SEISMIC PERFORMANCE OF RC STRUCTURES CONSIDERING FOUNDATION FLEXIBILITY

Nitesh B. Yawalkar 1, Prof. H. Rangari 2 , Prof. Girish Sawai 3

1 PG Student, Dept. of Civil Engineering, V M Institute of Engineering and Technology, Nagpur, Maharashtra

2 Assistant Professor, Dept. of Civil Engineering, V M Institute of Engineering and Technology, Nagpur, Maharashtra

3 Assistant Professor, Dept. of Civil Engineering, V M Institute of Engineering and Technology, Nagpur, Maharashtra

ABSTRACT

Modelling plays a very important role in design and analysis of structures. Generally, the effect of soil is neglected in structural design and the superstructure is considered fixed base. This assumption is true only if the structure is located on rock/hard type soil. In the present study, effect of foundation flexibility has been considered over the fixed base structures. A regular building of 5 and 10-storey with same plan has been considered in the present study. Structural modeling, analysis and design have been performed in SAP 2000 version 14.2.4. Detailed mathematical model has been prepared to represent the distribution of structural geometry of elements and loading in plan as well as in elevation. Thickness of slab at all floor level and roof level have been assumed to be same and modeled as rigid diaphragm. The considered building has been analyzed by using response spectrum analysis and designed as special moment resisting frame as per the specifications IS 456:2000 and IS 13920:2016 code. To consider the effect of foundation flexibility on seismic response of these structures, two conditions are considered. In the first case both the buildings are assumed to be fixed at the base and in the second case, the buildings are assumed to be located on medium soil condition, thereby, incorporating soil-foundation flexibility. In case of soil-foundation flexibility, linear and nonlinear modeling of the soil-foundation system is carried out along with the superstructure. The fixed and flexible base models are analyzed by using response spectrum analysis method. Further, to assess the seismic performance, non-linear static procedure i.e. static pushover analysis as per ASCE-41 is performed for all the models and their performances are compared. The considered buildings are assumed to be located on medium soil and situated in seismic zone V. Further, the response reduction factor (R) of considered models is also evaluated. The results show the performance of flexible-base model, considering linear soil-foundation system is in agreement with the fixed base model. The response reduction factor (R) is significantly affected by the

incorporation of foundation-flexibility. It can therefore be concluded that the type of soil and the foundation on which the structure is resting is very important for design purpose.

Key Words- Non- Linear Static Procedure, Soil Structure Interaction, Seismic Performance

1.INTRODUCTION

1.1General

The seismic response of an engineering structure is affected by the medium on which it is founded. On solid rock, a 'fixed-base' structural response occurs which can be evaluated by subjecting the foundation to the 'free-field' ground motion that would occur in the absence of the structure. On a deformable soil, however, a feedback loop exists—the structure responds to the dynamics of the soil while, simultaneously, the soil responds to the dynamics of the structure. Structural response is then governed by the interplay between the characteristics of the soil, the structure and the input motion. Soil–structure interaction (SSI), as this phenomenon has become known, has been of research interest for the past 30 years. Compared with the counterpart fixed-base system, SSI has two basic effects on structural response. Firstly, the SSI system has an increased number of degrees of freedom and thus modified dynamic characteristics. Secondly, a significant part of the vibration energy of the SSI system may be dissipated either by radiation waves, emanating from the vibrating foundation–structure system back into the soil, or by hysteretic material damping in the soil. The result is that SSI systems have longer natural periods of vibration than their fixed-base counterparts. A committee of engineering research deals with the study of soil-structure interaction only when these forces brings an appreciable effect on the basement motion when we are comparing it with the free-field ground motion. The free-field ground motion can be defined as the motion recorded on the surface of the soil, without the involvement of the structure. The structural response to an earthquake is highly dependent on the interactions between three linked systems, namely:

a) The structure
b) The foundation
c) The underlying soil

The soil-structure interaction analysis is the method of evaluating the collective response of the three linked systems mentioned above for a specified ground motion. The soil-structure interaction can be defined as the process in which the response from the soil influences the motion of the structure and the motion of the given structure affects the response from the soil. This is a phenomenon in which the structural displacements and the ground displacements are independent to each other. Soil-structure force are mainly interaction forces that can occur for every structure. But these are not able to change the soil motion in all conditions.

1.2 Objectives of Work

The following are the objectives:

1. To study effect of foundation flexibility on time period of structures.
2. To study seismic performance of building with linear and nonlinear modelling of the soil-foundation system.
3. To assess and compare nonlinear performance of RC building with fixed base and flexible base.
4. To assess and compare Response Reduction Factor 'R' of RC building with fixed base and flexible base.

2. LITERATURE REVIEW :

Consideration of Soil-Structure Interaction in past studies

1. Viladkar *et al.* (1994) discussed the finite element modelling of the plane-frame combined footing-soil system, subjected to biaxial loading. They presented the formulation of an isoparametric interface/joint element used to model the interface characteristics of beam and the soil medium. In addition to this, they have provided some useful suggestions regarding the proper selection of the values of tangential and shear stiffness. Further, they studied the comparison between the behaviour of a five storey two bay frame with interactive and non-interactive analysis. It was observed that the total settlement obtained from non-linear interactive analysis is about twice that due to linear interactive analysis.

2. Mylonakis and Gazetas (2000) studied about the advantages and disadvantages of seismic soil-structure interaction. They compared conventional code design spectra to actual spectra and it was shown that an increase in fundamental natural period of a structure due to SSI does not necessarily lead to smaller response, and that the prevailing view in structural engineering of the always-beneficial role of SSI, is an oversimplification which may lead to unsafe design. It was concluded that SSI may not always have a beneficial effect on the seismic performance of structures, particularly when the displacement is the design criteria in place of force and depends significantly on the response spectra.

3. Jeremic *et al.* (2004) investigated the role of Soil-Foundation-Structure (SFS) interaction on seismic behavior of an elevated highway bridge with deep foundations. They considered two models to carry out the seismic behavior of a bridge bent subjected to various earthquake events. In the first model, it was assumed that the bridge columns were rigidly connected to the foundation without SFS interaction. In the second model, equivalent springs were used to incorporate SFS interaction. It was concluded that SFS interaction can have both beneficial and detrimental effects on structural behavior and is dependent on the characteristics of the earthquake motion.

4. Gerolymos and Gazetas (2006) investigated static, cyclic and dynamic response of a massive caisson foundation embedded in nonlinear layered soil and loaded at its top. The caisson was supported against horizontal displacement and rotation by four types of inelastic springs and dashpots. Further, they compared the model with experimental results and subsequently incorporated in numerical study (3D finite element analysis). The numerical study addressed the lateral monotonic and dynamic (sinusoidal-type) response of a caisson embedded in cohesive soil. Two cases were studied: (a) nonlinear response of the soil only, and (b) nonlinear response of both soil (material nonlinearity) and soil–caisson interface (geometrical nonlinearity). It was found out that interface nonlinearities play an important role in the inertial response of a caisson.

5. Garcia (2008) investigated the influence of soil-structure interaction in the analysis and design of a 6-storey and basement reinforced concrete frame building. Models simulating two different conditions: namely soil-structure interaction, and fixed-base behavior were considered. The influence of the soil structure interaction in the dynamic behavior of the structure was reflected in an increase in the vibration period as well as increase in the system damping in comparison with the fixed-base model, which does not consider the supporting soil. The influence of the soil-structure interaction in the seismic design of the structure was reflected in a decrease of the horizontal spectral acceleration values. The inclusion of the soil in the structural analysis provides results, stress and displacement values, which were closer to the actual behavior of the structure than those provided by the analysis of a fixed-base structure.

6. El Ganainy and Naggar (2009) proposed a modelling approach to simulate 3D rocking, vertical and horizontal responses of shallow foundations based on the beam-on-a-nonlinear Winkler foundation (BNWF) model that are readily available in the element library of commercially available structural analysis programs. They provided simple calculation steps to evaluate the geometric and mechanical properties of the proposed assemblage of structural elements. The proposed model was validated with the experimental results from large scale model foundations subjected to cyclic loading. It was concluded that the proposed model can simulate the rocking and horizontal responses of shallow foundations with good accuracy.

3. METHODOLOGY

Earthquake and its occurrence, measurements, and its vibration effect and structural response have been studied for past many years. Since then structural engineers have tried hard to examine the procedure, with an aim to counter the complex dynamic effect of seismically induced forces in structures, for designing of earthquake resistant structures in a refined and easy manner. Various approaches to seismic analysis have been developed to determine the lateral forces. However according to IS 1893(Part1):2016 and ASCE 41-17 following methods have been recommended to determine the design lateral loads, 1.Static analysis method

a. Linear static analysis (Equivalent static analysis)
b. Nonlinear static procedure (Pushover analysis)

2.Dynamic analysis method

c. Linear dynamic analysis (Response spectrum method)
d. Nonlinear dynamic analysis (Time history method)

4.RESULTS

The results obtained from linear and nonlinear analysis has been presented in the graphical and tabular form. Comparative study of results for all the considered models is discussed further.

4.1 Modal Analysis Results

The result of modal analysis is tabulated in Table 6.1. It has been found that the modal mass participation ratio of all the models is greater than 70%. Also, the time period of Model 2 and 3 is greater than Model 1 and time period of Model 5 and 6 is greater than Model 4 in both longitudinal (X) and transverse (Y) direction. This shows that the incorporation of foundation flexibility in existing model reduces the rigidity of structure and converts to flexible. In case of 5-storey building i.e. Model 1, 2 and 3, the time period increases by 0.02 sec in longitudinal and transverse direction. In case of 10-storey building i.e. Model 4, 5 and 6, the time period increases by 0.02 sec in longitudinal direction and by 0.03 sec in transverse.

Table 4.1: Modal analysis results

Models	**Vibration mode 1**		**Vibration mode 2**	
	T_X (sec)	**Modal mass participation ratio (%)**	**T_Y (sec)**	**Modal mass participation ratio (%)**
Model 1	1.58	80	1.33	80
Model 2	1.6	80	1.35	80
Model 3	1.6	80	1.35	80
Model 4	2.38	76	2.27	77
Model 5	2.4	74	2.3	76
Model 6	2.4	74	2.3	76

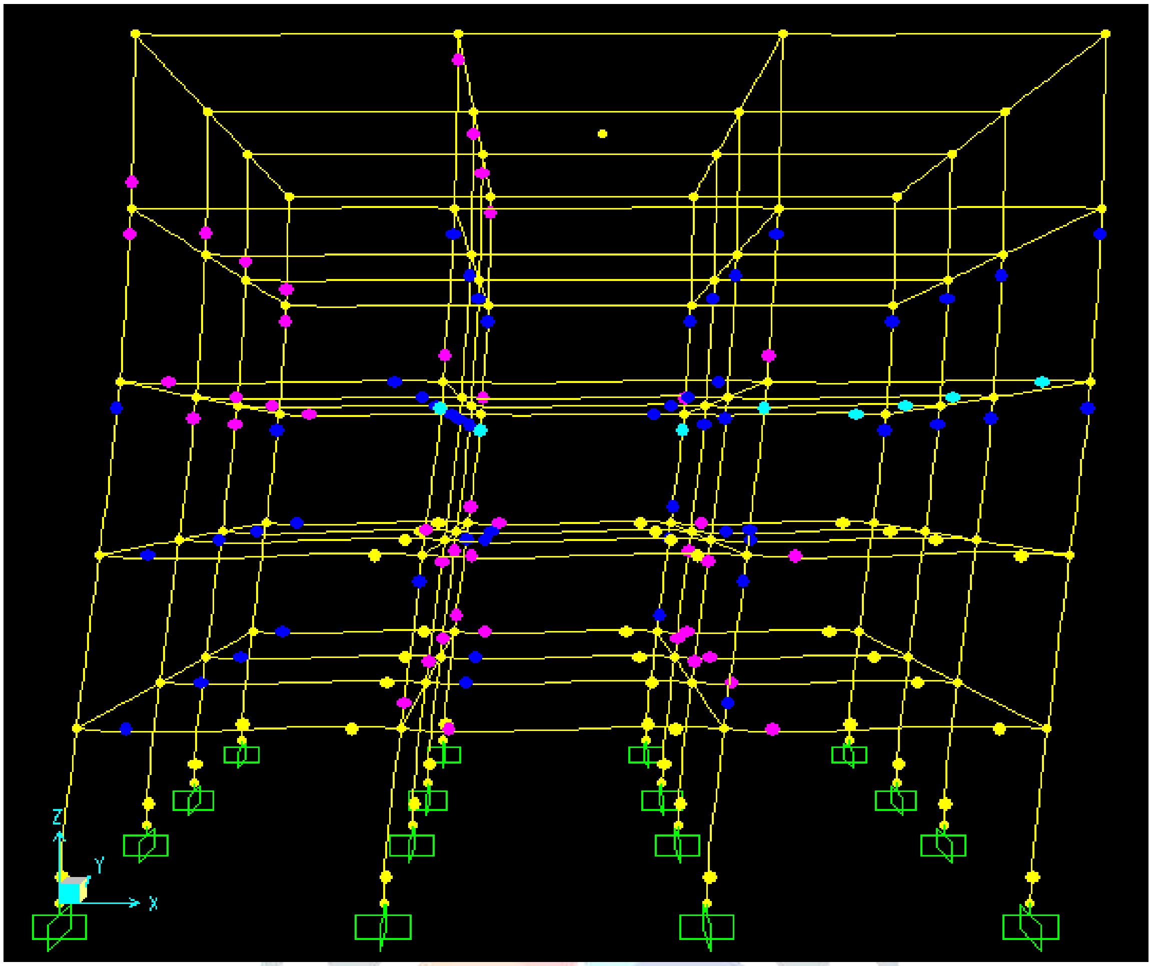

Figure 6.9: Hinge pattern of Model 1 Table 4.2: Pushover analysis results for Model 1, 2 and 3

Models	**Model 1**		**Model 2**		**Model 3**	
Direction	Long.	Trans.	Long.	Trans.	Long.	Trans.
Initial stiffness (kN/m)	4293	4892	4293	4892	2575	3200
Target Displacement (m)	0.35	0.32	0.35	0.32	0.36	0.32
Ductility	2.60	2.38	2.60	2.38	1.88	2.08
Over strength ratio	2.9	2.82	2.9	2.82	2.29	1.71
Response Reduction Factor (R)	7.5	7.30	7.5	7.30	5.75	4.01

Table 4.3: Pushover analysis results for Model 4, 5 and 6

Models	**Model 4**		**Model 5**		**Model 6**	
Direction	Long.	Trans.	Long.	Trans.	Long.	Trans.
Initial stiffness (kN/m)	7918	8783	7563	84252	5034	6243
Target Displacement (m)	0.41	0.39	0.41	0.39	0.41	0.39
Ductility	3.57	3.21	3.33	3.12	2.97	2.00
Over strength ratio	1.80	1.84	1.85	18.41	1.19	1.26
Response Reduction Factor (R)	7.16	6.68	6.88	6.31	4.04	2.76

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