STUDY OF SOIL STRUCTURE INTERACTION ON SEISMIC PERFORMANCE OF STEEL STRUCTURE

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ABSTRACT

In order to study structural behaviour under seismic excitation forces, it is prominent to study the effects of soil structure interaction (SSI). In present study, attempt have been made to study the influence of soil structure interaction on seismic behaviour of steel structure considering two different bracing systems V and X bracing. Usually the structural behaviour is analysed assuming the fixed support conditions at the base of structure. In conventional method, the foundation flexibility of soil mass is ignored which is likely to affect the structural response of building. The soil flexibility is integrated in the analysis of structure using Winkler's spring model approach. For analysis G+11 multi storey steel building is considered with two different bracing arrangements. Three different soil strata's i.e. hard, medium and soft are used for SSI study. The dynamic analysis is carried out in SAP2000 software using response spectra of IS 1893-2002. The effect of SSI on various parameters like base shear, natural time period, storey drift, storey displacement, etc are studied and discussed. To get real behaviour of superstructure the subgrade must be modelled adequately well. The study reveals that the SSI significantly affects the performance of the structure.

Keyword: - *Soil Structure Interaction (SSI), Seismic behavior, Steel structure, Bracing system, Response spectrum method.,*

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1. INTRODUCTION-1

An earthquake is a shaking of the ground caused by sudden rupture and movement of large tectonic plates. Earthquakes are either tectonic or non-tectonic, about 90 percent of earthquakes are tectonic and 10 percent earthquakes are due to volcanism, manmade effect etc. The Indian sub-continent has a history of devastating earthquakes. After Killari (1993), Jabalpur (1997), and Bhuj (2001) earthquake it is clear that no part of the country is free from the seismic hazard. The main reason for the high intensity of earthquake in India is because of the movement of Indian plate towards the Eurasian plate at the rate of 49mm per year approximately. Geographical statistics shows that the India has almost 54 percent of land vulnerable to seismic hazards.
The advance countries like USA, Japan are already constructing the structures which can resists the earthquake of magnitude 7 and above. Unfortunately, in India not much awareness has been created in society, about the importance of constructing earthquake resisting structures.

1.1 Soil structure interaction-1

Most of the civil engineering structure involve some type of structural element having direct contact with grand. These are many circumstances in civil engineering for which interaction between structure and ground has to be considered prominently. This encourages the interaction between structural engineers & geotechnical engineers. During to external lateral forces such as earthquake the structural displacement & ground displacement both are interdependent on each other. It is impossible to depart the correlation between structures & ground motion.

Generally, when earthquake occurs seismic waves travel through different rock and soil media and arrives near the foundation region causing the structure to vibrate. It can be easily understanding that the interaction between soil and structure can indeed affect the performance of the structure during earthquake particularly structure founded on relatively flexible soils.

Soil structure interaction is the general phenomena involved in the behavior of structure which interacting with soil medium in response to the lateral loading imposed on the structure. The phenomena may be defined as “The process in which the response of soil influences the motion of respect to structure influence the response of the soil is termed as SSI”. This phenomenon deals with interaction between structure & sub soil

1.2 Need of soil structure interaction-2

In India from last few decades there is significance increase in the infrastructural development of country. There is gradually increase in size and embedment of structure. Since the structure are huge and heavy the effect like SSI are to be considered during the design procedure of such structures. The effect of SSI on structure is not considered in early stage of construction practices. But since last 3-4 decades it has achieved prominent importance to consider the SSI while designing the structure. The effect of SSI for light structure such as low-rise building can be neglected but its effect on heavy structure like high rise buildings, bridges, tall chimneys, nuclear power plants (NPP), elevated highways becomes prominent for better performance of structure during earthquake.

Many researchers have suggested different methods to study the effect of soil structure interaction during last few decades. Winkler’s spring model (1867) represents the soil medium as of identical but mutually independent, closely spaced, discrete, linearly elastic springs. George G Gazetas (1991) has presented complete set of algebraic formulas and dimensionless charts for readily computing the dynamic stiffness of springs which represents the soil medium. [8] H.R.Tabatabaiefar et al. (2010) studied the seismic behavior of steel structure on soft soil considering soil structure interaction[2].

2. LITERATURE REVIEW-2

Raheem and Ahmed [8] - The author has selected target multistory moment resisting frame building having 12 storey and 6 storey R.C. frame structure. Foundation type used for structure is raft foundation. He authors carried out three different methods of seismic analysis. Halkude and Barelikar [9] - The study is carried out on R.C. Frame building resting on raft foundation to know the effect of soil flexibility on the seismic performance of building. In study, they considered two frame structures, 2storey 2 bays in both X and Y direction and 5 storey 2 bays in X and Y direction with three types of soils i.e. hard, medium and soft soil for analysis purpose. Dynamic analysis is carried out using response spectra of IS: 1893 -2012 using SAP2000 software. Boostani and Moghaddamet. [10] - In order to understand the structural behavior, it is useful to study the effects of soil-structure interaction. But usually soil-structure interaction studies are done with the assumption that foundation is fixed to the soil. During strong earthquake motions, uplift in some parts of the foundation may occur depending upon the type of soil which structure is located on. This paper investigates the nonlinear behavior of various steel braced structures placed on different types of soil with varying hardness. This can help in better understanding of the actual behavior of structure during an earthquake. Mittal and Gajinkare et. al. [10] - The paper consists the guidelines on soil structure interaction in Indian seismic code. In respective study, the author has considered a 150m tall RC chimney for analysis. Parameter like time period, base shear and base moment are studied considering four different soil types i.e. soft soil, stiff soil, dense soil and rock for four different zones; zone 2, Zone 3, Zone 4 and Zone 5. The study is carried out for both cases with flexible and fixed base condition.

2.1 Objectives-1

- The primary objective of this work is to study the seismic response of Steel frame structure by response spectrum analysis using SAP 2000 software.
- To understand the influence of SSI on the seismic performance of steel structure considering three different soil strata’s.
- The study has been carried out to investigate the influence of soil structure interaction with different bracing arrangements in steel structure

3. METHODOLOGY-3

In this work, For the analysis of work a high-rise steel frame building G+11 floors are considered. The behavior of this building is studied during earthquake excitation forces considering the soil structure interaction. The building is 36m high and width is 16m, height of typical storey is 3m. Building is symmetrical along both the X and Y-axis having 4 bays on each side, each bay of 4m.Isolated footings are considered to be resting on three types of soil strata's namely, hard soil, medium soil, and soft soil.

Table 1: Soil Elastic Constants

Soil type	**Modulus of Elasticity (kN/m^2)**	**Unit Wt. (γ)**	**Poisson ratio (μ)**
Hard	Rigid support		
Medium	35000	16	0.4
Soft	15000	16	0.4

3.1 General data of building-1

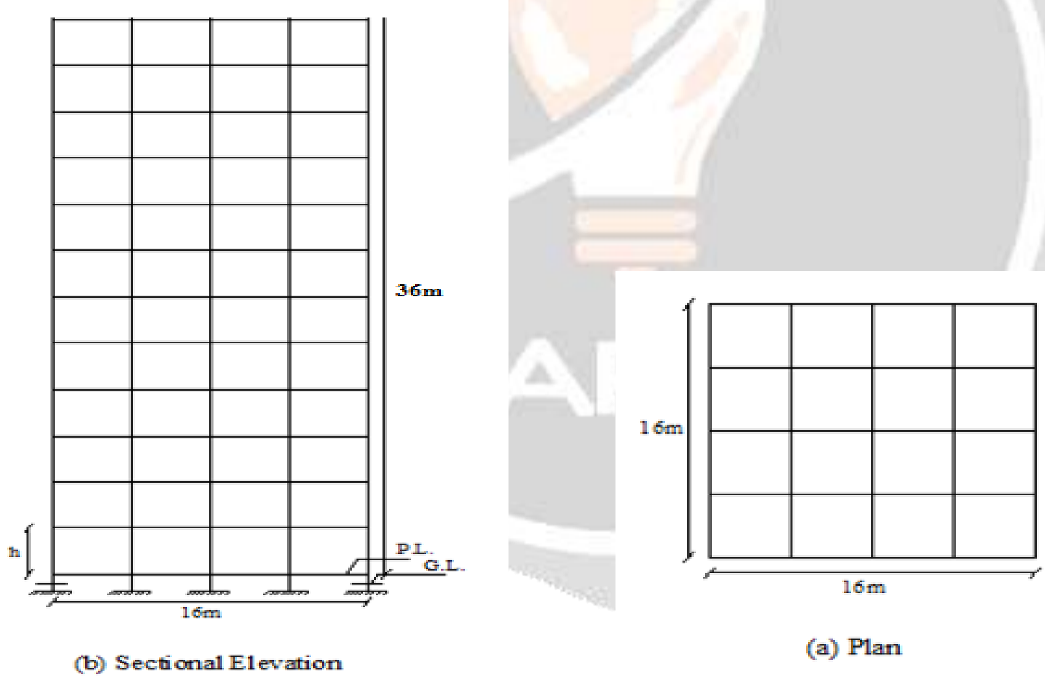

Fig -1 Plan and sectional elevation of building

Table 2: Geometric and material properties of building

Description	**Data**
Number of storeys	12
Number of Bays in X direction	4
Number of Bays in Y direction	4
Bay width in X direction	4m
Bay width in Y direction	4m
Storey height	3m
Section used for beam	ISMB 400
Built up section used for Column	FR 2ISMC 400
Foundation type	Isolated

3.2 Winkler's spring model-2

Soil structure interaction is carried out by using Winkler's approach[1] by considering equivalent springs with six degree of freedom (fig.1) which represents the soil medium. Each spring has specific stiffness which depends upon the properties of respective soil conditions. The stiffness is calculated by George Gazetas formulas[8] and shown in table3.

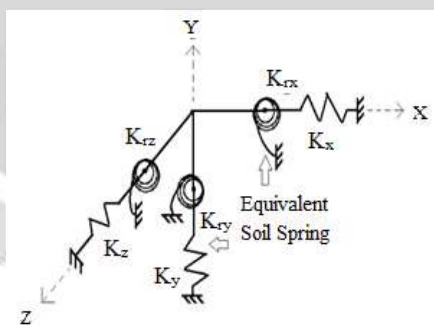

Fig -2 Equivalent spring stiffness

Where, Kx, Ky, Kz = Stiffness of equivalent soil springs along the translational DOF along X, Y and Z axis. Krx, Kry, Krz= Stiffness of equivalent soil springs along the rotational DOF along X, Y and Z axis.

Table 3: Spring stiffness formulas (G Gazetas)[8]

Degrees of Freedom	**Stiffness of equivalent soil spring**
Horizontal (lateral)	$[2GL/(2-v)](2+2.50\chi^{0.85})$ with $\chi = A_b/4L^2$
Horizontal (longitudinal)	$[2GL/(2-v)](2+2.50\chi^{0.85})-[0.2/(0.75-v)]GL$ $[1-(B/L)]$ with $\chi = A_b/4L^2$
Vertical	$[2GL/(1-v)](0.73+1.54\chi^{0.75})$ with $\chi = A_b/4L^2$
Rocking(about longitudinal)	$[G/(1-v)]I_{bx}^{0.75}(L/B)^{0.25}[2.4+0.5(B/L)]$
Rocking (about lateral)	$[G/(1-v)]I_{by}^{0.75}(L/B)^{0.15}$
Torsion	$3.5G\, I_{bz}^{0.75}(B/L)^{0.4}(I_{bz}/B^4)^{0.2}$

Table 4: Calculated Spring Stiffness for Soil Springs

Degrees of freedom	**Calculated Stiffness of soil springs (kN/m)**	
Soil Type	***Medium***	***Soft***
Horizontal (lateral direction)	106586.57	45928.98
Horizontal (longitudinal)	10658657	45928.98
Vertical	150856.12	68123.76
Rocking (about longitudinal)	254812.21	109542.17
Rocking (about lateral)	262842.63	113281.13
Torsion	52176.21	19012.87

4. RESULTS AND DISSCUSSION-4

4.1 Base shear-1

The variation in the base shear of structure in different bracing arrangement with respect to different support conditions i.e. Hard soil, Medium soil, soft soil and by considering Fixed support condition are shown by graphs below

Table 5: Base shear of structure in plane (without bracing) and with different bracing arrangement with respect to different support conditions

	Plain	X-Bracing	V-Bracing	Inverted V bracing	Diagonal Bracing
Fixed support	2050.1	2508.49	2203.916	2043.538	2016.79
Hard soil	1940	2429.829	2161.426	2170.807	2187.078
Medium soil	2445.2	2924.42	2669.204	2677.65	2693.944
Soft soil	2650.8	3050.849	2842.849	2846.51	2860.49

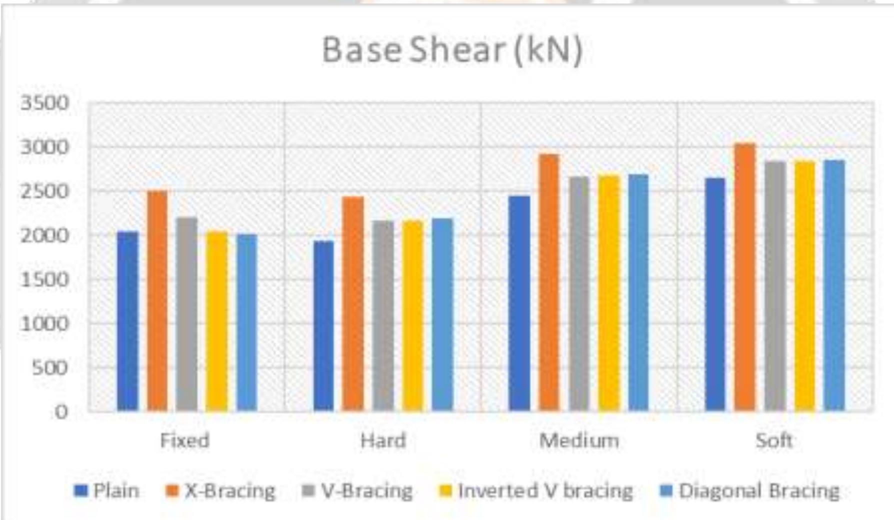

Chart -1: Base shear in plane (without bracing,) X Bracing, V Bracing, Inverted V Bracing and Diagonal Bracing in different support conditions

From Chart -1: It is observed that the base shear of the building increases with increase in the base flexibility of the soil. For building without bracing the increment in the base shear from fixed to flexible base is 22.65%. For V braced building the increment in the base shear from fixed to flexible base is 22.47%. For X braced building the increment in the base shear from fixed to flexible base is 17.77%. For inverted V braced building the increment in the base shear from fixed to flexible base is 28.20%. And for diagonal braced building the increment in the base shear from fixed to flexible base is about 29.49%.

4.2 Roof deflection-2

For the seismic design, it is important to evaluate maximum lateral displacement of the structures due to sever earthquakes for several reasons. Such as assessing minimum separation joint width to avoid pounding and estimating maximum storey drifts to avoid destruction of nonstructural elements. The variation of roof displacement in X-direction and Y-direction for different support conditions respective to the bracing system is as shown in below figure.

Table 6: Roof displacement in X-direction

	Plain	X-Bracing	V-Bracing	Inverted V	Diagonal
Fixed support	84.9	53.8	74	72.7	72.5
Hard soil	91.4	71.4	84.6	92.1	84
Medium soil	130.1	110	121.7	129.2	121.2
Soft soil	178.8	150.7	171.6	179.3	171.3

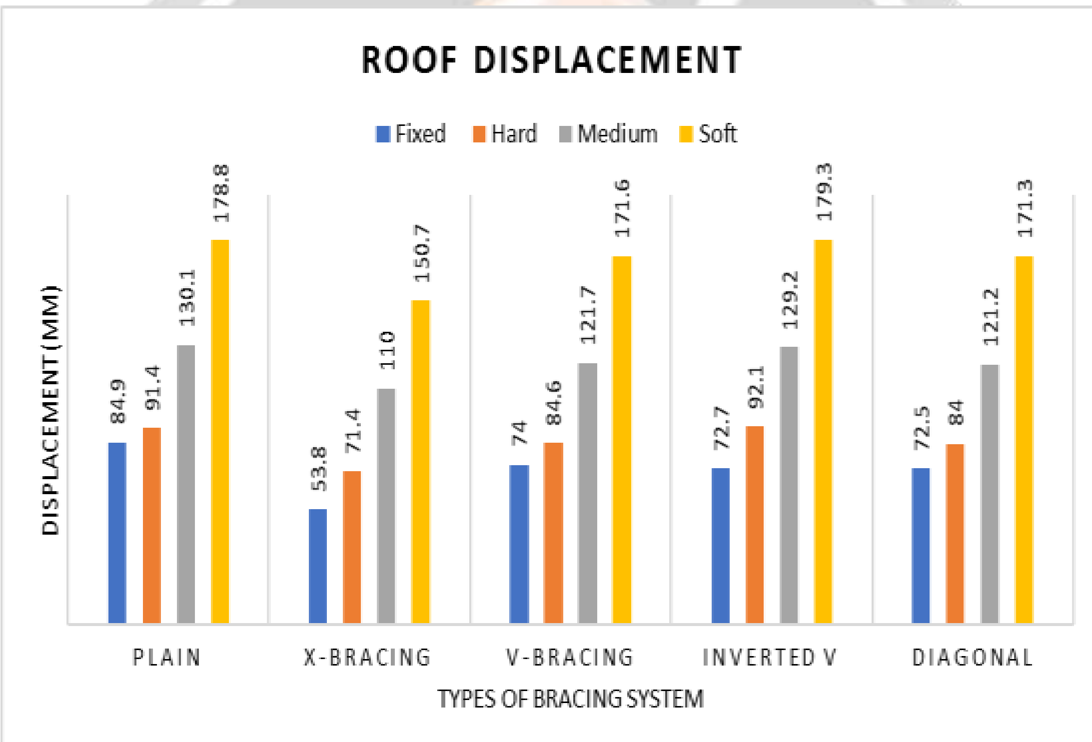

Chart -2: Roof displacement in X-direction

Table: 7 Roof displacements in Y-direction

	Plain	X-Bracing	V-Bracing	Inverted V	Diagonal
Fixed support	92.8	56.8	78.6	76.5	76
Hard soil	99.5	82.6	89.8	96.3	89.1
Medium soil	140.3	118.6	129.3	128.7	128.4
Soft soil	192.6	160.8	181.2	188.9	180.6

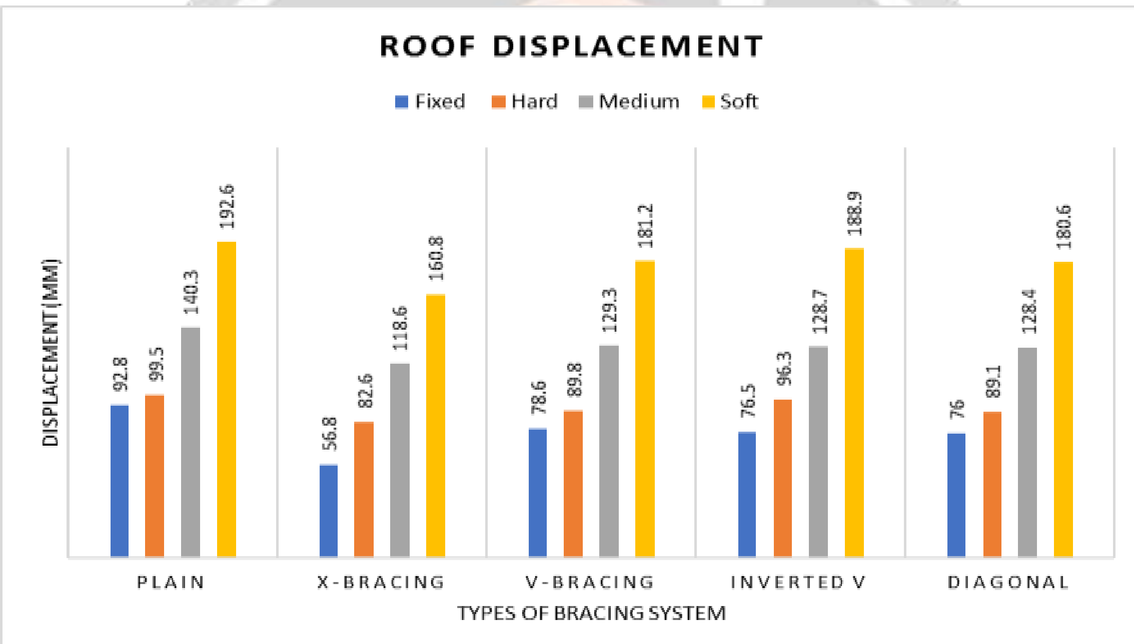

Chart -3: Roof displacement in Y-direction

From Chart -3: It is observed that the roof displacement increases with soil flexibility. The rate of increase of roof displacement from fixed to flexible base is 50% - 60%

4.3 Time period-3

Time period as per IS 1893 (Part 1) 2002 clause no.7.6.1. is equal to

$T_a = 0.085h^{0.75}$ ….for steel frame building

$= 0.085 \times (36)^{0.75}$

$= 1.25$ sec

Table:8 Time period for building without bracing (plain) and with bracing (in sec)

	Plain	X-Bracing	V-Bracing	Inverted V bracing	Diagonal Bracing
Fixed support	1.2654	0.82395	1.033873	1.010781	0.997727
Hard soil	1.341	1.082005	1.174137	1.168097	1.158769
Medium soil	1.3897	1.172342	1.241029	1.237708	1.22976
Soft soil	1.5303	1.373952	1.41091	1.410311	1.404419

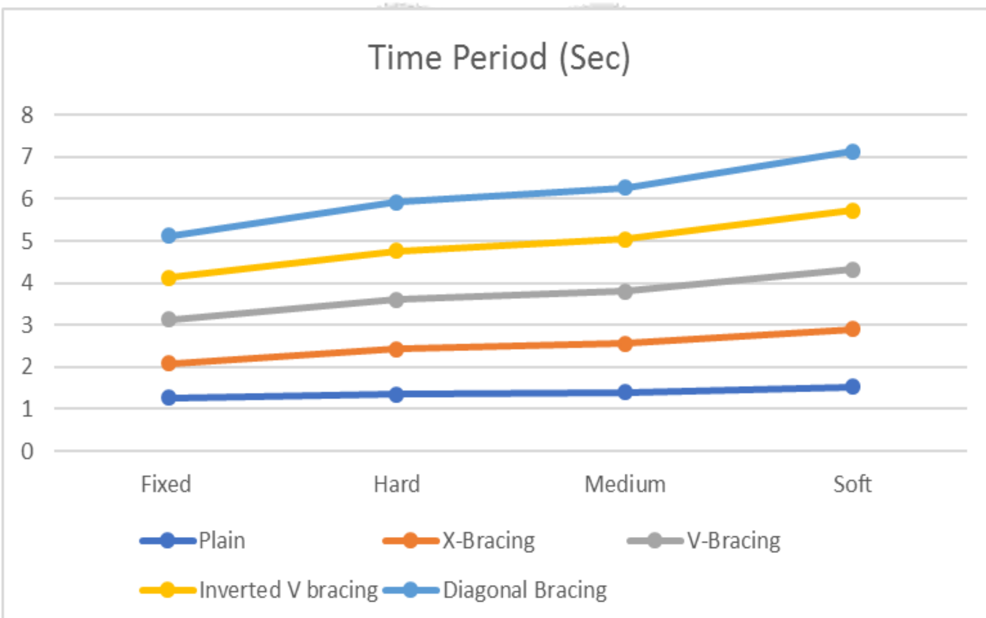

Chart -4: Time period for building in plain (without bracing) and with bracing in different support conditions.

From chart-4: It is observed that with the increase in soil flexibility the natural time period increases. The rate of increase of natural time period becomes abrupt with softer soil. The rate of increase of natural time period for building without bracing, V-bracing, X-bracing, inverted V-bracing and diagonal bracing is 17.64%, 26.95%, 40.02%, 28.36%, 29.48% respectively.

5. CONCLUSIONS

The results of the present study shows that considering soil structure interaction significantly affect the building during seismic excitation forces. On the basis of study carried out following are the conclusions derived

1. The conventional design procedure without considering the effect of soil structure interaction may not give adequate guarantee to the structural safety of the building.
2. The base shear of the building increases due to SSI effect, the effect of base shear is more as soil strata becomes soft;

For Hard Soil Strata

- For Steel building without bracing base shear increases by 5.3%
- For Steel building with V bracing base shear increases by 3%
- For Steel building with inverted V bracing base shear increases by 5.8%
- For Steel building with X bracing base shear increases by 3.12%
- For Steel building with diagonal bracing base shear increases by 7.78%

For Medium Soil Strata

- For Steel building without bracing base shear increases by 16%
- For Steel building with V bracing base shear increases by 17.1%
- For Steel building with inverted V bracing base shear increases by 23.68%
- For Steel building with X bracing base shear increases by 14.22%
- For Steel building with diagonal bracing base shear increases by 25.13%

For Soft Soil Strata

- For Steel building without bracing base shear increases by 22.66%
- For Steel building with V bracing base shear increases by 22.47%
- For Steel building with inverted V bracing base shear increases by 28.21%
- For Steel building with X bracing base shear increases by 17.7%
- For Steel building with diagonal bracing base shear increases by 29.49%

3. The natural time period of structure increases as the support conditions changes from fixed soil medium to flexible soil medium. Natural time period is a basic parameter which regulates the seismic lateral response of the building during earthquake.

For Hard Soil Strata

- For Steel building without bracing time period increases by 5.97%
- For Steel building with V bracing time period increases by 11.96%
- For Steel building with inverted V bracing time period increases by 12.93%
- For Steel building with X bracing time period increases by 24.07%
- For Steel building with diagonal bracing time period increases by 13.9%

For Medium Soil Strata

- For Steel building without bracing time period increases by 8.69%
- For Steel building with V bracing time period increases by 16.93%
- For Steel building with inverted V bracing time period increases by 17.88%
- For Steel building with X bracing time period increases by 29.91%
- For Steel building with diagonal bracing time period increases by 18.85%

For Soft Soil Strata

- For Steel building without bracing time period increases by 17.64%
- For Steel building with V bracing time period increases by 26.95%
- For Steel building with inverted V bracing time period increases by 28.37%
- For Steel building with X bracing time period increases by 40.14%
- For Steel building with diagonal bracing time period increases by 29.28%

Thus, evaluation of this parameter without considering SSI may cause significant errors in the design of structure.

4. SSI model with flexible support conditions displays higher roof displacements as compared to the rigid support conditions;

For Hard Soil Strata

- For Steel building without bracing displacement increases by 7.11%
- For Steel building with V bracing displacement increases by 12.5%
- For Steel building with inverted V bracing displacement increases by 21%
- For Steel building with X bracing displacement increases by 24.64%

- For Steel building with diagonal bracing displacement increases by 13.69%

For Medium Soil Strata

- For Steel building without bracing displacement increases by 34.74%
- For Steel building with V bracing displacement increases by 39.19%
- For Steel building with inverted V bracing displacement increases by 43%
- For Steel building with X bracing displacement increases by 51.09%
- For Steel building with diagonal bracing displacement increases by 40.18%

For Soft Soil Strata

- For Steel building without bracing displacement increases by 52.51%
- For Steel building with V bracing displacement increases by 56.87%
- For Steel building with inverted V bracing displacement increases by 60%
- For Steel building with X bracing displacement increases by 64.29%
- For Steel building with diagonal bracing displacement increases by 57.67%

Hence considering the effect of roof displacement without SSI could not give the reliable results while designing of any structure.

5. For base shear the effect of SSI on X-braced varies from 10% to 20% and for V-braced, inverted V and diagonal braced it varies from 6% to 12%.Time period for X-braced building varies from 10% to 35 % and for V-braced, inverted V and diagonal braced it varies from 7% to 20%.
6. Based on results obtained as displacement is less in X braced steel structure, X braced system gives better performance during earthquake.

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