Effects of Soil Structure Interaction on Infilled Building Frame with Raft Foundation

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Abstract - *In conventional analysis and design of structure, the structural engineer considers the base of R.C. building as fixed and avoids the effect of soil structure interaction (SSI). However in reality, the supporting soil system allows the deformation to some extent due to its compressibility. Also, the effect of infill masonry wall is ignored in design of R.C. buildings. In present work the effect of SSI is studied on G+7, 4 bay x 4 bay infilled R.C. building supported on raft foundation and resting on soft soil. The seismic forces are considered as per IS: 1893 (Part 1)-2002. The masonry infill wall is modelled by using an equivalent diagonal strut element. Analysis is carried out on fixed base and flexible base infill frame models using STAAD Pro software. The results obtained from the analysis indicate that story shear, floor displacement, story drift and time period considerably increases in flexible base system compared to fixed base infill frame system. The soil structure interaction causes non-uniform settlement of raft foundation which in turn modifies the forces and displacements in structure-foundation-soil system.*

Key Words: **Soil structure interaction, Raft foundation, Story shear, Floor displacement, Time period, Settlement**.

1. INTRODUCTION

In conventional design approach structural engineer assumes that structure is fixed at their base. The effect of soil compressibility is generally overlooked in seismic analysis of R.C. building frame. In reality the supporting soil medium dislodged to some degree because of its normal compressibility this prompts in reduction of the stiffness of the auxiliary structure and subsequently, increases the time period of the framework. The study has been done on various building frames resting on different type of foundations and varying soil compressibility to examine the effect of SSI. Such an investigation may provide thumb-rules to evaluate seismic response of the building frame possibly helpful for earthquake resistant design of structure. To incorporate the effect of SSI; structure, foundation and soil system is modeled as one unit using either rigid or flexible plates laying on elastic soil medium. R.C. structures with masonry infill wall have been broadly used for commercial, industrial and residential construction in various seismic zones. Masonry infill walls generally consist of concrete blocks or bricks used to fill the space between R.C. frames. Most of the time the stiffness of infill walls are not considered in the analysis and design of structure and regarded as non-structural element but some investigation has proved that practically presence of infill walls significantly affects the seismic performance of a R.C. building frame. The earthquake movement generates inertial forces and magnitude of these forces increases with the weight of the building. Thus, infill wall alters the stiffness and strength of the R.C. building frame. Hence for safe design, the effect of masonry infill wall should be considered.

2. LITERATURE REVIEW

Several investigators performed the various types of studies considering the effects of soil structure interaction and infill walls. They performed experimental and software based studies. The investigations of such researchers are as follows:

Murthy et al (2000) conduct an investigation and discussed the results obtained by experimental study of infilled frame structure under seismic loading. The response of infilled frame structure is compared with bare frame structure. They classified infill into two categories; brick work with and without reinforcement tied into the edge columns. They also discussed the impact of size of brick on hysteretic response. In light of their own experimental results and various past studies they stated the advantageous effects of brickwork infill walls on seismic response of RC frame building.

Garg et al (2012) reviewed the work of various investigators in the field of soil structure interaction. They attempted to study the possible alternative proposed by different specialists to analyze the impact of SSI. They classified the literature on the basis of soil modeling as linear, nonlinear, elasto-plastic and visco-elastic/plastic. The study shows that soil structure interaction causes redistribution of forces and alters the response of the structure.

Anuradha et al (2015) studied the behaviour of 2 bay x 4 bay, 4 storeys vertically irregular RC building considering the impact of SSI. The building is resting on isolated footings. The soil is modeled as soft, medium and hard considering its stiffness. They took the three linear elastic and isotropic soil models below the structure as rigid base, spring model and soil continuum and done the dynamic analysis using time history analysis by SAP 2000. In light of their outcomes, they inferred that lateral displacement, natural frequency, story drift and base shear increases because of soil structure interaction.

Bhojegowda et al (2015) investigated the effect of compressibility of soil on structure with rigid and flexible support foundation situated on various type of soil and provided systematic guideline for determining natural frequency and spring stiffness for different regular and irregular structure. The response spectrum analysis was done by using ETABS Software for isolated footing; raft and pile foundation and results were compared in terms of parameters like time period, base shear, bending moment in column and top storey displacement to find the effect of soil compressibility. For flexible base they modeled the soil and foundation as spring element and provided a systematic guideline for determining natural frequency and spring stiffness for various regular and irregular structures. They concluded that framed structure with pile foundation modeled as flexible base shows no difference in base shear value and not much variation in response of structure comparing with fixed base structure and also found that magnitude of base shear for raft foundation is increased while other parameters like settlement, bending moment and natural period is reduced in contrast with structure having isolated footing and on increasing the no. of stories of structure the parameters like base shear, time-period and responses also increased which indicate that structures supported over soft soil will have more displacement and flexible base analysis is required.

Kuladeepu et al (2015) analyzed the effect of interaction on response of 3D building frame structure led over raft foundation resting over a soil continuum under seismic forces software SAP2000. The soil continuum model was considered as homogeneous, isotropic and elastic half space. They made an attempt to assess the impact of parameters, for example, number of stories, type of soil and height extent for seismic zone-V and the responses in regards to time period, base shear and story drift, with and without soil compressibility was compared and effect of compressibility of soil on RC building frame was analyzed. They concluded that the fundamental time period and base shear values were more while considering effect of SSI as compared to without interaction case.

Malviya et al (2017) made an attempt to acknowledge the effect of soil compressibility in analysis and design of the RC building structure. A 4 bay x 4 bay (G+7) reinforced concrete building frame resting on sandy soil subjected to gravity and seismic loading constructed in zone V as per IS:1893 (Part-1)-2002 was investigated using STAAD PRO software. First they modelled and analysed the building frame by conventional approach i.e. assuming fixed base and vertical reactions were computed for various load combination. Then they replaced the fixed support by equivalent stiffness spring to perform the flexible base analysis. Based on these results, it was concluded that the soil compressibility caused settlements of foundations, change in support reactions, redistribution of forces in beam and column and also affected the requirements of reinforcement for design.

Venkatesh et al (2017) studied the effectiveness of analysis software to analyze effect of flexibility of soil under seismic loading on building resting on raft foundation. An 8 storey 2 bay x 2 bay R.C. building frame is taken for analysis and soil below raft is represented by equivalent soil stiffness spring. Response spectrum method was used for analysis of soil-structure model. The structure is modeled for two cases rigid base and flexible base. OMRF structure is analyzed for various type of soil (soft, medium and hard) and different seismic zones III, IV and V. They concluded that natural period, floor displacement, beam and column forces, forces in raft and settlement of raft significantly increases while on the other hand base shear decreases due to effect of SSI.

Zahir et al (2017) performed analysis of a G+9 storey 3 bay x 3 bay building frame to evaluate effects of infill wall on static and dynamic response of RC building frame. The building is situated in seismic zone V as per IS: 1893(Part I)-2002. Analysis of infill frame and bare frame model is carried-out using Static method and response spectrum method. Structure is analyzed with and without considering effect of infill wall using STAAD.Pro software. The infill has been represented as an equivalent diagonal strut component and infill panel. They concluded that story shear got increased while floor displacement, story drift, time period diminishes for infill frame models compared to bare frame model. This increase in terms of ratio is observed to be more at rooftop compared with base of structure.

Yadunandan et al (2017) performed a study to incorporate stiffness of the infill wall as equivalent diagonal strut whose width is computed by using different methodologies proposed by the various researchers. The objective of this research work is to exhibit a comparative study and analysis of G+3 story building with and without opening and soft story by performing linear and dynamic analysis using ETABS software. A general survey of the relations proposed by the researchers in computing the width of the equivalent diagonal strut is being made and analyzed. They also investigated the response of bare and infill frame. Results are compared in terms of base shear, story drift, story displacement, column forces and time periods for different models.

3. PROPOSED WORK

The 8 story, 4 bay by 4 bay reinforced concrete infilled building frame supported on raft foundation resting on soft soil is analysed as per Indian Standard Codes under gravity and seismic loading using finite element package STAAD Pro. The building is assumed to be in seismic zone III as per IS: 1893 (Part 1)-2002. The analysis is performed for two cases i.e. fixed base analysis and flexible base analysis. Equivalent soil stiffness springs as per Gazeta are used to consider the effect of SSI for flexible base analysis and stiffness of infill wall is considered by using equivalent diagonal strut element. Modelling of raft foundation is done by using plate element which is directly connected to soil stiffness spring at their centre of gravity.

3.1 Infill modeling

Stiffness of infill is considered in analysis of structure by using equivalent diagonal strut element. Width of equivalent strut is computed by using equations proposed by Hendry (1998).

3.2 Soil Modeling

The behaviour of the elastic half space is represented by using 6 linear soil stiffness springs acting in 6 degree of freedom according to George Gazetas, Formula and charts for impedances of surface and embedded foundation is shown in Table 1.

Table 1: Soil Spring Stiffness (George Gazeta)

Degrees of Freedom	Stiffness of equivalent soil spring
Vertical K_y	$[2GL/(1-\nu)](0.73+1.54\,\chi 0.75)$ with $\chi = A_b/4L^2$
Horizontal K_z (lateral direction)	$[2GL/(2-\nu)](2+2.50\chi 0.85)$ with $\chi = A_b/4L^2$
Horizontal (longitudinal direction) K_x	$[2GL/(2-\nu)](2+2.50\chi 0.85)-[0.2/(0.75-\nu)]GL[1-(B/L)]$ with $\chi = A_b/4L^2$
Rocking K_{rx} (about longitudinal)	$[G/(1-\nu)]I_{bx}^{.75}(L/B)0.25[2.4+0.5(B/L)]$
Rocking K_{rz} (about lateral)	$[G/(1-\nu)]I_{by}^{.75}(L/B)^{.15}$
Torsion K_{ry}	$3.5G\,I_{bz}^{.75}\,(B/L)^{.4}(I_{bz}/B^4)^{.2}$

Where, G = Shear modulus of soil, ν = Poisson's ratio;
A_b= Area of the foundation of proposed structure;
B and L= Half-width and half-length of a rectangular foundation, respectively;
I_{bx}, I_{by}, and I_{bz} = Moment of inertia of the foundation area with respect to longitudinal, lateral and vertical axes, respectively.

Table 2: Spring Stiffness values

Direction	Spring Values (kN/m)
Vertical K_y	9,08,000
Horizontal (longitudinal direction) K_x	6,75,500
Horizontal (lateral direction) K_z	6,75,500
Rocking (about the longitudinal) K_{rx}	10,36,32,150
Rocking (about the lateral) K_{rz}	10,72,05,680
Torsion K_{ry}	15,35,61,405

3.3 Raft Modeling

The raft foundation is represented as plate element of constant thickness and soil stiffness springs are connected to the Center of gravity of discretized elements of raft foundation. The value of spring stiffness for discretized plate element is evaluated using following equation:

$$K' = K * (A_P/A_G)$$

Where:

K' = Value of discrete spring for discretized plate element

K = value of gross spring for overall dimension of raft

A_P = Area of discretized plate element

A_G = Gross area of raft

The plan, elevation and isometric view of the proposed infilled building frame models is shown in fig. 1, 2 and 3 respectively.

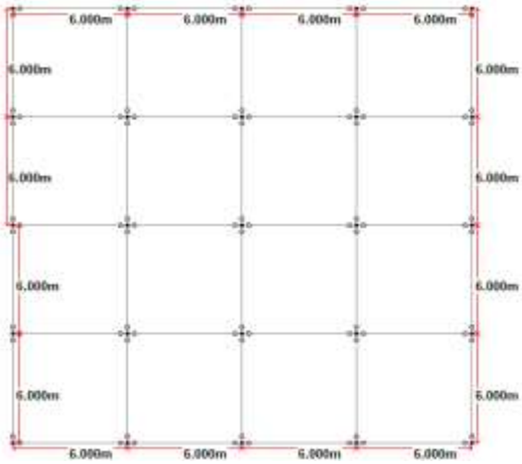

Fig -1: Plan of infilled building frame model

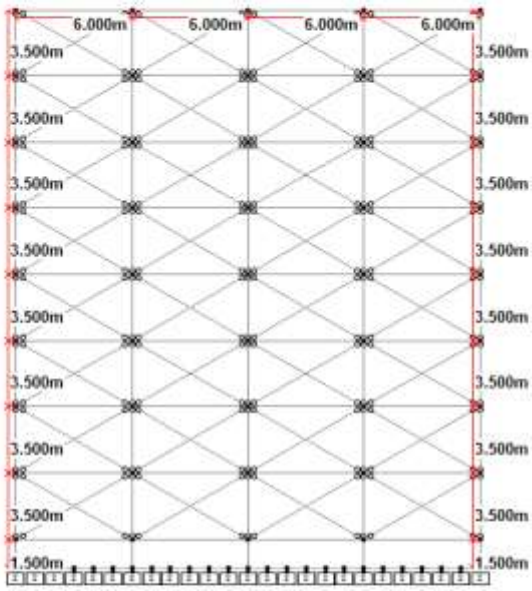

Fig -2: Elevation of infilled building frame model

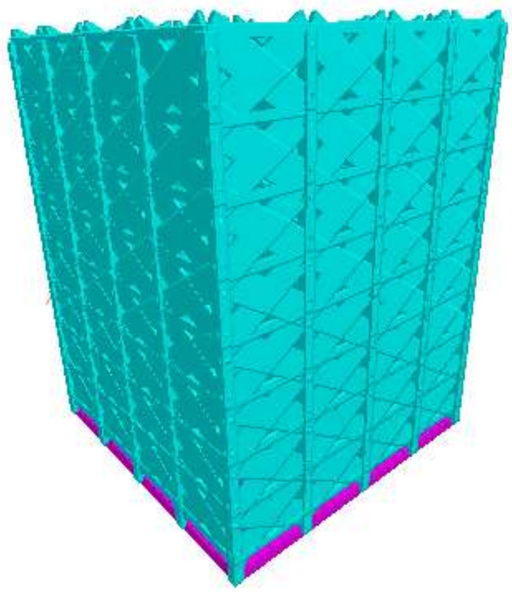

Fig -3: Isometric view of infilled building frame model

The properties considered for modelling and analysis of building frames are shown in table 3

Table -3: Properties of proposed infilled building frame models

Type of structure	Residential building (G+7)
Plan dimensions	24 m X 24 m
Total height of building above GL	28m
Height of each storey	3.5m
Foundation depth below plinth level	1.5m
No. of bays (both direction)	4
Bay width (both direction)	6m
Size of Beams	350 mm × 500 mm
Size of Column	650 mm × 650 mm
Thickness of slab	150mm
Thickness of Raft	800mm
Thickness of walls	200 mm
Width of equivalent strut	1.75m
Shear modulus of soil	10000 kN/m²
Poisson's ratio of soil	0.4
Concrete grade	M-25
Density of reinforced concrete	25kN/m³
Young's modulus of concrete,	2.17×10^4 N/mm²
Poisson ratio of concrete,µ	0.2
Young's modulus of brick, E_c	1.38×10^4 N/mm²
Poisson ratio of brick ,µ	0.15
Seismic zone	III

In present work, dead load (self-weight of the structural members i.e. frame, slab and masonry walls), live load and the seismic load for analysis of building frame models is taken as per IS: 875 (Part 1)-1987, IS: 875 (Part 2)-1987 and IS: 1893 (Part 1)-2002 respectively.

4. RESULTS AND DISCUSSION

Proposed infill masonry building is analysed for following two different cases:

i) Fixed Base infill frame model.
ii) Flexible Base Infill frame model.

The story shear, floor displacement, story drift, time period and settlement are evaluated and compared between fixed and flexible base infilled building models to evaluate the effect of Soil Structure Interaction.

4.1 Effect of SSI on Story Shear

Comparison of story shear at different story for fixed base and flexible base infill frame models are shown in table 4

Table 4: Comparison of story shear (kN) at different story between fixed base and flexible base infill frame model

Floor Level i	Story Height (m)	Storey Shear (kN)		Ratio (Flexible/ Fixed base)
		Fixed Base	Flexible base	
8	29.50	1401.90	1628.23	1.16
7	26.00	2993.53	3618.10	1.21
6	22.50	4185.49	5108.29	1.22
5	19.00	5035.45	6170.93	1.23
4	15.50	5601.11	6878.13	1.23
3	12.00	5940.16	7302.00	1.23
2	8.50	6110.27	7514.68	1.23
1	5.00	6169.13	7588.27	1.23
GL	1.50	6172.86	7592.62	1.23
BASE SHEAR		6172.86	7592.62	1.23

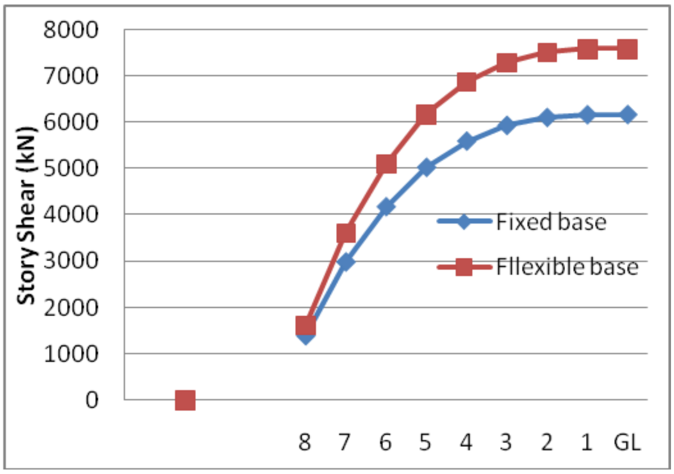

Fig -4: Story shear (kN) at different story for fixed base and flexible base infill model.

The Table 4 and Fig. 4 indicates that story shear for flexible base infill model are found to be more compared to fixed base infill models. The total design base shear values for the flexible base infill frame is 7592.62 KN which is 1.23 times of the base shear of the fixed base infill frame model i.e. 6172.86 KN.

4.2 Effects of SSI on Floor Displacement

The displacement of all the floors for fixed base and flexible base infill frame models are given in tables below:

Table 5: Comparison of floor displacement (mm) between fixed base and flexible base infill frame model.

Story	Story Height (m)	Displacement (mm)		Ratio (Flexible/ Fixed base)
		Fixed base	Flexible base	
8	29.5	5.38	37.59	6.98
7	26	4.83	33.84	7.01
6	22.5	4.21	30.03	7.13
5	19	3.57	26.18	7.33
4	15.5	2.93	22.32	7.62
3	12	2.31	18.50	8.00
2	8.5	1.75	14.75	8.43
1	5	1.28	11.10	8.67
GL	1.5	0.85	7.52	8.80
BASE	0	0.00	5.64	*

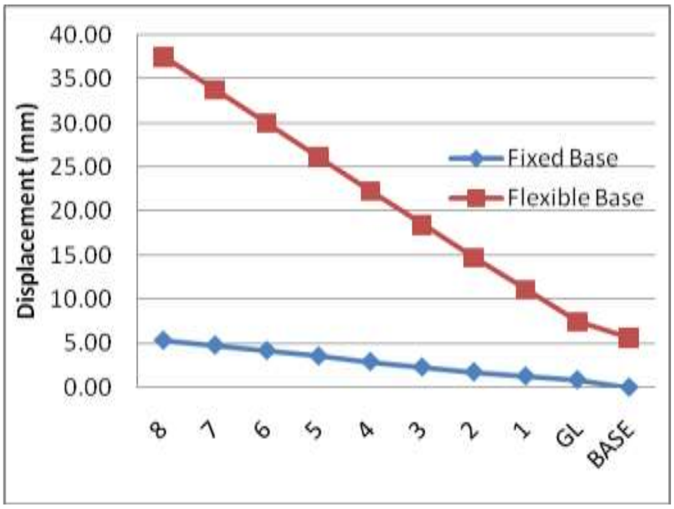

Fig 5: Displacement (mm) at different stories between fixed base and flexible base infill model.

The table 5 and Fig. 5 indicate that displacement for flexible base infill frame is considerably increases compare to fixed base infill frame. The displacement for flexible base infill frame increases about 8.80 times of fixed base infill frame.

4.3 Effects of SSI on Story drift

The story drift of all floors for fixed base and flexible base infill frame models is given in table 6

Table 6: Comparison of Story Drift (mm) at different story level between fixed base and flexible base infill frame model

Story	Height	Story Drift(mm)		Ratio (Flexible/ Fixed base)
		Fixed base	Flexible base	
8	29.5	0.56	3.75	6.71
7	26	0.61	3.81	6.23
6	22.5	0.64	3.85	6.00
5	19	0.64	3.86	5.99
4	15.5	0.62	3.82	6.20
3	12	0.56	3.76	6.69
2	8.5	0.47	3.64	7.77
1	5	0.43	3.58	8.39
GL	1.5	0.00	1.88	*

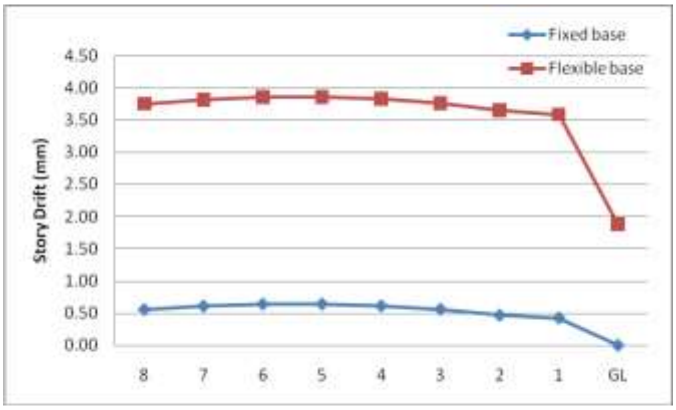

Fig 6: Story Drift (mm) at different story between fixed base and flexible base infill frame

The Table 6 and Fig. 6 indicate that the story drift is increases in flexible base infill frame due to the effect of soil structure interaction. The maximum increase in story drift in flexible base infill frame is about 8.39 times of fixed base infill frame model.

4.4 Effect of SSI on Time Period

The time period of building for first mode in fixed base and flexible base infill frame system is evaluated and compared to access the effect of soil structure interaction.

Table 7: Time period of building (Sec) for first mode fixed base and flexible base infill frame model.

Mode	Time Period (Sec)	
	Fixed base	Flexible base
1	0.55	0.94

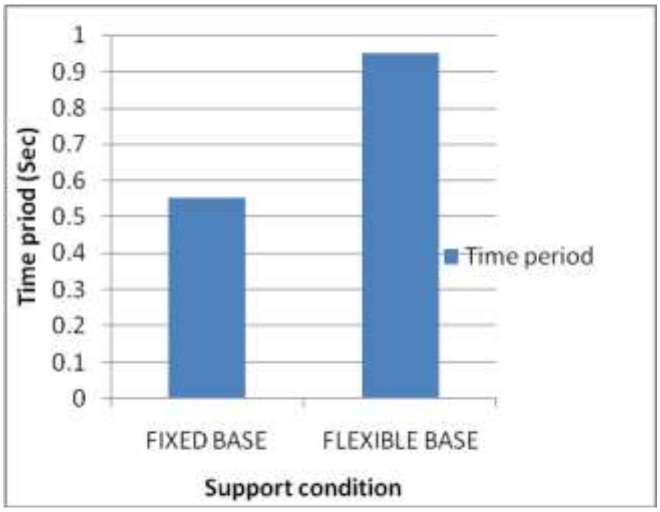

Fig 7: Time period (Sec) for fixed base and Flexible base infill frame model

The Table 7 and Fig. 7 shows, the time period for flexible base infill frame is 1.7 times more than the fixed base infill frame system.

4.5 Settlement of Raft

The flexibility of raft and soil compressibility causes non uniform settlement in raft foundation.

Table 8: Settlement of Raft (mm) in flexible base infill frame system

Location	Vertical displacement (mm)
Center	62.07
Corner	56.80

The maximum vertical settlement of raft in case of flexible base analysis is found 62.07mm at center and 56.80mm at corners of raft foundation. This non-uniform settlement of raft foundation modifies the forces and displacements in structure-foundation-soil system.

5. CONCLUSION

In present work the effect of SSI is studied on G+7, 4 bay x 4 bay infill R.C. building supported on raft foundation and resting on soft soil. The conclusions drawn from the present study are as follows:

- The story shear, floor displacement, story drift and time period considerably increases in flexible base system compared to fixed base infill frame system.
- The soil structure interaction causes non-uniform settlement of raft foundation which in turn modifies the forces and displacements in structure-foundation-soil system.

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