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Study of Soil Structure Interaction for Framed Structures with Raft(Shallow) Foundations

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Abstract

Generally, most of the structural designers do not consider the soil structure interaction(SSI) effect, which may be detrimental or beneficial effect on a structure, during dynamic loading (e.g.earthquake forces) although the structures are supported on soil. The structures rest on ground and transfers all loads to soil or rock through foundation continuum. The soil-structure interaction is a mechanism which comprises both structural and geotechnical engineering. The soil has a number of intrinsic and extrinsic properties which can affect the behaviour of the dynamic waves passing through the soil layers. In this way, the soil or rock conditions on which structure is to be rested can significantly affect the structural response.

The effect of SSI, however, becomes prominent for heavy structures resting on relatively soft and medium soils.When a structure is subjected to a dynamic load such as earthquake excitation, there occurs interaction of the foundation and soil with structure and thus changes the ground motion which means that the movement of the whole ground structure system is influenced by type of soil as well as by the type of structure. The framed structures are designed to meet the provision of relevant codes of practice IS:1893 (Part-1)-2016 “Criteria for Earthquake Resistant Design of Structures”. The aim of this paper is to investigate the response of the structure considering the effects of soil-structure interactionon framed structures for shallow foundations resting in different types of soil such as hard and medium.Framed structures supported on fixed and flexible foundations subjected to seismic forces were analysed under different soil conditions like hard and medium. The structures were analysed by various seismic design methods using software STAAD Pro. The response of framed structure in form of Base shear, Base moment and Lateral displacement values for a framed structure are presented in this paper.

Keywords: *Dynamic load,, Soil-structure interaction, Raft foundations, Fixed base, Flexible base, Base shear, Base moment, Lateral displacement, Static Design Method, SRSS Method,, CQC method,,Capacity Spectrum Method and ABS Method.*

1. Introduction

Three factors namely source characteristics, propagation path of waves, and local soil & site conditions are responsible for the ground motions due to earthquake.The process, in which the response of the soil influences the motion of the structure and vice versa, is named as Soil-Structure Interaction (SSI).The total interaction response in dynamic structure is a combination of kinematic and inertial interaction.When a dynamic seismic wave travels through a mass of soil, it vibrates and is displaced on account of distortion of waves through soil mass. Such type of process is known as kinematic interaction. When a dynamic seismic wave passing through a mass of soil reaches at the base of a structure, it results in a vibration of a structure. This type of phenomenon is called inertial interaction.

Out of many factors, the consideration of earthquake motion effects at the location of a framed structure is the most important part of seismic design of a structure. Initially,in structural design methods, it is assumed that the movement of the foundation of a structure is equal to free-field motion of ground. For the structures resting on rock or very hard/dense soils, this assumption is adoptable only. If the structures are considered to be constructed on in case of soft soils, ground foundation motion is usually different from the free-field motion. Hence, for analysis of the structures with rigid base, input motion at the base of the structures is considered as similar to the free-field ground motion. For analysis of the structures with flexible base, some properties of soil strata responsible for variation in the dynamic earthquake motion and thus the horizontal motion of the structure, are considered and in this way,some part of energy, developed in structure due to the vibrations will be transferred to the surrounding soil and may be dissipated.

For consideration of seismic activity, the analysis of soil-structure interaction effect consists of calculating the free-field response, dynamic motion and the interaction. The effect of soil-structure interaction is considered generally by two methods named as direct method and substructure method. In direct method, the kinematic and inertial interaction is analysed by modelling the soil-structure system as one unit while in substructure method, analysis of soil structure interaction is divided into various steps and the total response of the system is obtained by summing up the response of each individual step.

2. Objectives of the Study

The objectives of the study are to find out the effect of soil-structure interaction on response parameters (Base Shear, Base Moment & Lateral Displacement) by using various seismic design methods and comparing them in case of RCC framed structures with raft foundations resting in medium and hard soils.

3. Literature Review

Several studies have been conducted by researchers on the effects of soil-structure interaction in framed structures. The studies have also been conducted on type of foundations that can be adopted for framed structures.

Anand, N. and Mightraj, C. (2010) conducted study of the seismic response of multi-storeyed framed structures to assess the effect of shear wall considering different soil stratas (hard, medium, soft). The structural behaviour by the values of Base shear, Axial force and Lateral displacement were compared between the structures. They observed that the values of lateral displacement, base shear, axial force and moment in the structural column increases as the soil nature changes from hard to medium to soft for all the structures. On the basis of this study, they concluded that the soil-structure interaction must be considered for designing structures with earthquake effect.

Behnamfar,F. and Sugimura,Y.(1999) analysed the effects of one, two, ten and twenty storeyed framed structures due to earthquake loading. They concluded that as structures come nearer, the amplification frequency enhances and the buildings reaction also enhances in some events.

Fatahi, B., Tabatabaiefar, S. and Samali, B., (2014) carried out study of the soil-structure interaction of foundations built in soft soil of multi-storeyed framed structures involving seismic effect in structure design. They considered the local site effect but did not consider the soil structure interaction effects.For this purpose, they considered three structural models of 5, 10 and 15 storey structures with two types of soil and used the four different earthquake ground motions. They analysed the structural behaviour and compared base shear. From this study, they concluded that by adopting only local site conditions and not adopting soil- structure interaction, it may affect the safety of structures founded on soft soils.

Hosseizadeh,N.A. and Nateghi,A. (2004) carried out a study on multi-storeyed framed structures due to earthquake loading. For testing purpose, soft soil was adopted as ground model specimen and steel structures models consisting of 5, 10, 15 and 20 storeys were considered. The dynamic excitation was adopted by using the two real earthquake records and they were generated by shake table. From the test results they concluded that the effect of kinematic interaction was negligible in comparison with inertial interaction. In lower buildings, the horizontal and rocking motions of foundations were the main causes of soil-structure interaction. By increasing the height of buildings, a major manifestation of SSI was a contribution of the rocking motion of the foundation. The cross-interaction has not significant effect in changing of resonance frequency of adjacent buildings.

IS:1893 (Part-1)-2016 was followed for seismic analysis of multi-storeyed framed structure.

Katzenbach,R. and Schmitt,A. (2004) conducted a study of soil-structure-foundation interaction of shallow & deep footings of multi-storeyed framed structures. At the time of the study, Deutcshe Bank's adjacent blocks built on shallow foundations were considered. A second multi-storeyed framed structure was also considered which was built on both pile-raft foundation. They concluded that combined pile-raft foundation reduces differential settlement as compared to only pile foundation.

Pandey, A.D., Kumar, P. and Sharma, S. (2011) carried out a study for the soil-structure interaction effect in on hilly structures. They chose five structures with changing support conditions using static pushover analysis. The three soil conditions, i.e. hard, medium and soft soils were considered for these structures in the analysis using SAP2000 software. The structural response parameters (base shear, base moment and lateral displacement) had been analysed for fixed base condition to compare the effect of flexible base condition. They concluded that soil structure interaction was reflected by decrease in reduction factor and with increasing time period.

Ravishankar, P. and Satyam, N. (2013) carried the study on the failures of various types of foundation due to seismic excitations and concluded that SSI effect must be considered for design of foundation of framed structures.

4. Analytical Study

The progress in the field of the earthquakes, their characteristics, structure's seismic behaviour; other factors e.g.theory of response parameters, period of vibration of the structures, ductility, etc. has resulted in the successive development of seismic design methodologies. In the present work, following analytical methods have been considered to compute the effect of soil-structure interaction:

i. Static Method (SM)
ii. Square Root of the Sum of Squares Method (SRSSM)
iii. Complete Quadratic Combination Method(CQCM)
iv. Capacity Spectrum Method (CSM)
v. Absolute Sum Method (ABSM)

For determining the response parameters to assess the SSI effect, some of available seismic design methodologies (as enumerated above) were adopted. In the study, the framed structures supported on raft foundations with fixed and flexible base subjected to seismic forces under different seismic zones (Zone-II to Zone-V) were analysed for hard and medium soils to understand the behaviour under earthquake forces. The software STAAD.pro was used in the analysis. Following parameters were considered in the study:

- Size of the building : 30m x 36m
- Type of structure : RCC framed structure (X- bays=5, Z-bays=6)
- Type of foundation: Raft
- Height of the building : 40m
- Number of storey : 10 with height of each
- storey as 4m
- Imposed load : 4 kN/m^2
- Grade of concrete: M-25
- Grade of steel: Fe-500
- Depth of foundation: 1.5m
- Beam sizes: 0.3mx0.5m
- Column Sizes: 0.5mx0.5m
- Slab thickness: 175mm
- Brick wall thickness: 230mm
- Thickness of raft: 750mm
- Unit weight of RCC: 25kN/m^3
- Unit weight of Masonry: 20kN/m^3
- Seismic zone: Zone-II to Zone-V as per IS:1893(Part-1)
- Method of seismic analysis: Response spectra as per IS:1893(Part-1)
- Damping: 5%
- Type of soil : Medium and Hard
  and Soil stiffness : 8000 kN/m²/m for medium soil and 40000 kN/m²/m for Hard soil

Elevation of the modelled multi-storeyed building with raft foundation is shown in Fig.1..A three-dimensional geometric model of the framed superstructure-raft foundation-soil system is considered for analysing its response adopting the bases of column first as fixed and then the raft foundations are considered to get the effect by adopting the bases of column as flexible. The effect of soil-structure interaction on the response of the frame is then calculated by the interaction analysis.The Discretization of structural elements of the superstructure (beam, column and slab), raft foundation and of soil elements is carried out as continuum elements for analysis purpose. Base shear, base moment and displacement in three directions in X, Y and Z are compared in this paper.

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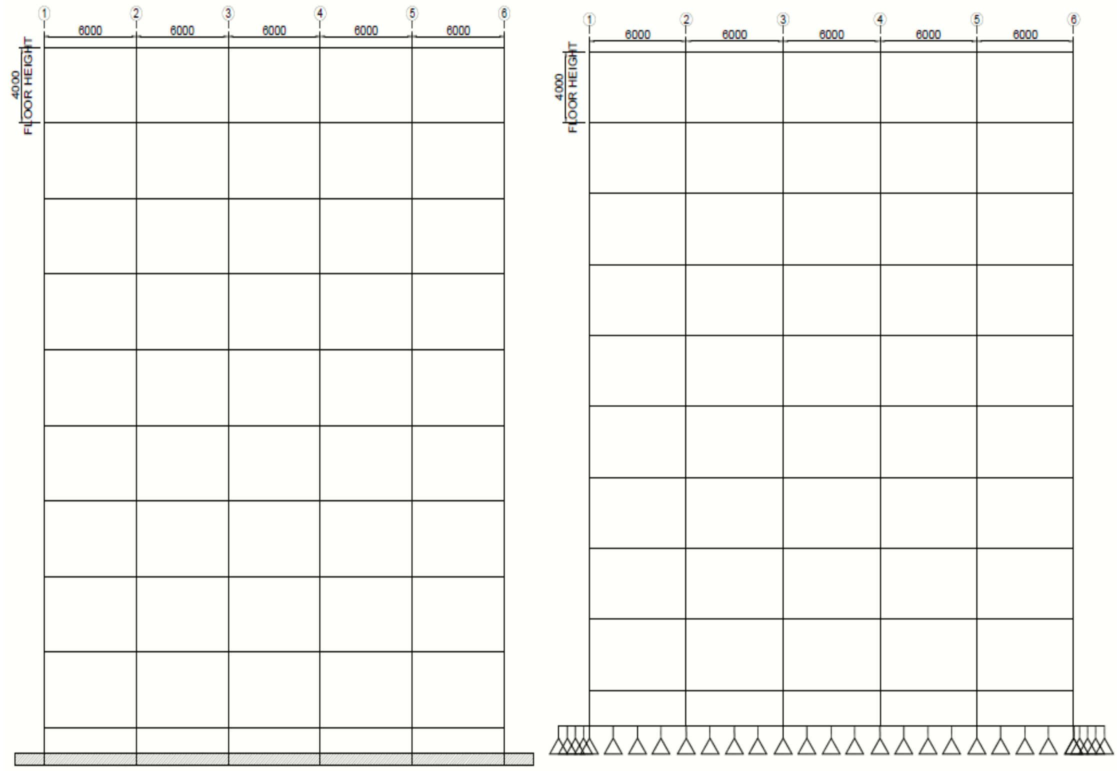

a) Fixed Base b) Flexible base

Fig.1: Elevation of the modelled multi-storeyed building with Raft foundation

5. Results and Discussion

Computed values of base shear, base moment and lateral displacement for both the types (fixed and flexible based) of building frames (situated in different seismic zones) using the above mentioned five analytical methods are plotted and shown in Fig.2 to Fig.6 for base shear; Fig.7 to Fig.11 for base moments and Fig.12 to Fig.16 for lateral displacements.

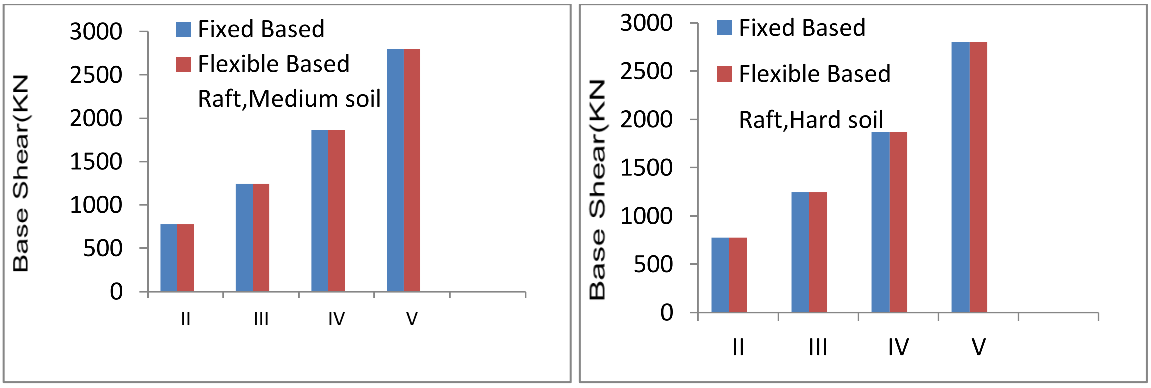

Fig.2: Effect of Soil Structure Interaction in case of Base Shear using SM

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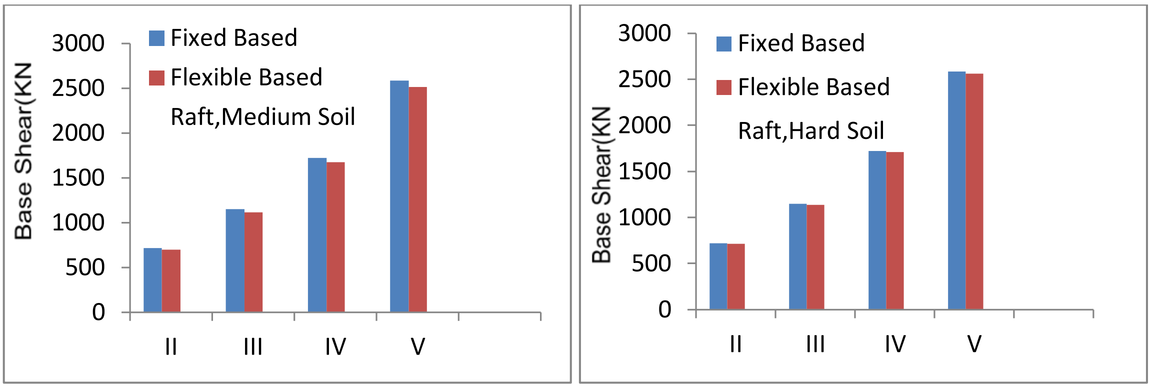

Fig.3: Effect of Soil Structure Interaction in case of Base Shear using SRSSM

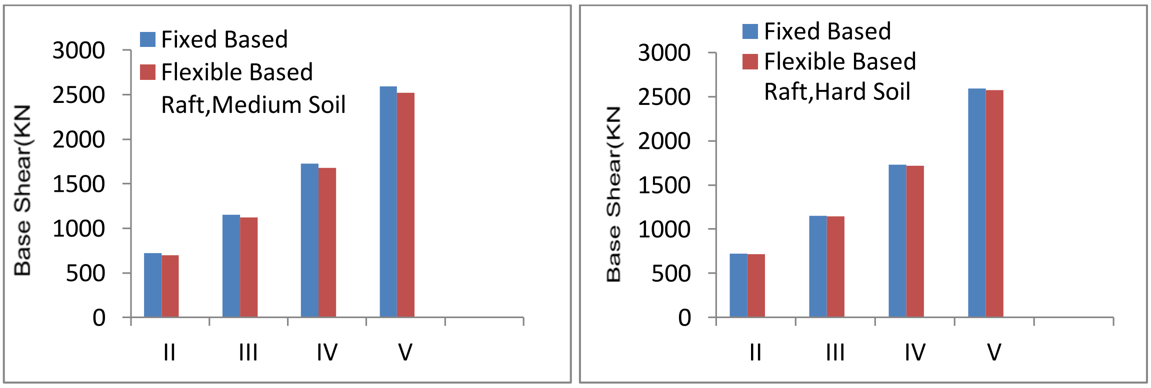

Fig.4: Effect of Soil Structure Interaction in case of Base Shear using CQCM

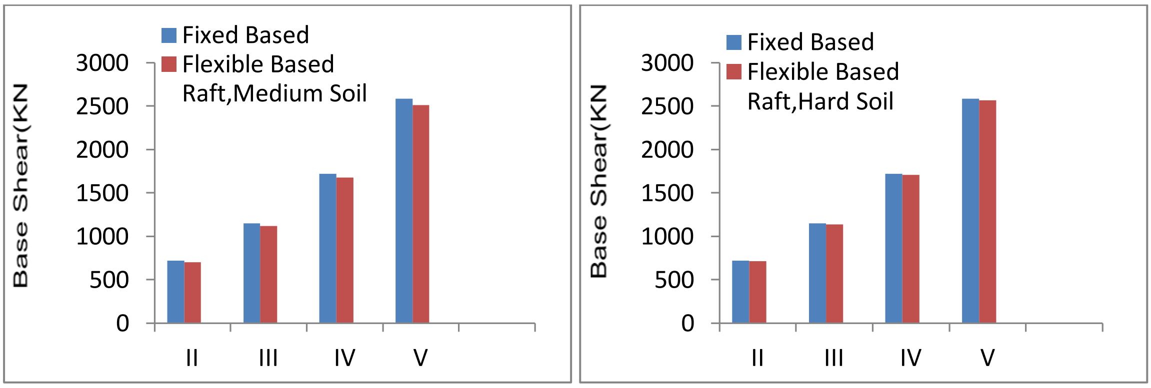

Fig.5: Effect of Soil Structure Interaction in case of Base Shear using CSM

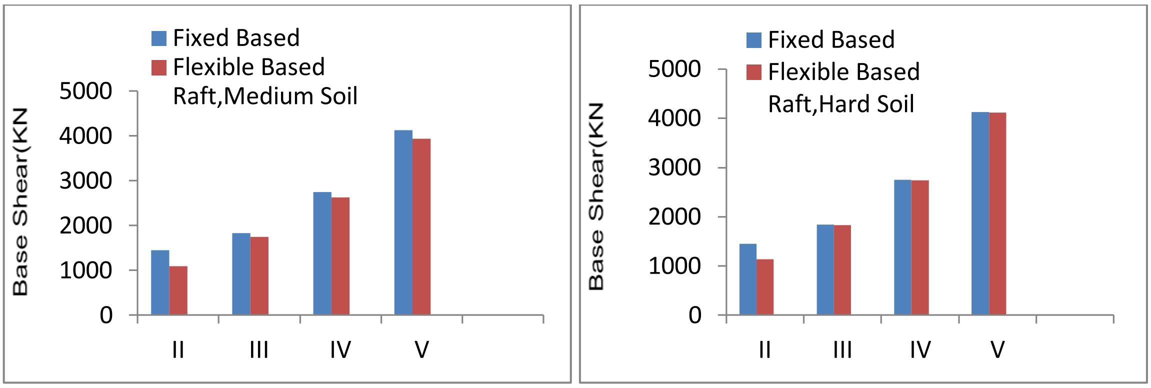

Fig.6: Effect of Soil Structure Interaction in case of Base Shear using ABSM

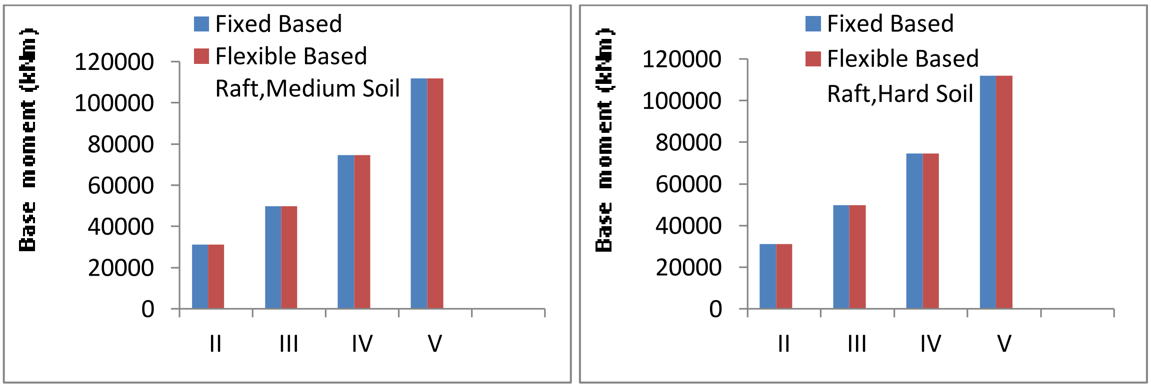

Fig.7: Effect of Soil Structure Interaction in case of Base Momentusing SM

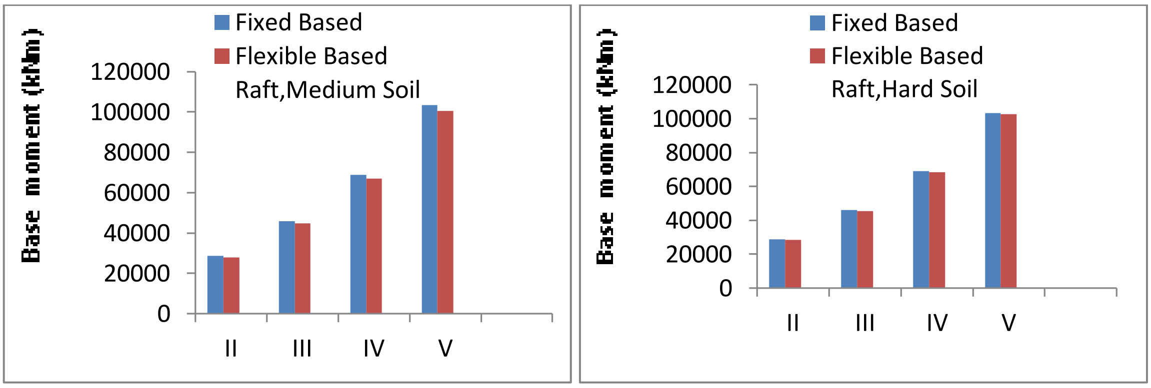

Fig.8: Effect of Soil Structure Interaction in case of Base Moment using SRSSM

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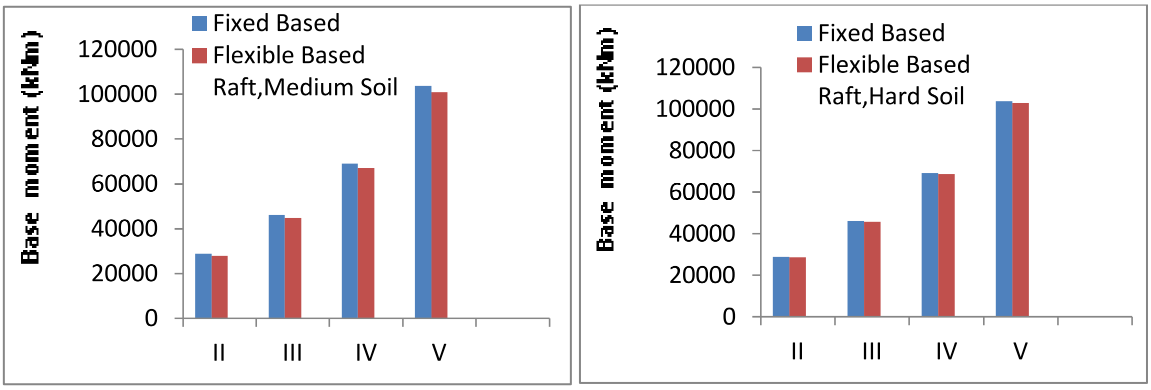

Fig.9: Effect of Soil Structure Interaction in case of Base Moment using CQCM

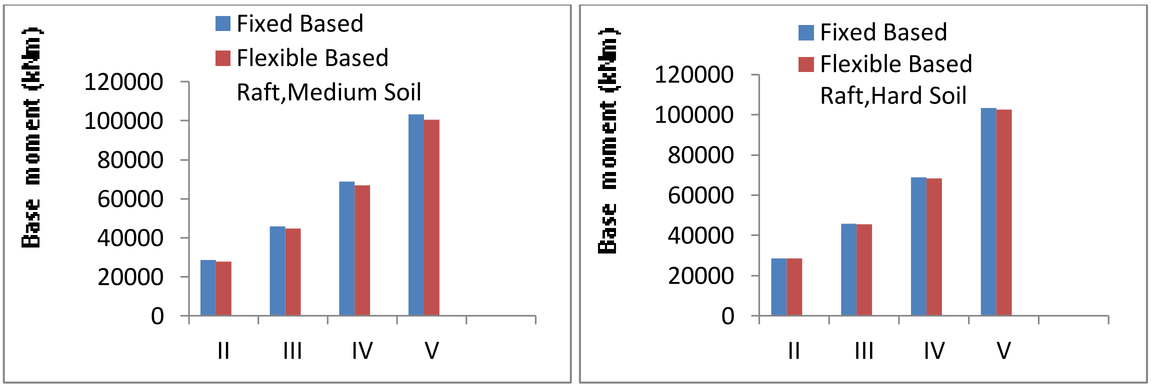

Fig.10: Effect of Soil Structure Interaction in case of Base Moment using CSM

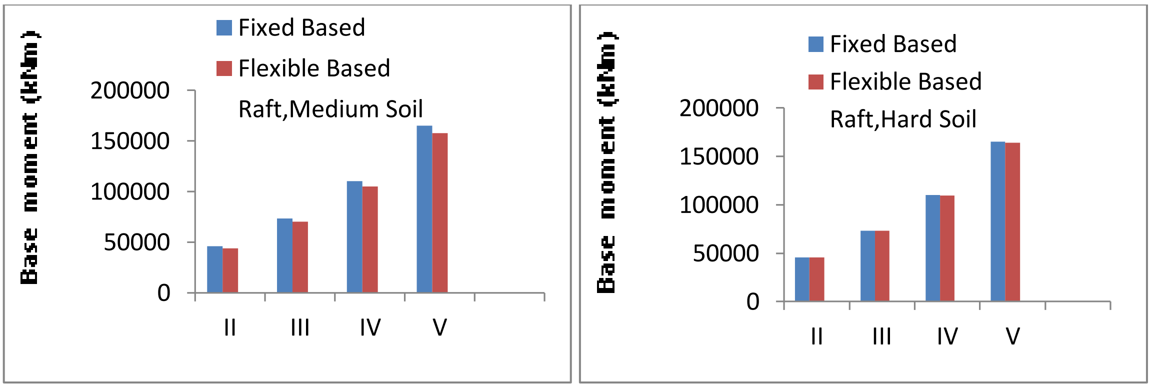

Fig.11: Effect of Soil Structure Interaction in case of Base Moment using ABSM

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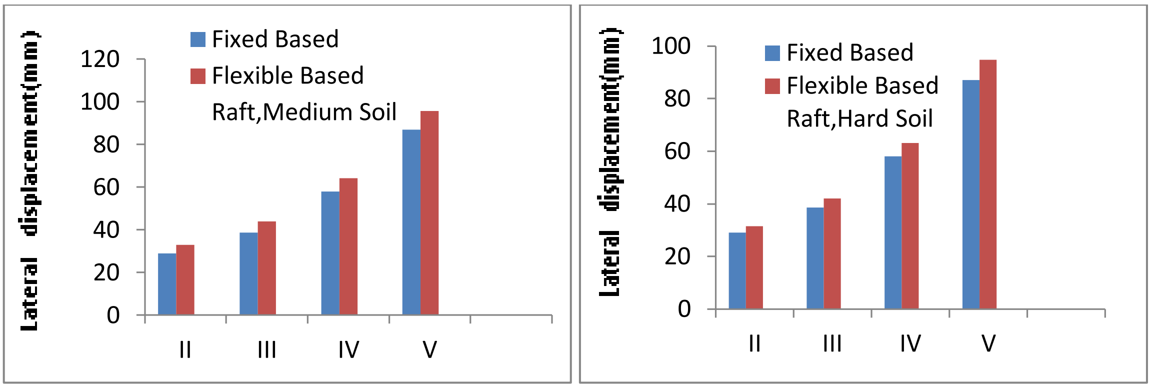

Fig.12: Effect of Soil Structure Interaction in case of Lateral displacement using SM

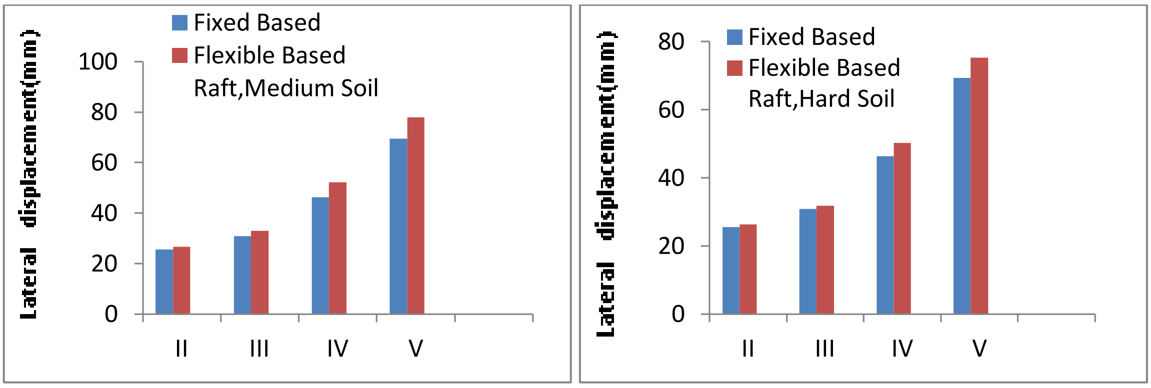

Fig.13: Effect of Soil Structure Interaction in case of lateral displacement using SRSSM

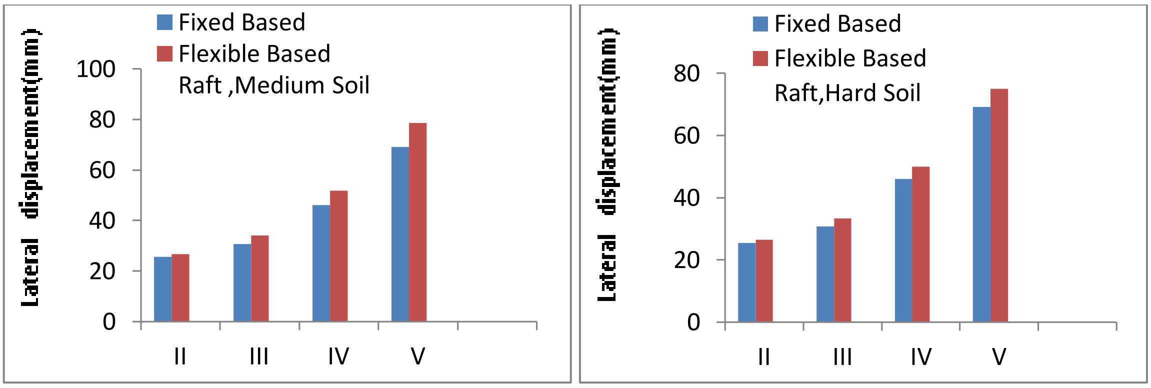

Fig.14: Effect of Soil Structure Interaction in case of lateral displacement using CQCM

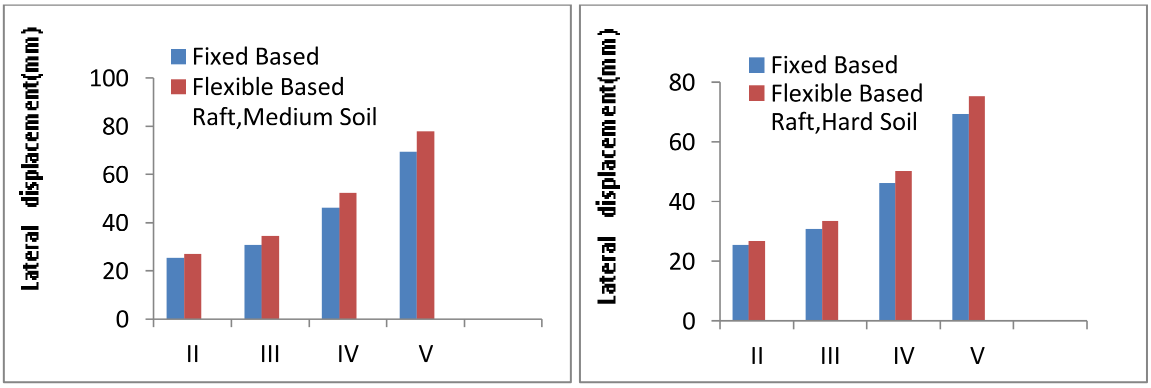

Fig.15: Effect of Soil Structure Interaction in case of lateral displacement using CSM

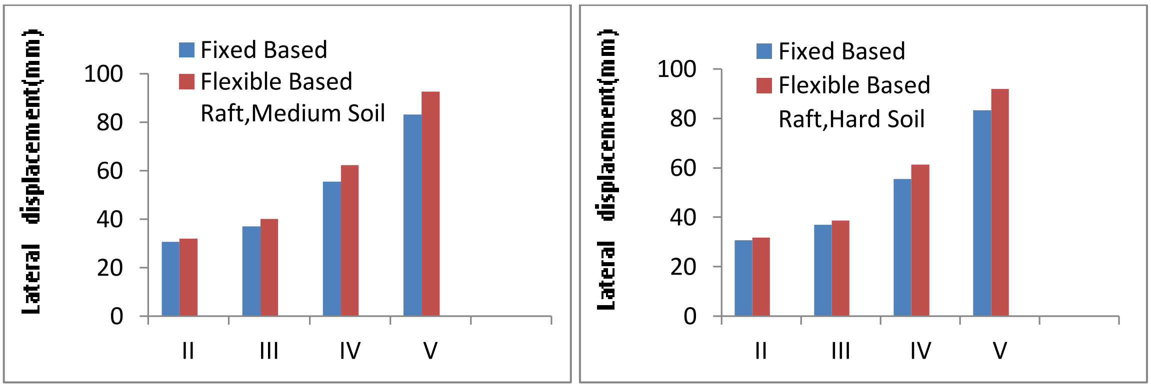

Fig.16: Effect of Soil Structure Interaction in case of lateral displacement using ABSM

It can be seen from Fig.2 to Fig.16 that the values of Base Shear, Base Moment and Lateral Displacement (at the top of frame) for framed structures with raft foundations are found to be varying in different soil conditions and seismicity, Lateral Displacements being higher for foundations founded on medium soil as compared to hard soil while Base Shear and Base Moment being higher for foundations on hard soil as compared to medium soil. These response parameters are higher for framed structures located in zone-V as compared to zone-IV and higher in zone-IV as compared to zone-III and so on. These response parameters are higher for structures with flexible base as compared to fixed base.

From the above parametric study results, carried out on a framed structure with raft footings, it is observed that top lateral displacement is very less when the framed structure bases are assumed to be fixed and increases when the effect of soil-structure interaction(flexible based) is taken into consideration. Hence, if the mechanism of soil-structure interaction is considered, it is found to increase the top lateral displacement much when compared with the displacement obtained in view of the fixed base condition.

6. Conclusions

For assessing the effect of soil-structure interaction, a ten storeyed framed structure was selected for which raft foundations in soils with both fixed and flexible bases were considered. Five methods of seismic design were adopted for analysing response parameters i.e. Base Shear, Base Moment and Lateral Displacement.These parameters were analysed for two different conditions, medium and hard, of soil strata. The seismic zones II to zone-V were considered in which framed structures were assumed to be located. The values of response parameters were analysed adopting above mentioned conditions and obtained results were compared. From the comparison of the response parameters, following conclusions were drawn:

- The values of Base Shear, Base Moment and Lateral Displacement for framed structures with raft footings are found to be varying in variable soil conditions and seismicity.
- The increase in the value of Lateral Displacement being more for foundations founded on medium soil (the variation found in the range of 4.19-13.65%) as compared to hard soil (the variation found in the range of 2.97-10.4%) while the decrease in the value of base shear and base moment being more for foundations founded on medium soil (the variation found in the range of 2.71-4.64%.%) as compared to hard soil (the variation found in the range of 0.51-0.75%) for both cases, fixed and flexible bases.
- These response parameters are higher for framed structures located in zone-V as compared to zone-IV and higher in zone-IV as compared to zone-III and so on for both cases, fixed and flexible bases. These response parameters are higher for structures with flexible base (the effect of SSI taken into consideration) as compared to fixed base. On the basis of above analysis and comparisons, it is concluded that the response parameters vary substantially, sometimes which may be detrimental to the structure, if flexibility of soil is considered, hence the effect of soil-structure interaction by incorporating stiffness of soil should be taken into consideration for designing the framed structures for considering the earthquake excitation forces.

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