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Study of RCC Structure Considering the Effect of Flexible Base

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Abstract- Though the structures are supported on soil, most of the designers do not consider the soil structure interaction and its subsequent effect on structure. When a structure is subjected to an earthquake excitation, it interacts the foundation and soil, and thus changes the motion of the ground. It means that the movement of the whole ground structure system is influenced by type of soil as well as by the type of structure. Tall buildings are supposed to be of engineered construction in sense that they might have been analyzed and designed to meet the provision of relevant codes of practice and building bye-laws. IS 1893: 2002 "Criteria for Earthquake Resistant Design of Structures" gives response spectrum for different types of soil such as hard, medium and soft. An attempt has been made in this paper to study the effect of Soil-structure interaction on multi storeyed buildings. Also response of buildings subjected to gravity and lateral loading is finding out by ANSYS 11.0.

Index Terms - Foundation, Frame, Soil-Structure Interaction (SSI), Displacement, etc…

1 INTRODUCTION

When forces are applied externally to the structure, internal forces develop and both components must deform and move in a compatible manner. This is because neither the displacements of the structure nor the ground displacements are independent of each other as a result of their physical contact. Because of this mutual dependence of the structure and soil behavior, these types of problems are broadly referred to as soil-structure interaction (SSI) problems. Because of this mutual dependence, which is termed as interaction, the stress resultants in structure and, stresses and strains in soil are significantly altered during the course of loading. Therefore it becomes imperative to consider the structure-foundation and soil as components of a single system for analysis and design of the structure and its foundation. The analysis that treats structure foundation- soil as a single system is called as Soil Structure Interaction (SSI) analysis [2, 3].

1.1 Classification of SSI based on treatment of Interactions

Based on the treatment of interactions of sub-domains in a system SSI analyses may be classified as 1) Monolithic or direct approach or domain, 2) Substructure approach.

- Monolithic or direct approach or domain: In the direct method the soil, structure and foundation is modeled together using finite element method (FEM) and analyzed in single step.
- Sub-Structure Method: The soil/foundation medium and the structure are represented as two independent mathematical models or substructures. The connection between them is provided by interaction forces of equal amplitude, acting in opposite directions of the two sub-structures [4, 5, 6, 7].

1.2 Static Soil Structure Interaction

Linear static analysis is concerned with the linear behavior of the elastic continua under prescribed boundary conditions and statically applied loads. The analysis has been carried out on a regular multistorey frame in the present study. Different combinations of dead load and imposed load as per the relevant code provisions have been considered and the critical values displacements are evaluated. Finite element models have been formulated for soil. The analysis has been repeated with and without considering the subsoil to study the soil structure interaction effects. The details of the analysis are described subsequently. SSI studies that take into account the yielding of structures and soil non –linearity are scarce, especially investigating the effects of non-linearity of SSI system on overall behaviour in terms of displacements and stresses [2, 3].

2 PROBLEM UNDER CONSIDERATION

In present problem a 3 bay x 3 bay three-storey RCC space frame resting on homogeneous soil mass and subjected to gravity loading is analyzed. The problem under consideration is symmetric about both axes in terms of geometry, material properties and loading. The superstructure of proposed model is depicted in Fig.2.1.

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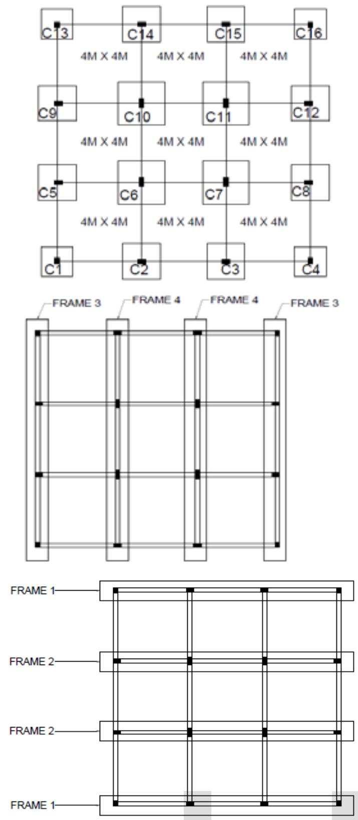

Fig. 1- Plan showing columns and footings

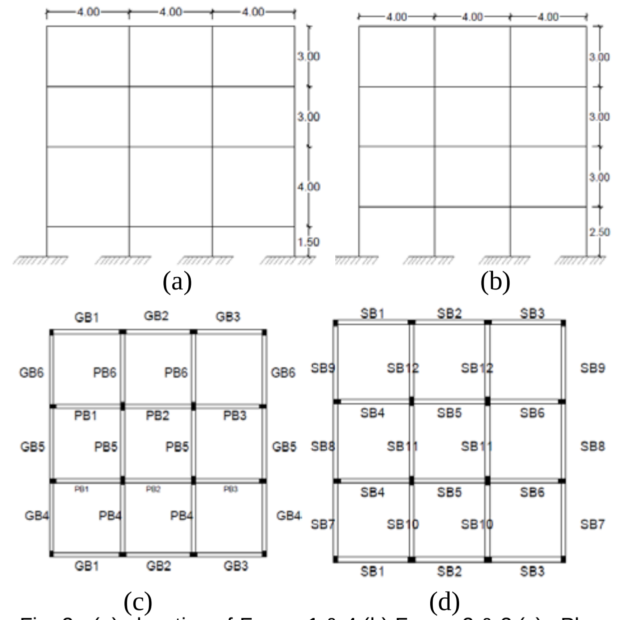

Fig.-2- (a) elevation of Frame 1 & 4 (b) Frame 2 & 3 (c) Plan showing Ground beams & plinth beams (d) Plan showing slab beams for first, second and terrace floor

To investigate the interaction behavior, the interaction analyses are carried out for the following three cases.

Case-1: The conventional non-interaction analysis (NIA) considering the columns fixed at their bases.

Case-2: The interaction analysis of space frame isolated footing-soil system considering the columns supported on individual column footings and resting on soil media (Elastic Analysis). (IAE)

Case-3: The interaction analysis of space frame isolated footing-soil system considering the columns supported on individual column footings and resting on soil media (Elasto-plastic Analysis). (IAEP)

where,

NIA - Non-Interaction Analysis, IAE - Interaction Analysis Elastic, IAEP - Interaction Analysis Elasto-Plastic

The frame, foundation are considered to be elastic and supporting soil mass as elastic as well as elasto-plastic to act as a single compatible structural unit for more realistic analysis. The geometric and material properties of proposed model are given in Table 2.1where as loading is given in Table 2.2(a) and Table 2.2 (b). And elevation of Frame 1, Frame 2, Frame 3, Frame 4 and plan of all beams are shown in figure 2.2.

Table-1- Geometric and material properties of 3 storey frame, footing and soil mass

Component	Description	Data
Frame	Number of bays in X direction	3
	Number of bays in Y direction	3
	Floor to floor height	3.0 m
	Plinth height	1.0 m
	Bay width in X direction	4.0 m
	Bay width in Y direction	4.0 m
	Beam dimensions	(0.23 x 0.3) m
	Columns C1,C13,C4,C16(A)	(0.23 x 0.3) m
	Columns C2,C14,C3,C15,C5, C9,C8,C12 (B)	(0.38 x 0.23) m
	Columns C6,C10,C7,C11(C)	(0.23 x 0.45) m
	Thickness of all slabs	0.15 m
Isolated Footing	Footing under Columns C1,C13,C4,C16(F1)	1.5m x 1.5m x 0.35m
	Footing under Columns C2,C14,C3,C15,C5,C9,C8 ,C12(F2)	1.8m x 1.8m x 0.4m
	Footing under Columns C6,C10,C7,C11(F3)	2.2m x 2.2m x 0.5m

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	Modulus of elasticity of footing for(M20)	22360 x 10^6 N/m^2
	Poisson's ratio of concrete	0.15
	Density of RCC	2500 kg/m^3
	Acceleration due to gravity (g)	9.81 m/s^2
Soil Mass (Medium hard clay)	Extent of Soil Mass	30.0m x 15.0m
	Modulus of elasticity of soil	100 x 10^6 N/m^2
	Poisson's ratio of soil	0.2
	Safe Bearing Capacity (SBC)	200 kN/m^2
	Density	2000 kg/m^3
	Cohesion	50 x 10^9 N/m^2
	Frictional angle	15 degree
	Shear modulus (G)	6900-34500 kPa
	Shear wave velocity (Average)	290 m/s

Table -2 (a)- Factored UDL Intensities on Beams

Structural Component	**U.D.L. Intensities (N/m)**
Ground Beams	25530
Plinth beams	9315
First and Second floor Outer slab beams Inner slab beams	 34630 41315
Terrace floor Outer slab beams Inner slab beams	 22900 38900

Loads are calculated by usual way i.e. for slab Live Load = 3kN/m^2, Floor Finish = 1.25kN/m^2, and after this factored it and distributed on beams as per IS 456-2000. For beams, the loads of walls are calculated and factored it [12].

As far as dead load is considered, Ansys'11 calculated dead weight of members from mass density and acceleration due to gravity hence these properties are required while assigning. Table 3.2 shows factored UDL intensities on all beams.

Also lateral forces on frame is calculated using IS 1893-2002 Provisions, considering building situated in seismic zone 3 and distribution of base shear on each floor is given in Table 3.2(b).

Table -2 (b)- Lateral force intensity on Each Floor

Floor	**Force Intensities (N)/frame**
Terrace floor	60170
Second floor	46095
First floor	20870
Ground level floor	525

2.1 Finite Element Modeling

The interaction analysis of the problem is carried out using ANSYS software (Version 11). The frame structure, footing and soil mass is discretized with 8 noded plane stress element (PLANE 82) for case 1 and case 2, with two degree of freedom per node (Ux and Uy). It is assumed that the joints between various members are perfectly rigid. The vertical displacements in soil mass are restrained at the bottom boundary whereas horizontal displacements are restrained at vertical boundaries. The soil mass is idealized as isotropic, homogeneous, half-space model. For Case 3, elastic-plastic behavior of the ground is modeled using Drucker-Prager criterion in ANSYS'11[13, 14].

The interface characteristics between the isolated footing and soil are represented by TARGE169 and CONTA172 elements. The element size for frame and footings are taken as 0.1m x 0.1m. The soil mass is discretized with 1m x 1m finer meshes in close vicinity of footing where stresses are of higher order [15].

3 SOIL STRUCTURE INTERACTION ANALYSIS

Soil structure interaction analysis is carried using ANSYS 11.0 and displacement result for terrace floor beam, footing are compared for NIA, IAE and IAEP. Both models i.e. gravity loading and Gravity+ Lateral loading are also compare with Non Interaction Analysis for Displacements and comparative study shows the effect of interaction. Also as per our previous study paper in "International Conference on Advances in Civil and Mechanical Engineering Systems (ACMES 2014)", entitled "Importance of Soil Structure Interaction for Framed Structure" Shows that the variation of displacement is predominant in middle frames i.e. Frame 2 and Frame 4 [17]. Hence the present study is based on comparative study of SSI with Non interaction analysis for both gravity and lateral loading. Thus following figure 3, figure 4, figure 5 and figure 6 shows the variation of displacement (due to settlement and deformation) for terrace story beams.

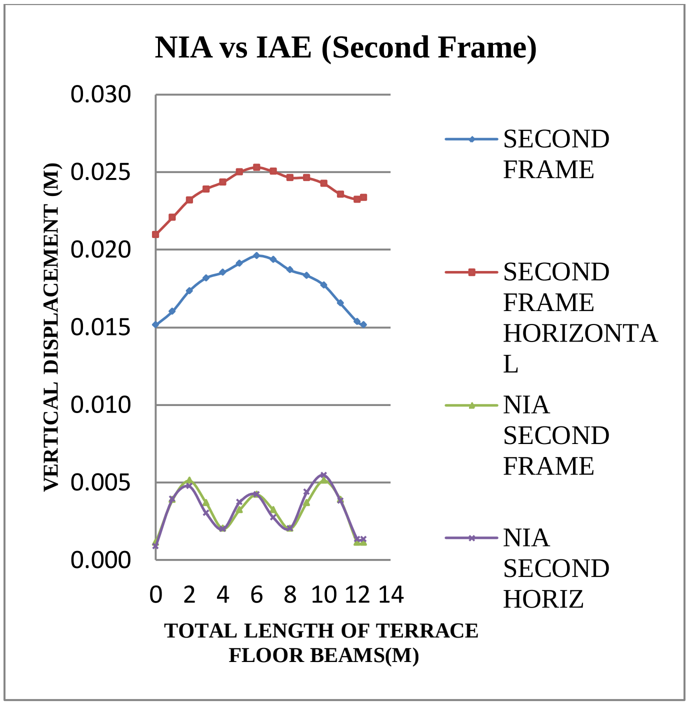

Fig.-3- Variation of displacements along length of terrace floor beams (Second frame Elastic Soil mass)

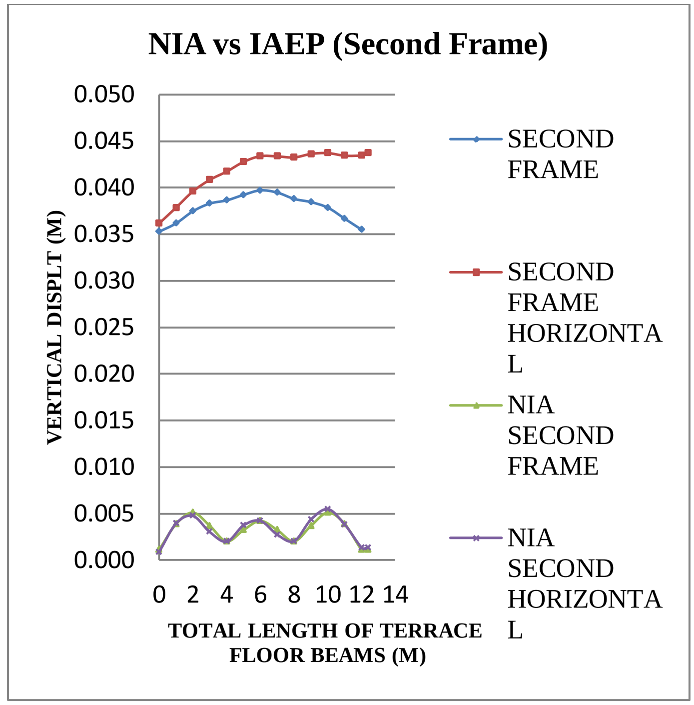

Fig. -5- Variation of displacements along length of terrace floor beams (Second frame Elasto-plastic Soil mass)

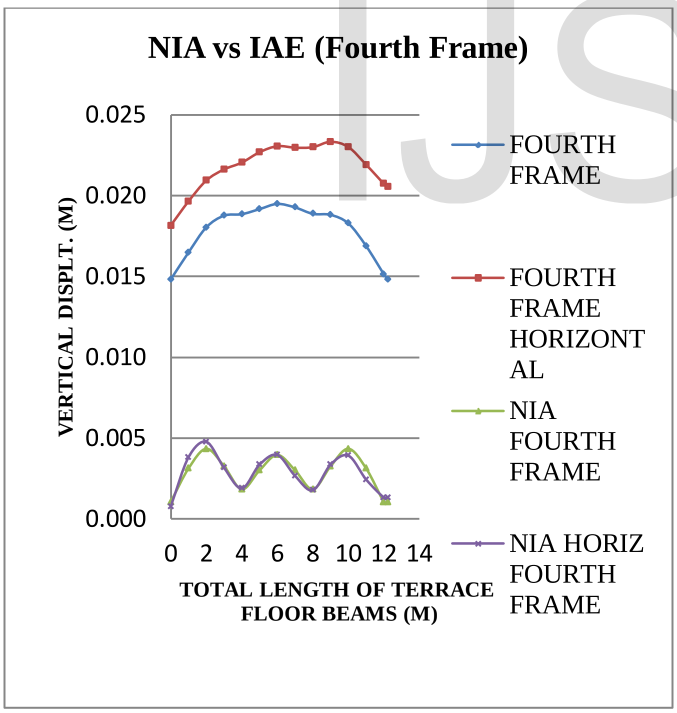

Fig.-4- Variation of displacements along length of terrace floor beams (Fourth frame Elastic Soil mass)

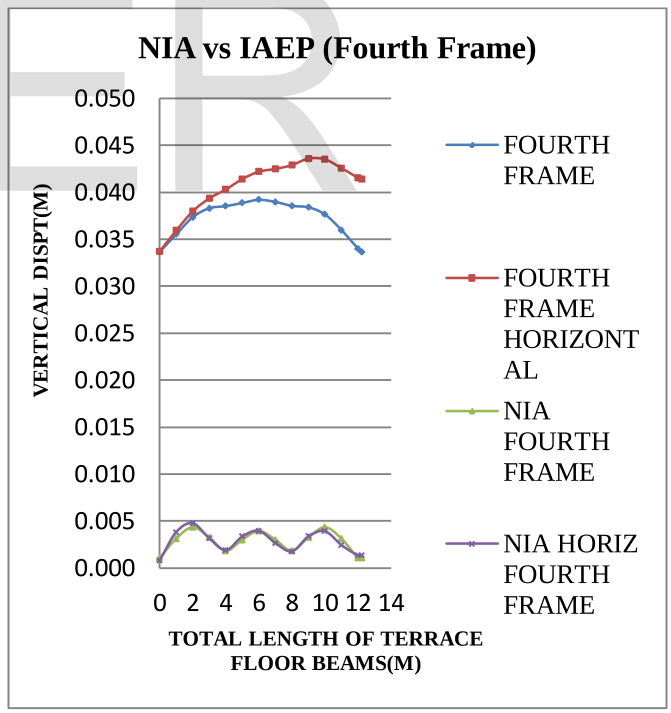

Fig. -6- Variation of displacements along length of terrace floor beams (Fourth frame Elasto-plastic Soil mass)

Above graphs in figure 3(second frame) and figure4(fourth frame) shows that while considering elastic soil mass the displacement in terrace floor beam due to gravity loading increases with respect to non interaction analysis and displacement after considering gravity + lateral loadings again increases and become more than gravity loading.

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Also lateral+ gravity loading for fixed supported frame shows slight increase in displacement at about 10m and slight decrease at about 2m due to effect of lateral loading.

Figure 5 (Second Frame) and figure 6 (Fourth Frame) compares displacement of terrace floor beams for elasto-plastic soil mass. It shows that increased displacement for gravity loading than non interaction analysis also displacement again increases after considering lateral + gravity loadings.

Thus if we compare elastic and elasto plastic soil mass it may be noted that for NIA displacement is least, for IAE displacement is moderate and for IAEP displacement is maximum for both gravity and lateral+ gravity loading. After getting response of terrace floor, the response of footing is also important. Hence displacement of footings is compare in Table 2 for all frames.

Table -2 Comparison of footing Displacements

	Vertical displacement (mm)					
	Gravity loading			Gravity+Lateral		
Frame 1	NIA	IAE	IAEP	NIA	IAE	IAEP
Footing under column						
C1,13	0	15.2	29	0	13	19.8
C2 ,14	0	17.1	29	0	18	27.7
C3,15	0	17.1	29	0	18	27.7
C4,16	0	15.2	29	0	15	31.7
Frame 2						
Footing under column						
C5,9	0	15.3	35	0	14	29.2
C6 ,10	0	19.6	40	0	20	34
C7,11	0	19.6	40	0	20	38.9
C8,12	0	15.3	35	0	17	38.9
Frame 3						
Footing under column						
C13 ,16	0	13.4	28	0	12	21.7
C9,12	0	17.2	28	0	18	26
C 5,8	0	17.2	28	0	18	26
C 1,4	0	13.4	28	0	18	30.3
Frame 4						
Footing under column						
C 14, 15	0	15.2	35	0	13	29.1
C 10, 11	0	19.5	39	0	21	38.8
C 6,7	0	19.5	39	0	21	38.8
C 2, 3	0	15.2	35	0	18	38.8

Table 2 gives insight about the footing displacement (due to settlement and deformation) which shows that inner footings under column C6, C7, C10, C11 displace maximum, due the same reason only second and fourth frame terrace floor beams displacement is given.

Table also shows that after applying lateral+ gravity loadings, the footings (from where the lateral load applies) are displace up and footings far away from application of lateral load displace down with respect to gravity loading analysis. Thus structure as well as footing shows predominant displacement after considering soil structure interaction effect where as no such displacement found in non interaction analysis.

4 CONCLUSIONS

1. Non interaction analysis shows only axial deformation or deflection of structural member as displacement which are obtain by considering support as fixed. But in practice soil may be fixed, pinned or something else we can't predict the exact nature of support condition thus considering soil structure interaction effect, the response of structure is completely different than non interaction analysis.
2. Soil structure interaction effect also differs for elastic soil mass and elasto-plastic soil mass.
3. In elasto-plastic soil mass the terrace floor beams displacement and displacement of footing are more than structure on elastic soil mass.
4. After considering lateral + gravity loadings at a same time the displacements again increases from elastic soil mass to elasto-plastic soil mass.
5. Footings are uplifted in the direction of application of lateral load and settle more in opposite direction. Thus such effect should not be considered without soil structure interaction analysis.
6. As number of story increased, the displacements also increase and response of structure again changes.
7. Again it shows that displacement in lateral + gravity loadings are more in opposite direction of application of lateral load.
8. Elasto-plastic soil mass must be considered for exact displacement analysis.
9. Present srudy is useful for deciding type of footing from displacement results.
10. Thus response of structure definitely changes after considering soil structure interaction effect.

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