Analysis of RC Building Frame with Flexible Isolated Footing Subjected To Seismic and Gravity Load

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Abstract— Reinforced concrete building consists of horizontal structural members such as beams and slabs and vertical structural members such as columns and walls that are supported by foundation system. The foundation support is assumed as either fixed or hinge support where the foundation transmit the loads from the structure to the soil medium which undergoes a settlement depending on the characteristics of the soil medium, which in turn causes vertical settlement and differential settlement and rotation of the footings, that results in redistribution of the column loads, the amount of which depends on the rigidity of structure and the load-settlement characteristics of the soil. Thus, the concept of soil-structure interaction comes into existence. In the present work, an attempt is made to analyse and study the multi-storeyed reinforced concrete building frames supported on isolated footings considering soil-structure interaction system, defining soil medium by springs of equivalent stiffness, subjected to gravity and dynamic loadings. A seven storey number of building frames are analysed and types of soil as medium sand supporting the foundation system to observe the more generalised effect of soil-structure interaction on building frames. The results obtained by analysis are used to study the effects of soil compressibility on foundation settlement, support reactions, column and beam forces in the building frames. The study reveals that vertical and differential settlements are found more critical in seismic loading compared to gravity loading and the values of critical support moment are observed to be more in flexible base system than that of fixed base system. This study also reveals that the variations in bending moments is found more in lower storey as compared to upper storey of buildings in gravity as well as in seismic loading.

Keywords: RC Building Frame, Seismic and Gravity Load

I. Introduction

The buildings are the most extensively constructed structure within the construction industry. Now days, the reinforced concrete buildings have become quite common in India. Reinforced concrete building consists of horizontal structural members such as beams and slabs and vertical structural members such as columns and walls that are supported by foundation system. Normally, the structure is subjected to various loads such as self-weight, dead load, live load, wind load, earthquake load, snow load, etc. and the structural strength of slabs and the brick walls is not generally considered while designing the structures. The foundation support is assumed as either fixed or hinge support where the foundation transmit the loads from the structure to the soil medium which undergoes a settlement depending on the characteristics of the soil medium, which in turn causes settlement (vertical, differential) and rotation of the footings, that results in redistribution of the column loads, the amount of which depends on the rigidity of structure and the load-settlement characteristics of the soil. Hence, in reality due to uneven deformation of supporting soil medium under the action of loads, the redistribution of forces in the frame members and stresses in the supporting soil media can effectively be seen. Thus, the concept of soil-structure interaction comes into existence which can be defined as the process in which motion of the structure is encouraged by the response of the soil and the response of the soil is influenced by the structural motion. However, this effect is generally neglected by the structural analyst in the conventional structural analysis, and the structure is analysed and designed by idealizing the fixity at base neglecting the effect of soil-structure interaction. For more realistic and safe design, flexible base analysis should be performed compared to conventional analysis.

It is generally seen that (Lahri and Garg, 2015) buildings supported on isolated footings resting on compressible soil media are more susceptible to differential settlement and rotation of footings, which may cause a significant tilt in the structure, making occupants uncomfortable, cracks in the foundation and walls, non-uniform settling of doors and windows, bulging of walls and sinking of slabs, etc. So, such effects can be widely adverse and cannot be ignored. Thus, there is a need for investigation of the effects of soil compressibility on such buildings. In the present work, an attempt is made to analyse and study the multi-storeyed reinforced concrete building frames supported on isolated footings considering soil-structure interaction system, defining soil medium by springs of equivalent stiffness, subjected to gravity and dynamic loadings. A seven storey number of building frames are analysed and types of soil as medium sand supporting the foundation system to observe the more generalised effect of soil-structure interaction on building frames. The results obtained by analysis are used to study the effects of soil compressibility on foundation settlement, support reactions, column and beam forces in the building frames.

A. Objective of this study

1) To evaluate the effects of soil compressibility on foundation settlements, support reactions, column and beams forces for building frames of different storeys resting on soils of varying stiffness.
2) To compare the critical forces and displacement in structure with the variation of number of storeys and soil compressibility.
3) To evaluate the variation in material quantities required for fixed and flexible base systems.

II. Literature Review

Mohod and Dhadse (2014) studied a 3 bay three-storey regular RCC space frame supported on isolated footing resting on homogeneous soil mass and subjected to gravity loading using finite element method. Three cases were considered for analysis as fixed base analysis, elastic analysis and elastoplastic analysis. It was investigated that during non-interaction analysis displacement is purely a deflection of beams and during elastic analysis displacement is due to settlement as well as deflection, whereas in case of elastoplastic analysis displacement is majorly due to settlement and very small due to deflection and an increase in displacement was found with the increase in number of storeys. Badry and Satyam (2016) made an attempt to reduce the computational cost by using equivalent pier method for deep foundation system and found their approach to be effective in optimising the computational efficiency. This approach was used in the analysis of L-shaped eleven storey building resting on pile foundation with homogenous soil conditions under dynamic loading. Menglin, Huaifeng, Xi et al. (2011) reviewed and presented various numerical models and computer programs for solving the problems of soil-structure interaction effects. It may be noted that the choice of method is dependent upon the type of problem considered for investigation and on the effects that are to be evaluated. Raychowdhury and Singh (2012) incorporated the Winkler based approach to evaluate the effects of nonlinear soil-structure interaction on the seismic responses of a three storey steel moment resisting frames. The nonlinear Winkler models are well suited in finite element approach, it also positively applicable with boundary element method. Kampitsis, et al (2013) used nonlinear Winkler foundation model in conjunction with boundary element method to account for the shear deformation, rotary inertia, geometrical nonlinearity and nonlinear P-δ effects in the soil-pile-structure interaction problem. The results obtained using this approach took minimum computational time and effort, and are in good agreement with the response of the finite element solutions. Rao, Kumar and Kumar (2014) analysed a building frame structure considering the foundation soil settlement (soil medium defined by a set of springs) under different wind zones for different heights of building and various subgrade modulus of foundation soil. Based on the results, it was inferred that the response of the building frames such as lateral deflection, storey drift and base shear values increases when the soil becomes soft for both fixed and flexible base buildings and these values for fixed base building was found to be lower as compared to flexible base building. In the present work, an analysis is performed to evaluate the effect of compressibility i.e. soil structure interaction of soil under gravity and dynamic loading on reinforced concrete building frames supported on isolated footings founded on compressible soil.

III. MODELLING AND ANALYSIS OF BUILDING FRAMES

A 3 bay by 3 bay multi-storeyed reinforced concrete frame supported on isolated square footing resting on compressible soil are analysed as per Indian Standard Codes under gravity and seismic loading in finite element package STAAD Pro. The sandy soil is considered to account the effects of compressibility of soil. The structural strength of slab is considered by assuming it as plate element. The building is assumed to be in seismic zone V as per IS: 1893 (Part 1)-2002. Building frame are analysed for a heights of seven storey and for types of soil as medium sand, keeping other dimensions and properties same for maintaining regularity in the building frame models. The size of beams and columns are optimised as per safety and economy for each building frame. The analysis is performed as both fixed base analysis and flexible base analysis. For flexible base analysis, the springs of equivalent foundation stiffness at each support are used. To calculate the equivalent foundation stiffness, the modulus of sub grade is assumed depending upon the nature of supporting soil.

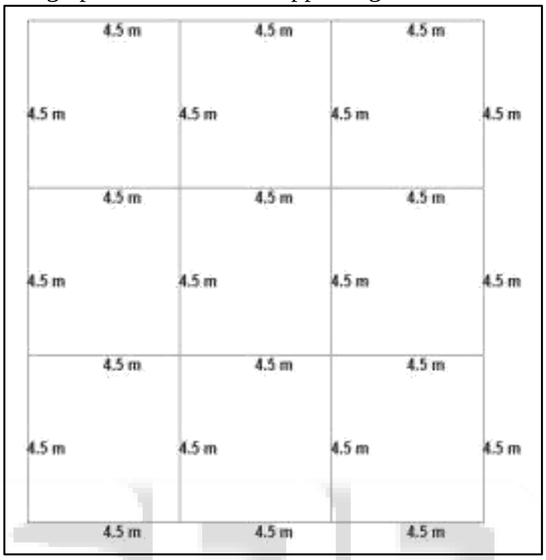

Fig. 1: Plan of building frame model

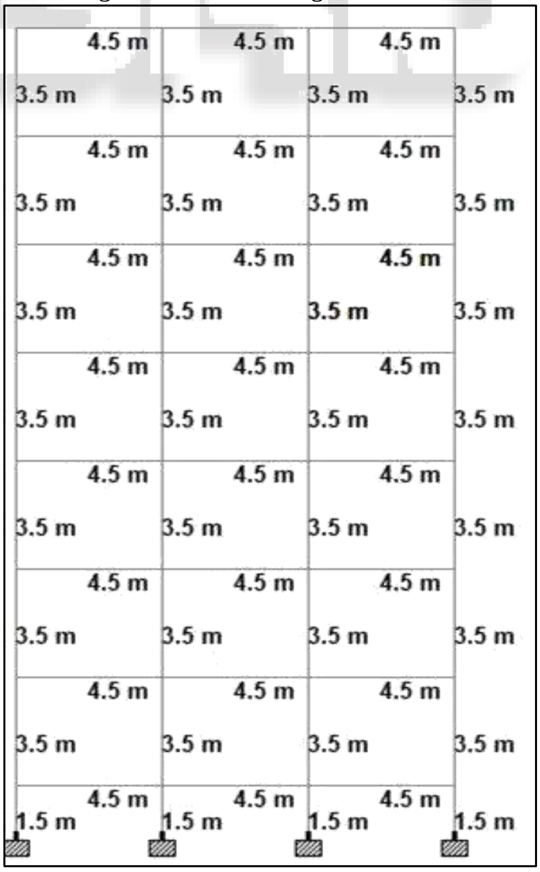

Fig. 2: Elevation of building frame model

S. No.	Material property	Values
1	Concrete grade	M 20
2	Density of reinforced cement concrete	$20 kN/m^3$
3	Young's modulus of concrete, E_c	$2.23x10^4$ N/mm^2
4	Poisson ratio of concrete, μ	0.17
5	Steel grade	Fe 500

Table 1: Material properties of building frame model

Soil type	Modulus of subgrade reaction for 0.30 m X 0.30 m plate(K_{plate}) in kN/m^3	Soil bearing capacity in kN/m^2
Medium	35000	220

Table 2: Soil properties considered for medium sandy soil

IV. RESULTS AND DISCUSSIONS

These analyses are performed on regular reinforced concrete building frame model for types of supporting soil medium as medium sand.

The values of critical support moment are observed to be more in flexible base system than that of fixed base system. The maximum values of vertical support reaction decreases by 0.90 to 0.94 times and support moment increases by 1.04 to 1.13 times in critical foundation in flexible base system compare to fixed base system. the critical axial forces are over-estimated for interior columns and under-estimated for exterior columns. Apart from redistribution, the reversal in the nature of bending moment is also observed for some columns. The shear force and bending moment in beams of all building frames supported on different types of soil varies from 0.68 to 1.31and -1.26 to 1.39 respectively in flexible base system as compared to fixed base system. there is increase of 1% to 5% in the total quantity of steel in flexible base system compared to fixed base system, the analysis and design of structure assuming flexible base is found to be more accurate and rational.

S. No.	Analyses	Fixed	Flexible	Ratio (Flexible/Fixed)
	Parameters	Medium	Medium	Medium
		M1	M2	M2/M1
1	Vertical support reaction Fy (kN)	1354.23to 2523.54	1422.56to 2322.45	0.82 to 1.05
2	Support moment Mz (kNm)	184.45to 213.34	203.67to 244.76	1.02 to 1.21
3	Axial force in columns Fy (kN)	136.98 to 2553.47	141.69 to 2333.75	0.89 to 1.06
4	Bending moment in columns Mz (kNm)	-86.55 to 242.78	-112.43 to 264.88	0.89 to 1.53
5	Shear force in beams Fy (kN)	19.45 to 82.44	16.78 to 86.18	0.74 to 1.26
6	Bending moment in beams Mz (kNm)	-55.44 to 118.33	-70.33 to 124.87	-1.23 to 1.29

Table 3: Minimum to maximum values of critical forces in structural components of seven storeyed building frames for both fixed and flexible base analyses

V. CONCLUSION

The following are the points concluded as a result of present work:

- Due to the effects of soil compressibility the values of vertical and differential settlements are found more critical in seismic loading compared to gravity loading.
- Significant variation in support reaction is observed due to compressibility of soil. The vertical support reaction redistributes from inner foundations to peripheral foundations in the flexible base system compared to fixed base system. The values of critical support moment are observed to be more in flexible base system than that of fixed base system. The maximum values of vertical support reaction decreases by 0.90 to 0.94 times and support moment increases by 1.04 to 1.13 times in critical foundation in flexible base system compare to fixed base system.
- The soil compressibility causes redistribution of axial force and bending moment in columns. The transfer of axial forces from interior columns towards the exterior columns is observed in the flexible base system compare to fixed base system. It may be inferred that in conventional analysis, the critical axial forces are over-estimated for interior columns and under-estimated for exterior columns. Apart from redistribution, the reversal in the nature of bending moment is also observed for some columns. The flexible base analysis provides substantial values of bending moment for interior columns which are negligible in fixed base analysis under gravity loading.
- The redistribution in the shear force and bending moment in beams takes place due to the compressibility of soil. The shear force and bending moment in beams of all building frames supported on different types of soil varies from 0.68 to 1.31and -1.26 to 1.39 respectively in flexible base system as compared to fixed base system. It clearly shows that some members are under designed and others are over designed during conventional analysis. The critical ratio of shear force in critical beam is same for same storeyed building and the critical ratio of bending moment in critical beam increases with increase in number of storey and stiffness of soil. The variations in bending moments is found more in lower storey as compared to upper storey of buildings in gravity as well as in seismic loading.

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