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Seismic Analysis of Soil Structure Interaction on Different Structural Parameters using ETABS Software

Sandhya V[1], Shubhalakshmi B S[2]
[1*2]Assistant Professors, Department of Civil Engineering, Dayananda Sagar Academy of Technology & Management, Kanakapura road, Bengaluru -560082, Karnataka, India
Email: [1*]sandhya.v@dsatm.edu.in
Corresponding author: [2]shubhalakshmibs@gmail.com
Orcid: [2]0000-0002-4459-5566

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ABSTRACT

The purpose of the investigation is to study the behaviour and interaction between the super-structure and sub-structure by modelling the soil as Winkler Springs. The present study is performed on regular space frames of 3 bay in both x and y directions, 10 storey (3x3x10) and irregular space frames (re-entrant corner L, mass irregularity and stiffness irregularity) of 10 storey, all space frames resting on raft foundation with fixed and flexible base. Mainly three types of soil i.e. Hard, Medium and soft soil are considered for the study. The analysis is carried out in seismic Zone-V. The present analysis has been made using the Response Spectra Method of IS: 1893 -2002 (Part 1) [1]. The models are developed and analysed using ETABS V 13.2 software. The structural parameters such as natural period, storey shear, storey-drift, roof displacement, storey stiffness, axial forces and moments in columns are studied. The comparison is made between Soil Structure Interaction (SSI) and Non Soil Structure Interaction in Zone V.

Keywords: Soil Structure Interaction, Etabs, Base Shear, Natural Time Period, Displacement, Drift

INTRODUCTION

The behaviour of the structure subjected to dynamic actions is largely influenced by the foundation and the soil on which it rests **[2].** The stresses and deformations in the supporting soil are induced due to the base shear and moment generated due to lateral forces. These deformations lead to the change of structural response. The dynamic inter-relationship where the response of soil influences the motion of structure and the response of structure influences the motion of soil is called soil-structure interaction. Seismic response of buildings is found to be highly complicated because of the non-linear behaviour of soil when earthquake occurs **[3].** Generally in the seismic design, soil-structure interaction is not considered and the dynamic behaviour of the structure is assessed by assuming a fixed or a hinged base **[4].** Moreover in the conventional method of design of raft foundation, flexibility of soil mass is neglected which is likely to affect the performance of the structure. Because of the complexities involved in the analysis procedures the code based method of seismic analysis is hardly based on soil structure interaction **[5].**

Earthquake is one of the most destructive natural disasters. Earthquake results in a number of hazards such as faults, ground tilting, liquefaction, landslides, tsunami etc. The damages depend on various parameters such as soil type, earthquake intensity, quality of construction, duration and frequency of ground motion etc **[6].** During an earthquake the primary damages occur to the structures resulting in casualties and economical loss**.** Therefore, structure has to be designed to resist moderate earthquake forces without causing much of structural damage and severe earthquakes without resulting in collapse of structures **[7].**

LITERATURE REVIEW

Boussinesq (1885) represented soil media as a continuous, semi-infinite, isotropic, homogeneous, linear elastic solid for analysis under static loading using theory of elasticity **[8].** The loading was taken as concentrated, Boussinesq found the vertical stiffness K_z and the stress distribution σ_z for a rigid circular plate under centred vertical load under the assumption of smooth contact surface **[9].** Bowles (1977), made a comparison of the results of the field settlements with those computed using an unconfined compressive test data indicate that the laboratory Es value underestimate the field Es by considerable amount **[10].** Allowable soil pressure was considered based on some maximum amount of deformation including the factor of safety, thus evaluating the modulus of sub grade reaction.

Ahmed Abdelraheem Farghaly and Hamdy Hessain Ahmed [11] analysed a 3, 6, 12 storey building for SSI using time history analysis of El Centro earthquake of 0.25g (PGA) earthquake. He modelled the structures in SAP2000 with isolated footing and raft foundation and calculated the time history of displacement and time history of base shear. He found unfavourable effects on the top displacement response and performance. Compared to fixed base columns, the column base shear was found to reduce to 70% for high rise buildings and 30% for low rise buildings. The axial force was found to decrease by 20% for heavier buildings (12 storey). **Er.Puneet Sharma et.al [12] and H.K. Chinmayi & B.R Jayalekshmi [13]** performed Interaction analysis on asymmetric RC building frame with shear walls. Structure was analysed with and without incorporating the effects of shear wall and SSI and soil was modelled as Winkler model using elastic half space approach. There was considerable variation in member forces when SSI and shear walls were considered. The column moments were found to decrease with increase in flexibility. **Anand N et. al [14] and Shehata E Abdel Raheem et. al [15]** studied the seismic behaviour of RCC shear wall under different soil conditions. One to fifteen storey building space frame with and without shear wall were analysed and designed using ETABS. Hard, medium and soft soils were considered. It was found that up to three storeys the base shear was found to be the same for all types of soils. Above three storeys the base shear, the lateral drift, the moments in the columns and axial force were found to increase when the soil type changes from hard to medium and medium to soft. The percentage decrease in base shear varies from 0 to 26.5% when the soil type changes from medium to hard and 0 to 18.7% when the soil type changes from soft to medium. **Ayman Ismail [16]** studied the effect of Soil-Structure Interaction on natural period of low rise building with isolated footing and raft foundation using SAP software. It was found that the natural period increased when the soil become soft i.e. dependent on elasticity of soil. The responses obtained for isolated footing and raft foundation showed no variation. The column base shear was also found to reduce when interaction effect was considered. **A.Krishnamoorthy & Anitha S [17]** studied the effects of SSI on the responses of a plane frame subjected to four earthquake ground accelerations. Soil was modelled as elastic continuum using FEM. They found that the responses such as base shear and bending moment remained the same for hard soil and decreased for soft soil. For medium soil depending on the earthquake acceleration it either decreased or increased leading to the conclusion that SSI may be beneficial or detrimental depending on the type of soil and need to be considered for realistic analysis.

SUMMARY

In Conventional methods of structural analysis, the effect of soil compressibility medium is ignored for practical design. This leads to an an under estimation of forces in members causing unsafe design. Soil Structure Interaction has to be considered for the actual estimation of design. Soil-structure interaction can be ignored if the structure is very flexible or differential settlement under the columns is negligibly small. Since the last few decades considerable amount of research has been carried out on soil flexibility

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both on static as well as dynamic behaviour of structures. Significant analytical and experimental research has been extended in understanding the behaviour of soil on superstructure under the applied loads. From the literature review it is observed that only limited studies have been made on the soil-structure interaction effect for high rise regular and irregular structures. The comprehensive study of building with Raft foundation considering soil flexibility is limited. Hence an attempt has been made to study the Soil-Structure Interaction of regular and irregular frames on raft foundation.

METHODOLOGY

Analysis is carried out in seismic Zone V. A 3D space frame, symmetrical in plan and geometry is analysed by varying the support conditions. A 3D space frame with plan irregularity i.e. Re-entrant Corner (L-shaped) irregularity is analysed for various support conditions **[18].** A 3D space frame with Mass Irregularity is analysed for various support conditions. A 3D space frame with Stiffness Irregularity is analysed for various support conditions. Method of Analysis adopted are Linear Static Analysis and Linear Dynamic Analysis (Equivalent lateral force and Response spectrum method) **[19].** Analysis is done Using ETABS V13.2.2

The analysis of 3D bare frame structures, Regular and Irregular with raft Foundation resting on Hard, Medium and Soft soils subjected to seismic load as per the seismic code IS: 1893-2002 (Part 1) **[1]** are carried out.

Table 1 Idealization of Structure

Component	Description	Data
Frames	Number of storeys	10
	Bays in X direction	3
	Bays in Y direction	3
	Ht of Storey	3.2m
	Bay width in X direction	4m
	Bay width in Y direction	4m
	Beam Dimension	0.23 m x 0.45 m
	Column Dimension	0.23 m x 0.6 m
	Slab Thickness	0.150 m
	Es	$2x10^8$ N/mm²
	Ec	$25x10^6$ N/mm²
	Density – RCC	25 KN/m³
	Density - steel HYSD 415	76.97 KN/m³
	Grade of Concrete	M30
	LL on Floor	3 KN/m²
	LL on Roof	1.5 KN/m²
	For Mass Irregularity LL on 4th and 8th Floor	8 KN/m²
	For Stiffness Irregularity, Base storey height	6.4m
Earthquake Data	Zone Factor	V
	Importance Factor	1
	Response Reduction Factor	5

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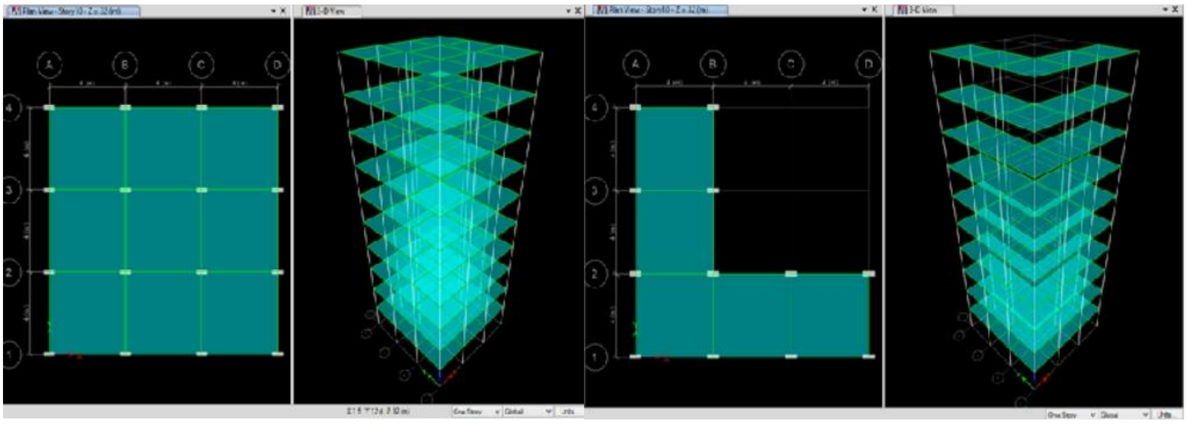


Figure 1 ETABS Model of a Regular 10 Storey Frame in Plan and 3D View and L Shaped Re-entrant Corner 10 Storey Frame

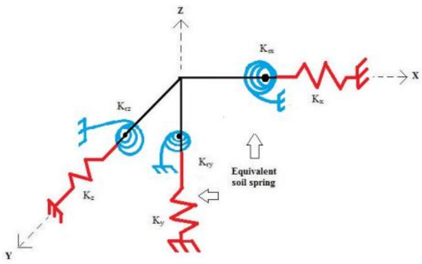


Figure 2 Equivalent Spring Stiffness

RESULTS AND DISCUSSIONS

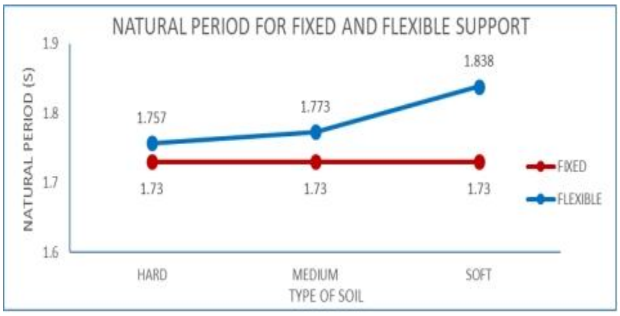
The seismic analysis results carried out as per the methodology mentioned with relevant figures and tables.
The analysis of structure soil system was done by considering soil as equivalent spring. (Winkler Model), by Response Spectrum Method of IS1893:2002 (Part 1) **[1]**, is carried out using ETABS V13.2.2. The comparative results of the structural responses between the fixed and flexible support conditions are presented below.

The following seven parameters of 3 bay x 3 bay regular and irregular space frame with raft foundation are studied.
Fundamental Natural Period, Storey Shear, Storey Stiffness, Max Lateral Displacement, Storey Drift, Axial force in columns, Column moments **[20].**
The variations of these responses are studied as a function of the following parameters namely.

1 Zone Factor V mentioned in IS 1893:2002 (part1) **[1]**
2 Soil type (type I, type II and type III as hard, medium and soft resp) as per IS 1893:2002(part 1) **[1]**
3 No of storeys considered - 10
4 Models considered for the analysis are
(i) Model 1 - regular frame
(ii) Model 2 - L shaped re-entrant corner,
(iii) Model 3 - frame with mass irregularity
(iv) Model 4 - frame with stiffness irregularity.
5 Type of foundation used – Raft foundation

- For all the models, there is no change in natural period as the zone value changes from zone III to zone V and also when soil type is changed from hard to medium to soft.

- The percentage variation remains the same irrespective of zone factor for interaction analysis and is maximum for soft soil and minimum for hard soil.
- Of all the models, natural period is more in re-entrant corner structure. The percentage variation is 13.28% for soft soil compared to 4.99% for regular structure and is least for structure with stiffness irregularity.
- For all the models, compared to non-interaction analysis base shear is reduced in interaction analysis.
- Base shear is increased with increase in zone severity.
- Percentage variation of interaction analysis with respect to non-interaction analysis remains constant across zones.
- Percentage reduction is maximum for re-entrant corner structure (10.81%) compared to regular structure (4.7) in soft soil.
- Displacement increases with flexibility of soil i.e. decrease in shear modulus of soil.
- Displacement increases with severity of zone.
- Displacement is more for re-entrant corner structure and least for regular structure.
- The percentage variation of interaction analysis with respect to non-interaction analysis is maximum for soft soil for all the models and it is maximum in re-entrant corner structure (9.25%) and least for regular structure (4.38%).
- Irrespective of the type of structure there is an overall reduction in axial forces in the base columns from fixed base to flexible base.
- Axial forces are increased as the soil changes from hard to soft.
- There is a only marginal decrease in column loads as severity of zone decreases i.e. zone V to zone III.
- Maximum reduction in axial loads is observed in soft soil with flexible base.
- Variations in column moments are more significant in re-entrant corner compared to all the other models and least for stiffness irregular structure.
- Irrespective of the type of structure there is an overall reduction in column moments from fixed base to flexible base.
- Column moments increased as the soil changes from hard to soft.
- Column moments decreased as severity of zone decreases i.e. zone V to zone III.
- Maximum reduction is observed in soft soil.
- Variations in column moments are more significant in re-entrant corner compared to all the other models and least for regular structure.



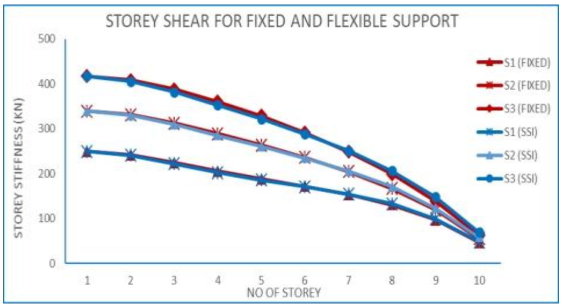


Figure 3 Natural Period and Storey Shear for a Re-entrant corner Frame with Fixed and raft foundation

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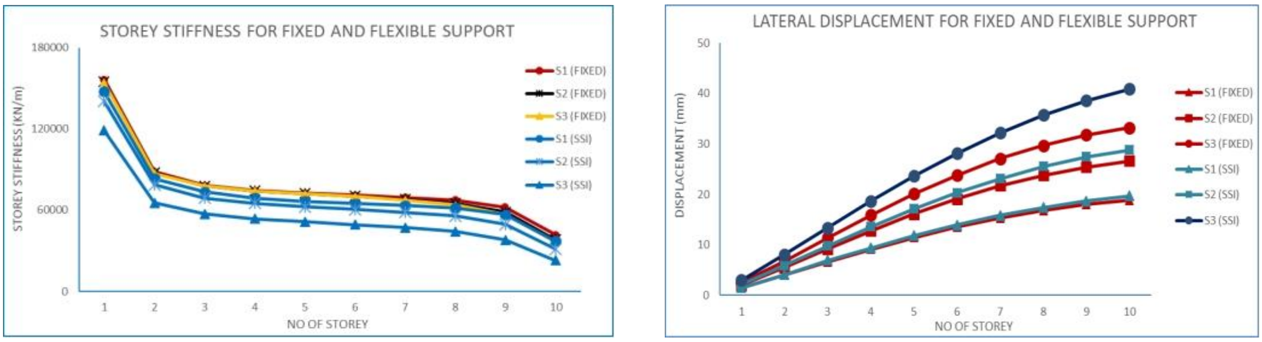

Figure 4 Storey Stiffness and Lateral Displacement of an Irregular Re-entrant Corner Frame with Fixed and Raft Foundation

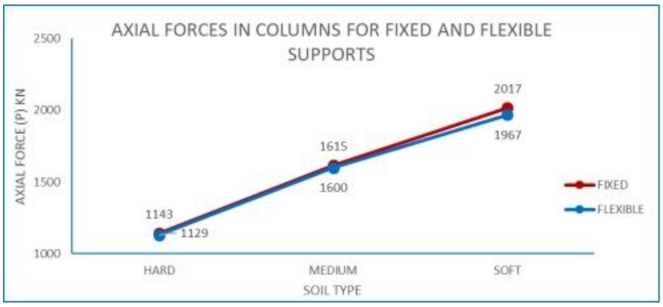

Figure 5 Axial Forces in Columns of a L Shaped Irregular Frame

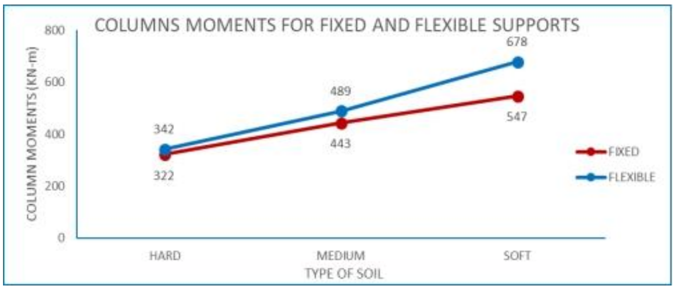

Figure 6 Column Moments of a Regular Frame with Fixed and Raft Foundation

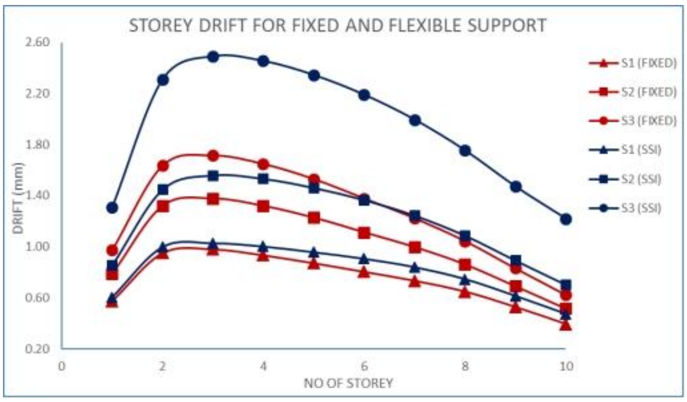

Figure 7 Storey Drift of an Irregular Re-entrant Corner Building with Fixed and Raft Foundation

CONCLUSION

The following Conclusions are drawn from the work done.

- The present study makes an effort to evaluate the effect of soil flexibility on seismic response of regular and irregular structures on seismic zones Zone V and Zone III on hard, medium and soft soil resting on raft foundation. The study also extends to find the effect of soil flexibility on important structural parameters like natural time period, base shear, storey drift, roof displacement, axial forces and moments in columns.
- Natural period increases from hard to soft soil when SSI is considered. This is because the modulus of elasticity or shear modulus of soil is decreased when soil changes from hard to medium and medium to soft. Flexibility of the structure is increased with decrease in shear modulus.
- Percentage variation of flexible base compared to fixed base is more in soft soil due to its low shear modulus and is more predominant for re-entrant corner structures due to its increased flexibility.
- Percentage increase of interaction analysis compared to non-interaction analysis is more for soft soil in the upper storey due to its increased flexibility. SSI effect is more in re-entrant corner frame due to increased flexibility as a result of lengthening of natural period.
- Percentage decrease in storey stiffness of flexible base when compared to fixed base is maximum for soft soil and it is maximum for re-entrant corner structures. This is due to the increased flexibility of re-entrant corner frames due to increased natural period.
- Drift also increases with flexibility of soil i.e. decrease in shear modulus of soil and increases with severity of zones.
- Irrespective of the type of structure there is an overall reduction in axial forces in the base columns from fixed base to flexible base
- Axial forces are increased as the soil changes from hard to soft.
- There is a only marginal decrease in column loads as severity of zone decreases.
- Column moments increases as the soil changes from hard to soft and there is an overall reduction in column moments from fixed base to flexible base and maximum reduction is observed in soft soil
- Considering all the four models the drift and displacement are more for Re-entrant corner structures when SSI is considered and least for stiffness irregular structure.

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