https://doi.org/10.29042/2020-10-1-98-104

Helix (2020) 10 (1): 98-104

Analysis of Reinforced Concrete Structure Considering the Influence of Soil Structure Interaction

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Received: 22nd October 2019, Accepted: 31st January 2020, Published: 29th February 2020

Abstract
The response of the soil influences the motion of the structure and response of the structure changes the ground motion history making the competition very complex and this phenomenon is known as Soil Structure Interaction. Various field tests indicate that the Soil-Structure Interaction (SSI) has a very significant impact on behaviour of structural elements of multi-storeyed buildings, which may lead to an unexpected structural seismic responses and/or failure. In this study, a simple five storied structure with fixed support is modelled by using ETAB. Numerical results obtained from analysis of fixed-base condition are compared with the results obtained from flexible-base condition. It was observed that the flexibility of structure reduces the overall stiffness and at the same time the natural period of the system were increases with considering the influence of the Soil Structure interaction of the system. The presence of the soil in the structural analysis provides the result of various parameters such as storey displacement, storey drift which are nearer to the actual dynamic behaviour of the structure than those provided by the analysis of a fixed base structure.

Keywords
Soil Structure Interaction, Natural Time Period, Stiffness, Fixed Base, RCC Structure

Introduction
The response of the soil influences the motion of the structure and response of the structure changes the ground motion history making the competition very complex and this phenomenon is known as Soil Structure Interaction. [10] The dynamic behaviour of the structure with the impact of soil structure interaction is reflected is an increase in the shaking period in comparison with the fixed base model, which does not consider the supporting soil.[5] Due to the relative movement of soil medium affect the building to deform for some extent. This decreases the overall stiffness of structural system and these increases the natural period.[1] For low rise building constructed on soft soil the effects of SSI become higher when subjected to earthquake load. Ramadan (2012) [8] investigated that increases the construction cost due to neglecting effect of seismic response analysis in soil structure interaction. Hence the analysis of Soil-Structure Interaction of high rise buildings [7] is the main focus of this research. In this work emphasis is laid to analyse a five story building for the influence of soil structure interaction on the structure. Modelling of the building is carried out for fixed-base as well as for flexible-base condition [9] using ETABs.
The main objectives of the study are;
i) To estimate the effects of Soil Structure Interaction (SSI) by using dynamic properties of structure rest on medium stiff soil
ii) To compare the result of fixed base with flexible base condition obtained for building from the ETABs
iii) To compare the results for different parameters such as the lateral displacement, natural frequency, story drifts and time period with respect of no. of storey of building

Materials and Methods
I. Mathematical Modelling
For the analysis, a six storey RCC building is considered. The plan of building is symmetrical about X-axis and Y-axis as shown in fig.1. It has 5 bays of 4m width in X- direction and 5 bays of 3m width in Y direction. Height of each floor is 3m and 1.5m below the ground level.
II. Soil Conditions
Foundation is considered to be resting on Medium hard soil. Different parameters such as Shear wave velocity (Vs), Poisson's Ratio (μ), Density of soil (ρ) and shear modulus (G) for different types of soil are required for analysis and this is considered from IBC CODE-2006. [5] The shear modulus (G) is estimated from the following expression $G= (Vs)^2 * \rho$ [10]
Details of soil properties and material properties are considered as per table 1 and table 2

Types of Soil	Shear wave velocity (Vs) (m/sec)	Poisson's ratio (μ)	Density of soil (ρ) (kN/m^3)
Stiff soil	750	0.3	18
Medium Stiff soil	360	0.4	16
Soft soil	180	0.4	16

Table 1: Details of Soil Parameters

III. Material Properties

Component	Description of Model	Data
Model details	Number of storey	6
	Number of bays in x direction	5
	Number of bays in y direction	5
	Floor height	3000mm except bottom story 1500mm
	Bay width in X direction	4000mm
	Bay width in Y direction	3000mm
	Size of beam	230 x 400 mm
	Size of column	300 x 600mm
	Thickness of slab	150mm
	Grade of concrete	M 25
	Grade of steel	Fe500 (HYSD)
Soil	Type of soil	Medium stiff soil
	Type of footing	Isolated footing
Seismic parameters [1]	Type of structure	SMRF
	Seismic zone	V (severe)
	Importance factor (I)	1
	Response reduction factor (R)	5

Table 2: Geometric and Material Properties of Frame, Footing and Soil

IV. Spring Model Idealization

The movement of the foundation is generally considered in three different directions out of that two are horizontal and one in vertical direction.[4] Therefore, the rotations of the building about these three directions are to be considered. Hence, from the accepted literatures of Gazetas 1991,[2] the building is modelled with isolated footing, three translational springs along three directions and three rotational springs about those mutually perpendicular axes should be put together below every column to estimate the effect of soil flexibility.[3]

Details of Spring Stiffness values are considered as per given below table 3.

Degree of Freedom (Soil I for Exterior Column)	Stiffness of Equivalent Soil Spring (kN/m)
Vertical Direction	22458760.49
Horizontal (Transverse Direction)	27332188.79
Horizontal (Longitudinal direction)	22103279.2
Rocking (Longitudinal Direction)	39734787.35
Rocking (Transverse Direction)	47666679.52
Torsion	179468.8641

Table 3 (a): Spring Stiffness Values (Soil I for Exterior Column)

Degree of Freedom (Soil II for Interior Column)	Stiffness of Equivalent Soil Spring (kN/m)
Vertical Direction	25330563.46
Horizontal (Transverse Direction)	30857042.09
Horizontal (Longitudinal Direction)	24975089.17
Rocking(Longitudinal Direction)	68440613.69
Rocking (Transverse Direction)	58537070.07
Torsion	285323.7434

Table 3 (b): Spring Stiffness Values (Soil II for Interior Column)

Figure.1 shows Winkler model of (G+5) Structure where the fixed support is replaced by spring with desired stiffness values as shown in Table 3 (a) and Table 3 (b).

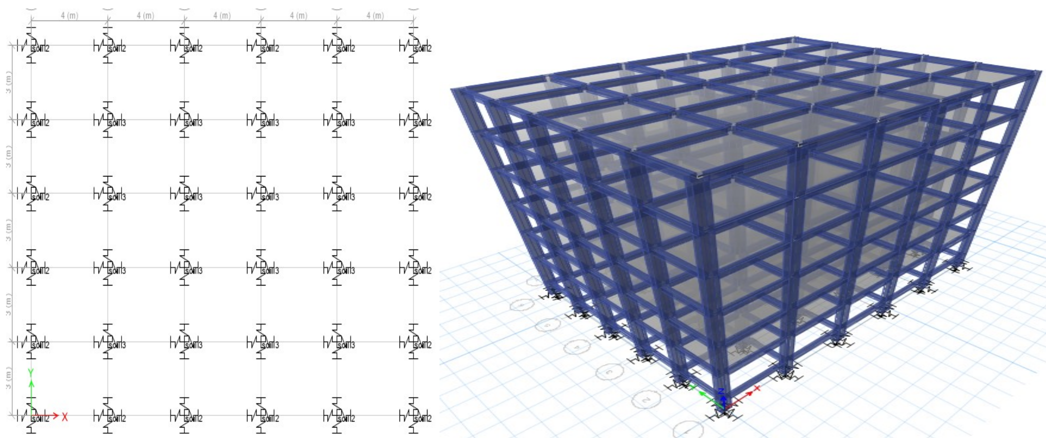

Figure 1: Winkler Model of (G +5) Structure with Spring

Results and Discussion

A symmetric frame of 5 bays, 6 stories with isolated footing with corner footing size as 3.2m x 2.9m and interior footing size as 3.6m x 3.3m with soil structure model viz. Spring Winkler model is considered. The influence of with and without soil structure interaction is studied by considering the effect medium stiff soil and structural parameters based on seismic performance of building.[11]

The various parameters such as story stiffness, story drift, story displacement, fundamental modal period and frequencies are also studied and their comparisons are also studied.

1. Story Stiffness

Story Height (m)	Story Stiffness (kN/m) Fixed Base	Story Stiffness (kN/m) Flexible Base
19.5	219282.43	219076.4
16.5	263357.957	263194.7
13.5	268056.611	267925
10.5	271424.751	271302.5
7.5	288437.267	288296.2
4.5	377516.321	377217.4
1.5	2180986.756	2173322

Table 4: Tabulated Value of Story Stiffness (kN/m) for EQx

Story Height (m)	Story Stiffness (kN/m) Flexible Base	Story Stiffness (kN/m) Fixed Base
19.5	199375.634	199727.962
16.5	213492.321	213711.461
13.5	214481.897	214653.716
10.5	215144.163	215297.774
7.5	217870.243	218020.565
4.5	245081.004	245265.116
1.5	1450838.223	1453753.013

Table 5: Tabulated Value of Story Stiffness (kN/m) for EQy

2. Storey Drift

Story Height (m)	Story Drift Flexible Base	Story Drift Fixed Base
19.5	0.000913	0.000824
16.5	0.001453	0.001083
13.5	0.001827	0.001382
10.5	0.001954	0.001555
7.5	0.001955	0.001556
4.5	0.001517	0.001225
1.5	0.0005309	0.0004306
0	0	0

Table 6: Tabulated Value of Story Drift for 1.5 (DL –EQx)

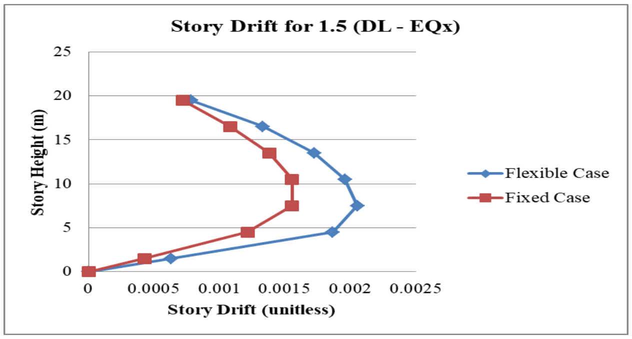

Fig 2: Maximum Story Displacement (X Direction) Pertaining to Story Height

Story height (m)	Story Drift Flexible base	Story Drift Fixed base
19.5	0.000985	0.000788
16.5	0.001666	0.001333
13.5	0.002157	0.001725
10.5	0.00245	0.00196
7.5	0.002571	0.002057
4.5	0.002335	0.001868
1.5	0.000792	0.000633
0	0	0

Table 7: Tabulated Value of Story Drift for 1.5 (DL – EQy)

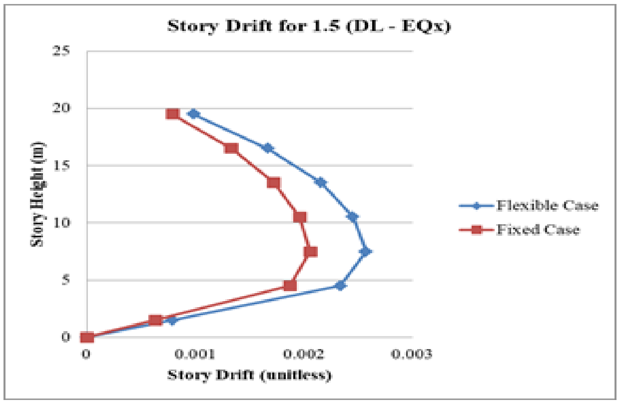

Fig 3: Maximum Story Displacement (Y direction) Pertaining to Story Height

3. Story Displacement

Story Height (m)	Story Displacement (mm) Flexible Base	Story Displacement (mm) Fixed Base
19.5	29.2	23.1
16.5	26.1	21.2
13.5	22.1	17.5
10.5	17.2	13.4
7.5	11.1	8.89
4.5	5.3	4.3
1.5	0.8	0.6
0	0.002345	0

Table 8: Tabulated Value of Story Displacement for 1.5 (DL – EQx)

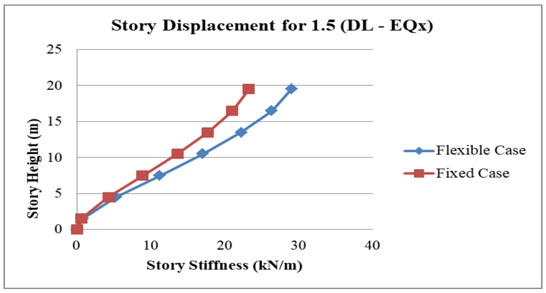

Fig 4: Graphical Representation of Max. Story Displacement (X Direction) Pertaining to Story Height

Story Height (m)	Story Displacement (mm) Flexible Base	Story Displacement (mm) Fixed Base
19.5	36.7	30.1
16.5	35.7	27.7
13.5	29.7	23.7
10.5	22.3	18.5
7.5	15.9	12.7
4.5	8.2	6.4
1.5	1.3	1
0	0.002031	0

Table 9: Tabulated Value of Story Displacement for 1.5 (DL – EQy)

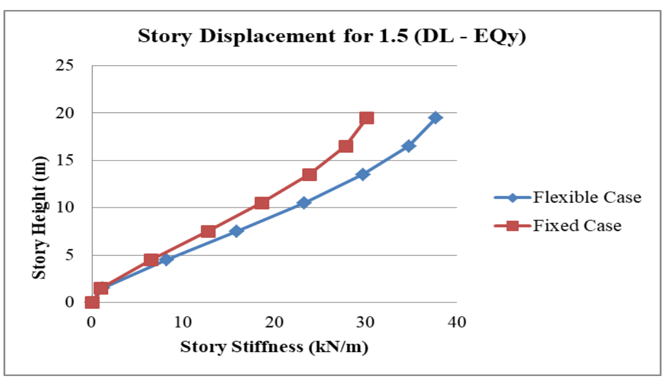

Fig 5: Graphical Representation of Max. Story Displacement (Y Direction) Pertaining to Story Height

Mode	Period (Sec) Fixed-Base	Period (Sec) Flexible-Base
1	0.796	0.808
2	0.686	0.679
3	0.673	0.681
4	0.259	0.265
5	0.214	0.1219
6	0.209	0.212
7	0.149	0.154
8	0.118	0.123
9	0.109	0.114
10	0.103	0.107
11	0.079	0.085
12	0.077	0.081

Table 10: Tabulated Values of Fundamental Time Period

Mode	Period (Cycle/Sec)	Period (Cycle/Sec)
	Fixed Base	Fixed Base
1	1.703	1.669
2	1.948	1.934
3	2.115	2.074
4	5.121	4.975
5	6.028	5.617
6	6.325	6.097
7	8.202	7.575
8	10.136	9.900
9	10.29	9.615
10	20.92	17.857
11	22.042	19.230
12	24.046	20.408

Table 11: Tabulated Values of Fundamental Frequencies

Conclusion

As per analyses, the following conclusions are to be recommended.

1. Among all the load combination, the most critical load combination was found to be 1.5(DL- EQ) for both direction i.e X as well as Y- direction.
2. For this load combination the storey displacement values increases with increase in soil flexibility means displacement value for flexible base condition is more than fixed based condition.
3. Similarly for the story drift values increases with increase in soil flexibility.
4. Considering the effect of flexibility, it has reduces the overall stiffness of the structure. Therefore, optimized design should be adopted while construction of the structure so that the structure can desirably resist the earthquake effects acting on it.
5. As the height of the building increases, the lateral displacement, natural frequency, story drifts and time period increases.
6. It was also concluded that, if the fundamental natural period of the system is increase then the fundamental frequency of the system is decreases.
7. Base shear value for the structure with fixed-base condition and flexible-base condition has not varied; this is because the structure for both conditions is analyzed for only medium hard soil.

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