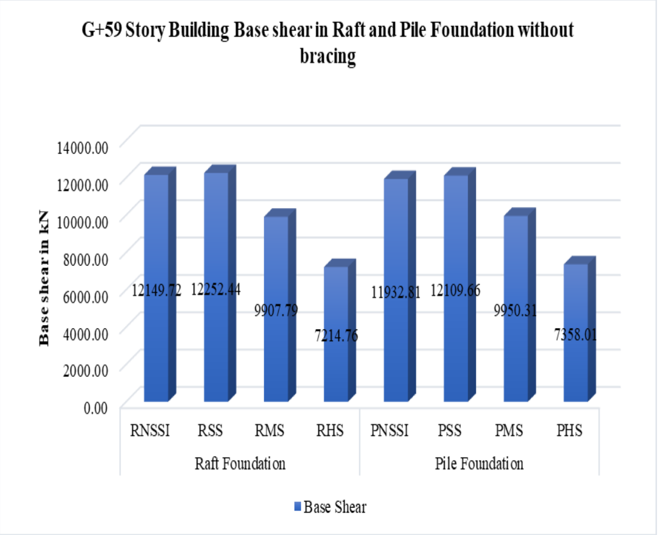

Chart 18 G+59 Story building base shear

It is apparent from the chart 18 that highest base shear observed in RSS is 12252.44 kN at Base. The maximum base shear in base is 12149.72 kN in RNSSI, 12252.44 kN in RSS (Raft foundation with soft soil), 9907.79 kN in RMS (Raft foundation with medium soil), 7214.76 kN in RHS (Raft foundation with hard soil), whereas 11932.81 kN in PNSSI (Pile foundation with No Soil Structure

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Interaction), 12109.66 kN in PSS (Pile foundation with soft soil), 9950.31 kN in PMS (Pile foundation with Medium Soil), and 7358.01 kN in PHS. (Pile foundation with hard soil)

XIII. 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

The highest displacement observed in G+39 story building at top story, which was 120.02mm in PNSSI (Fixed base) when incorporate with bracing and shear wall. There was a gradual growth in displacement from RNSSI to PNSSI, which was 2.89 %.

When the height of building increase at same time, the highest displacement observed in G+49 story building at top story, which was 299.34 mm in RNSSI (Fixed base); whereas building was incorporated with bracing and shear wall. There was a slight decline in displacement from RNSSI to PNSSI, which was 0.84 %. In g+49 story building the displacement is reduced by 1.79 %, when building is incorporating with RHS to PHS.

In g+59 story building the displacement is reduced by 8.96 %, when building is incorporating with RHS to PHS, As a result, raft foundations are ideal at a particular height of building, but as the height of the building increases, pile foundations are suitable.

STORY DRIFT

The highest story drift observed in G+39 story building between 21 to 26, which was 0.000896 in RNSSI (Fixed base) when incorporate with bracing and shear wall. There was a gradual growth in story drift from RNSSI to PNSSI, which was 8.5 %.

When the height of building increase at same time, The highest story drift observed in G+49 story building between 23 to 26, which was 0.002453 in RNSSI (Fixed base); whereas building was incorporated with bracing and shear wall. There was a slight decline in displacement from RNSSI to PSS, which was 0.92%. In g+49 story building the story drift is reduced by 1.88 %, when building is incorporating with RHS to PHS.

In g+59 story building the Story drift is reduced by 17.70%, when building is incorporating with RNSSI to PNSSI, whereas,27.37%,8.38% in, RMS to PMS and RHS to PHS respectively. As a result, raft foundations are ideal at a particular height of building, but as the height of the building increases, pile foundations are suitable.

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, Addition of bracings leads to increase in the value of base shear. The value of base shear decreases up to 7.61% from corner bracing to without bracing in RSS, and There was a significant decrease in the base shear in soft soil to hard soil, when building resting on the raft foundation and same trend shown in pile foundation.

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