Evaluation of R.C. Multi-storey Building Response under the Effect of Soil-Structure Interaction

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Abstract – *Recent studies shows that SSI effect can be unfavourable to seismic response of structure and neglecting effect of SSI may cause an un-conservative design. Nevertheless, the conventional design procedure involves assumption of fixity at the base of foundation neglecting the flexibility of foundation and the compressibility of the supporting soil medium. Consequently, the effects of foundation settlements on further redistribution of shear forces and moments demands. In this paper, G+12 storey building models with and without considering SSI effect are studied. The effect of soil structure interaction interactions are analysed for RC multi-storey building resting on raft foundation. The underneath soil is modeled by Winkler spring approach with evaluated soil stiffness based on modulus of subgrade reaction. All structures are modeled and analysed in this paper using finite element software ETABS and SAFE. The effect of SSI on seismic response including storey drift, storey displacement, base shear natural time period and bending moment variation in structural elements are evaluated. Results obtained using SSI are compared to those corresponding to fixed base support modeling assumption.*

Key Words: soil–structure interaction, RC multi-storey building, finite element software, seismic response, raft foundation, fixed base support, flexibility of foundation

1. INTRODUCTION

Every civil engineering structure involve structural elements which are in direct contact with ground. When the forces are transferred on these structural elements, neither the structural displacements nor the ground displacements, are independent of each other. 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).

The investigations have been carried out by many researchers on the structural behavior of RC buildings with SSI by considering parameters like foundation type, soil conditions, lateral forces, ratio of flexural stiffness of beam and column. Very less investigations have been carried out on soil-structure interaction of RC buildings under different soil conditions, particularly in Indian seismic zones. Therefore, the present study has proposed R.C. multi-storey building with raft foundation on soil medium to study the structural response and compared with fixed base conditions for Storey

drift, Storey displacement, Base shear and Natural time period.

2. Description of the Proposed R.C. Building

A G+12 Storey R.C. building, a real structure which is under construction in Mumbai is considered for the present study to investigate SSI effects on R.C. buildings. The plan dimension of the building is 12.46 m x19.40 m and the height of the building is 39 m from the ground level. Elevation and storey details are shown in TABLE I.

Mumbai falls under Seismic Zone-III of IS 1893-2002 is located in a coastal region and structures are exposed to coastal environment and surfaces of buildings are protected by plastering and painting coats. As per IS 456-2000 (Table 3), moderate exposure condition shall be considered in design. Basic wind speed for Mumbai, Vb is 44 m/sec.

Table -1: Heights and Elevation of Storey

Level	Heights (m)	Elevation (m)	Similar to
Terrace	3	39	
Storey 12	3	36	
Storey 11	3	33	
Storey 10	3	30	
Storey 9	3	27	
Storey 8	3	24	Storey 1
Storey 7	3	21	
Storey 6	3	18	
Storey 5	3	15	
Storey 4	3	12	
Storey 3	3	9	
Storey 2	3	6	
Storey 1	3	3	Master storey
GF	3	0	
Base	0	-3	

3. METHODOLOGY

Following methodology is adopted for analysis work:

1. Modeling of typical plan of proposed building, assigning section properties and structural loadings by using ETABS.

2. Analysis of R.C. building without considering SSI that is fixed base support using ETABS.
3. Modeling and analysis of Raft foundation of building with considering SBC of soil by using SAFE.
4. Modeling and analysis of R.C. building on raft and soil spring together that is flexible base support using ETABS.
5. Comparison of results

4. Modeling and Analysis of R.C. Building

The 12 story building modeled using ETABS software for ease of modeling. The whole building is modeled as three dimensional R.C frame model. Details of beam, slab and column sections used in modeling are shown in TABLE 2. Details of structural loading and seismic parameters applied for analysis are shown in TABLE 3.

Table -2: Beam, Slab and Column section Details

Sr. No.	Elements	Sections (mm)	Grade of Concrete
1	Beam	150X320	M25
		150X450	
		150X600	
		230X600	
		230X450	
2	One way Slab	120	M25
		150	
3	Two way Slab	120	
		150	
4	Shear Walls/ Column	230X300	M40
		230X380	

Table -3: Details of Structural loading data considered

Sr. No.	Parameters	Value
1	Live Load	For floors - 2 KN/m² For Stairs and Passage - 3 KN/m²
2	Floor finish Load	1.5 KN/m²
3	Wall Load	For floors – 0.230 m wall on periphery and 0.115 mm on inner beam
4	Wind Load	As per IS-875 (part-1):2015
5	Earthquake Load	As per IS-1893 (part-1):2002
6	Seismic Zone	III
7	Zone factor	0.16
8	Importance factor, I	1
9	Response Reduction factor	5
10	Damping	5%

4.1 R.C. Building with Fixed Base

The co-ordinate points are the placements of columns according to the base plan layout of the structure. All the points will be constrained with ux, uy, uz, rx, ry and rz coordinates for fixed base condition, which means no linear and rotational displacements are allowed. The complete building has been modeled using appropriate elements of beams, columns and slabs in each storey. The plan and three dimensional view of the R.C. building is as shown in Fig. 1.
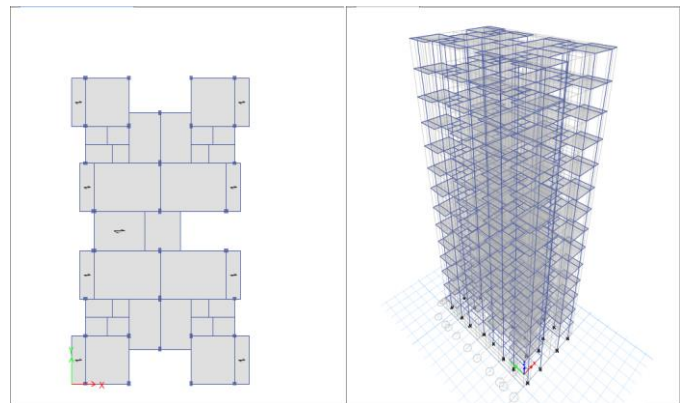

Fig -1: G+12 storey building at fixed base (Plan & 3D view)

4.2 Modeling and Analysis of Raft foundation

The design of raft foundation is done for the same building using software SAFE. The SBC of soil is 200 KN/m² with permissible settlement 15 mm. The equivalent sub -grade modulus is 13333.33 KN/m³.The DL, LL, WL, Earthquake Load and Load combination above base of G+12 storey building are directly imported from ETABS, The thickness of raft slab of 1m has been provided and grade of concrete for analysis is M30. The size of raft is 13.96mx21.40m. Raft slab is divided into 10 x 7 panels for providing sub -grade modulus in a confined way.
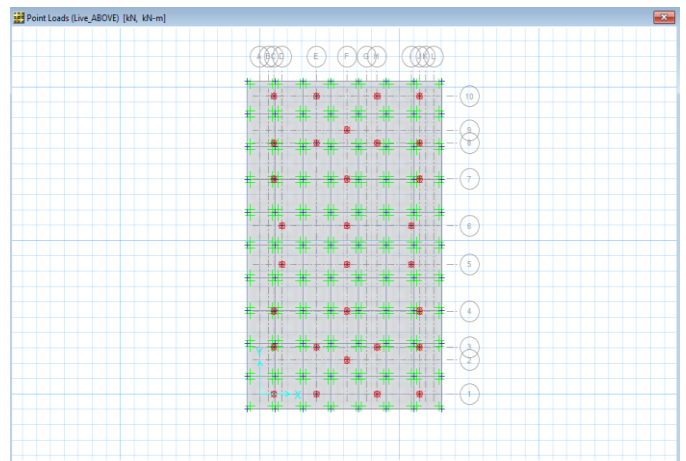

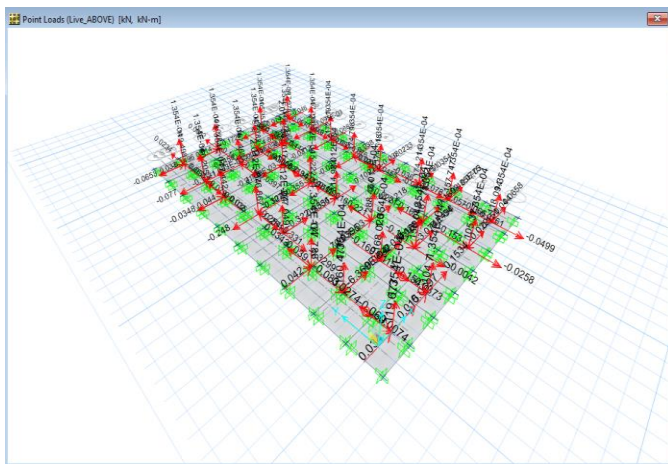**Fig -2:** RAFT foundation of G+12 storey (Plan view)

Fig -3: Snip of Loading above RAFT (3D view)

Building loading with raft as 2D plate element with fixed boundary condition has been analysed. Reaction (P) at each node of element has been obtained. The raft has been analysed with considering soil subgrade modulus with permissible settlement to obtain the displacement (Δ) at each node.

4.3 Modeling and Analysis of R.C. Building with Flexible Base

The modelling of same R.C. building with raft is done using ETABS. The soil stiffness has been calculated by using eq.1 and applied at each node. The building with raft and soil spring is shown in fig -5.

$$K = P/\Delta \quad \ldots\ldots\ldots\ldots\ldots (1)$$

Where, K = stiffness (KN/m)

P = reaction at each node (N)

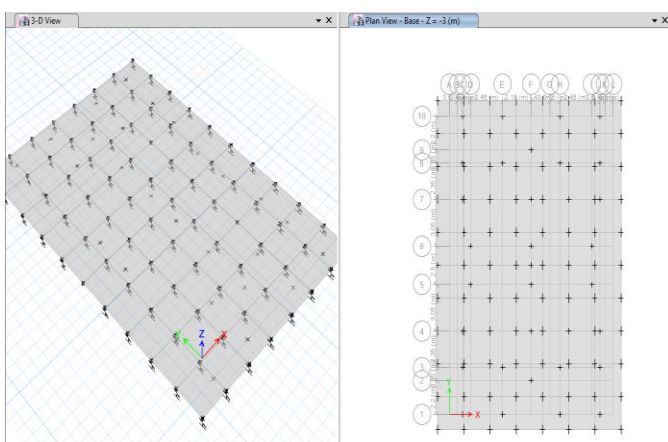Δ = displacement at each node (mm)

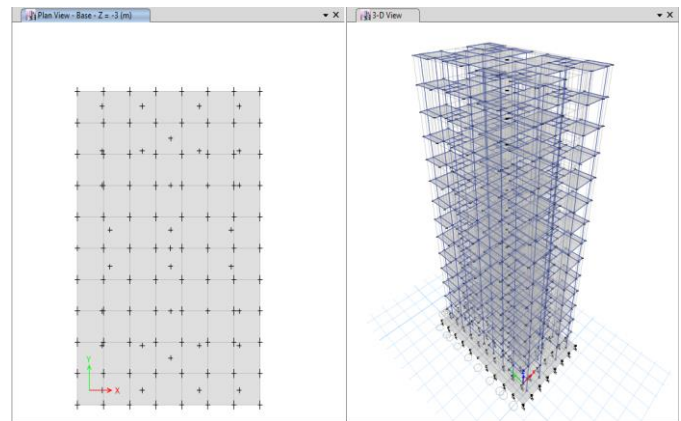**Fig -4:** Assigning of soil point spring under raft

Fig -5: G+12 storey building at flexible base (3D view)

5. Result and Discussion

Structural response has been studied with respect to storey drift, Storey displacement, base shear and natural time period of R.C. building without SSI (fixed base) and building with SSI (flexible base). Results obtained are compared by using graphs.

5.1 Story Drift Ratio Response

Story drift ratio is the maximum relative displacement of each floor divided by the height of the same floor. The comparison of storey drift ratio of R.C. building on fixed base (NSSI) and flexible base (SSI) conditions in earthquake X and Y direction are shown in fig- 6 and fig- 7.

Figure -6 shows that story drift ratio distribution of 12-story model in X-direction increases gradually and reaches its maximum value in the 6th story level. The maximum values for NSSI and SSI in EQX-direction are 0.001524 and 0.001777 respectively.
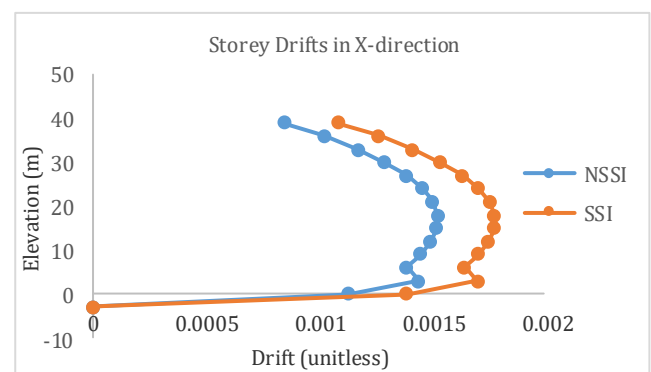

Fig -6: Storey drift ratio response comparison for fixed (NSSI) and flexible base (SSI) conditions in EQX

Figure -7 shows that story drift ratio distribution of 12-story model in Y-direction increases gradually and reaches its maximum value in the 5th story level. The maximum values for NSSI and SSI in EQY-direction are 0.001429 and 0.001613 respectively.
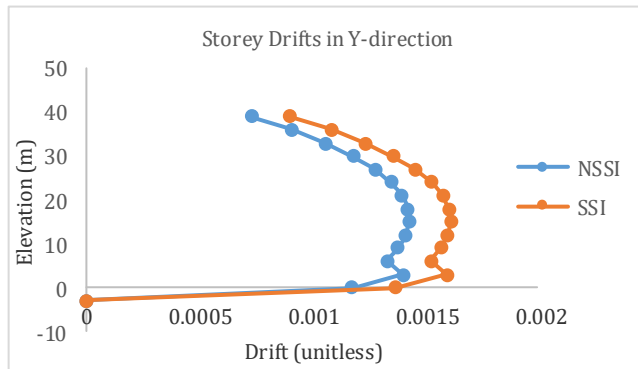

Fig -7: Storey drift ratio response comparison for fixed (NSSI) and flexible base (SSI) conditions in EQY

5.2 Storey Displacement Response

Figure 8 and 9 shows that story displacement profile over building height of 12-story increases nonlinearly with the structural height. The maximum displacement response in EQX direction for NSSI and SSI models are 55.88 mm and 66.47 mm respectively.
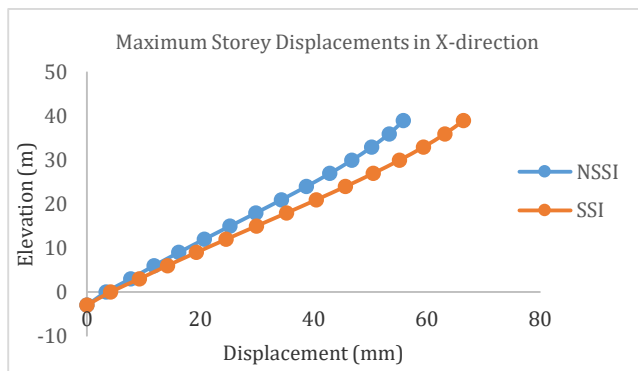

Fig -8: Storey displacement response comparison for fixed (NSSI) and flexible base (SSI) conditions in EQX

The maximum displacement response in EQY direction for NSSI and SSI models are 52.39mm and 60.05mm respectively.
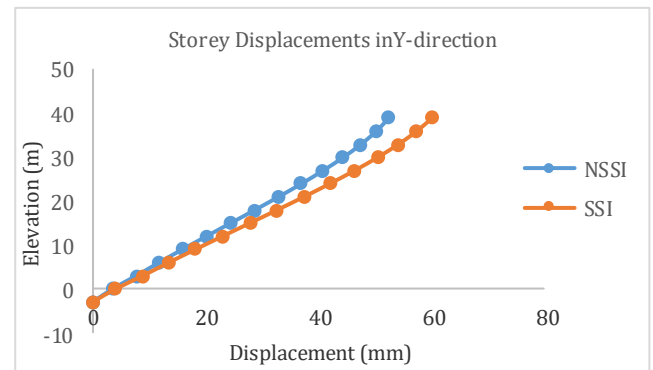

Fig -9: Storey displacement response comparison for fixed (NSSI) and flexible base (SSI) conditions in EQY

5.3 Base Shear Response

The base shear value for fixed and flexible base condition are constant value of 382.5483 and 477.0707 in earthquake direction X and Y respectively by using equivalent static method. The story shear response obtained is independent of SSI effects and depends only on the building weight.

5.4 Natural Time Period

In Modal analysis the building is analysed as a continuous model with finite number degrees of freedom and natural frequencies. The Natural time periods are the important factors, which affect the seismic behaviour of the structure. Natural time periods obtained from the analysis of fixed base and flexible base support conditions are shown in Table- 7.

Table -4: Modal Behaviour of Building

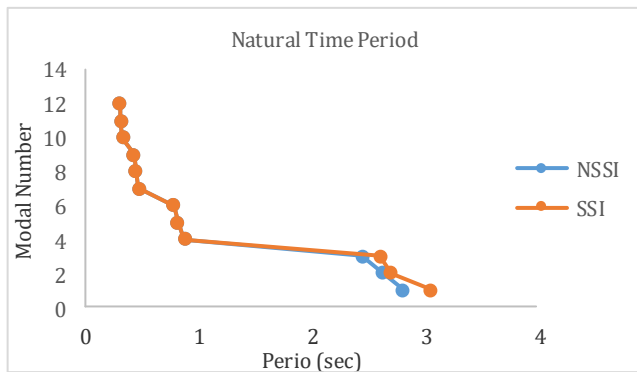| Model No.	Period (sec)	
	Fixed Base	Flexible Base
1	2.816	3.063
2	2.639	2.703
3	2.454	2.607
4	0.876	0.877
5	0.821	0.821
6	0.78	0.781
7	0.477	0.478
8	0.446	0.446
9	0.433	0.434
10	0.331	0.331
11	0.311	0.331
12	0.304	0.304

Fig -10: Natural time period comparison with respect to mode numbers for fixed and flexible base conditions

5.5 Bending Moment Variations

The bending moment variation of beam of R.C. building has been studied on seismic response and also under the effect of gravity load i.e. 1.5 (DL+LL) for both fixed and flexible base conditions. Beam B139 at first floor has been taken for study. Table -8 shows the bending moment variations in selected beam.

Table -5: Bending Moment variation of selected Beam

Sr. No.	Load conditions	Moment (kN-m)	
		Fixed Base	Flexible Base
1	EQX	+59.91	+60.77
2	EQY	-9.43	-10.54
3	1.5 (DL+LL)	-40.56	-38.99

6. CONCLUSIONS

R.C. building of G+ 12 storeys with fixed base has analysed with and without considering SSI. SSI has been incorporated by using soil springs. Equivalent static method is used to analyse the structure response as per IS 1893 (Part-I) 2002. Seismic response results of flexible base in terms of storey drift, storey displacement, base shear and modal behavior are compared with fixed base condition.

The following conclusions are drawn after comparing the responses of both support conditions.

(a) Variation of storey drift in both the cases is parabolic with middle storeys showing maximum drift. When SSI is considered there is a magnification of storey drift in the middle storeys.

(b) The effect of SSI on the story lateral displacement 12-story buildings has been studied. It is observed that the displacement increase occurs in SSI models.

(c) The natural time period in case of building with fixed base in first mode is 2.816 sec and increases to 3.635 sec in case of flexible base condition.

Similarly, an amount of increase in the natural time period is found in all model.

(d) The mass participation ratio of first three modal of R.C. building in case of fixed support condition are 82.24% and 83.37% in x and y direction respectively. Similarly, in case of flexible base condition decreases to 75.64% and 76.65%.

(e) Under the effect of seismic load the bending moment of beam slightly increases under effect of SSI. Under the gravity load the bending moment of beam is higher in case of fixed base condition.

(f) The response of R.C. building has shown significant increase compared to conventional approach of assuming fixed base.

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