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Effect of Soil -Structure Interaction on Seismic Analysis of Structures

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ABSTRACT

In the conventional method of analysis flexibility of soil mass is ignored which is likely to affect the performance of structure. In the proposed study an attempt is made to understand the effect of soil flexibility on the performance of building frames resting on raft foundation. As the conventional analysis method does not address the soil-structure interaction explicitly, the effect of soil structure interaction on reinforced concrete structure is studied using response spectrum method. Three different storey structures on four types of soil, with or without soil interaction are modelled and subjected to earthquake. Buildings resting on raft foundation compared between fixed base and flexible base. Dynamic analysis is carried out using the Response Spectra of IS: 1893-2002. The soil flexibility is incorporated in the analysis using Winkler approach (spring model). Etabs 2016 is used for developing these models. The effect of SSI on various structural parameters i.e. natural time period, base shear, lateral displacement, roof displacement, member forces are studied and discussed. The study reveals that the SSI significantly affects the response of the structure. The results led to a criterion indicating that considering SSI in seismic design, for buildings on medium and soft soil is essential.

Keywords: Soil Structure Interaction, Seismic Response, Response Spectrum, Raft Footing, Winkler Method, Etabs 2016.

I. INTRODUCTION

1.1 General:

Earthquakes are among the most devastating natural disasters humans have faced over history. Since civilization has developed, and demand for all kind of buildings and other type of structures has increased, with the development of civilization during the last century, buildings and, infrastructure have increased exponentially in number and size, which inherently has increased the risks related to earthquakes. Even over the past few years direct and indirect effects by earthquake results in thousands of fatalities when affecting densely populated areas like in Southern Sumatra - Indonesia (2009), Haiti Region (2010), Southern Qinghai - China (2010) and Japan (2011), with 1,117; 316,000; 2,968 and 20,352 fatalities respectively.

Indian sub-continent is highly vulnerable to natural disasters like earthquake, draughts, floods etc. In October 2005, a 7.6-magnitude earthquake devastated Kashmir, Pakistan, toppling buildings and originating landslides that buried more than 85000 people. The 2001 Bhuj earthquake was the first instance of an Indian earthquake causing collapses of modern multi-storey buildings, since the earlier earthquakes had occurred in rural or semiurban settings. Approximately 14,000 deaths in this earthquake created unprecedented awareness amongst professionals, academics and the general public, and opened up a number of windows of opportunity for capacity-building for seismic safety.

Since the design of earthquake resistant buildings started assumption made that supports are fixed and traditionally, soil-structure interaction effects were ignored in seismic design of structures, since they were believed to only have favourable effects. The lengthening of the period shifts the structure response to the spectral branch of lower accelerations which implies a reduction of inertia forces in the structure. However, along modern response spectrum analysis principles soil structure interaction effects are recognized to not necessarily have beneficial but even may have very detrimental effects for the response of the superstructure Gazetas [1], [2], Mylonakis & Gazetas [3]. The global trend shift towards Earthquake resistance design in the seismic engineering branch implies an increasing focus on displacements rather than on inertia forces, which makes proper consideration of soil structure interaction a critical factor. Additionally, the failure of foundations their selves and possible effects of soil failure have become a more important issue in seismic design. The effects of soil structure interaction have been subjective to research for about half a century, but are still under discussion. Code provisions relating to soil-structure interaction nowadays are still very limited and straight forward procedures to account for soil structure interaction in design are not included in most codes. Simplified dynamic analysis methods are commonly used as a starting point, where the role and possible effects of soil-structure interaction in the response often remain unclear.

In earthquake engineering practice, it is well-recognized now that the foundation material on which a building is constructed may interact dynamically with the structure during its response to earthquake excitation to the extent that the maximum stresses and deflections in the system are modified significantly from the values that would have been developed if it were on a rigid foundation. However, forty years ago when the methods of analysis of structural response to earthquake motions were just beginning to be developed, such interaction effects were considered to be of little consequence, and hence were ignored.

1.2 Scope:

On the contrary research activities at universities all over the world already are far ahead, providing a variety of knowledge in this field. The connection with engineering practice however appears to be somehow lost, which forms a problem for practicing engineers dealing with design of structures in seismically active areas. This study focuses on the effect of soil structure interaction on seismic response of reinforced concrete building structure. The present study is concentrated at a R.C.C. building models, those typically meets the conditions regarding raft foundation in different types of soil.

1.3 Objectives:

The objectives of proposed work are as follows,

1. To study soil-structure interaction effects on seismic behaviour of reinforced concrete frame structure loaded and designed according to the Indian Standard Codes.
2. To assess the effect of soil structure interaction on various dynamic properties of R. C. frame such as natural time period, base shear, roof displacement, beam moment, column moment, etc.

3. To study the effect of soil structure interaction on fixed and flexible bases. To study effect of soil structure interaction of R. C. frame structure on different types of soil.

II.BACKGROUND

Soil Structure Interaction (SSI) is an interdisciplinary field of endeavour. It lies at the intersection of soil and structural mechanics, soil and structural dynamics, earthquake engineering, geophysics and Geo-mechanics, material science, computational and numerical methods, and other diverse technical disciplines. Its origins trace back to the late 19th century, evolving and maturing gradually in the ensuing decades and during the first half of the 20th century. SSI progressed rapidly in the second half stimulated mainly by the needs of the nuclear power and offshore industries, by the debut of powerful computers and simulation tools such as finite elements, and by the desire for improvements in seismic safety.

The importance of soil-structure interaction both for static and dynamic loads has been well established and the related literature covers at least 30 years of computational and analytical approaches for solving soil–structure interaction problems. Since 1990s, great effort has been made for substituting the classical methods of design by the new ones based on the concept of performance-based seismic design. In addition, the necessity of estimating the vulnerability of existing structures and assessing reliable methods for their retrofit have greatly attracted the attention of the engineering community in most seismic zones throughout the world.

III. LITERATURE REVIEW

If the structure is supported on soft soil deposit, the inability of the foundation to conform to the deformations of the free field motion would cause the motion of the base of the structure to deviate from the free field motion. Also the dynamic response of the structure itself would induce deformation of the supporting soil. This process, in which the response of the soil influences the motion of the structure and the response of the structure influences the motion of the soil, is referred as Soil Structure Interaction.

Gazetas [1] presented a complete set of algebraic formulas and dimensionless charts for readily computing the dynamic stiffness (K) and damping coefficient (C) of foundations harmonically oscillating on/in a homogeneous half-space. They considered possible modes of vibration, a realistic range of Poisson's ratios, and a practically sufficient range of oscillation frequencies. The foundations have a rigid base mat of any realistic solid geometric shape. The embedded foundations were prismatic, having a sidewall-soil contact surface of height d, which may be only a fraction of the embedment depth D. Two numerical examples illustrate the use of the formulas and charts and elucidate the role of foundation shape and degree of embedment on radiation damping for various modes of vibration. A companion paper Gazetas presents supporting experimental evidence from model tests. The two papers aim at encouraging the practicing engineer to make use of results obtained with state- of-the-art formulations, when studying the dynamic response of foundations.

Wolf et al. [4] surveyed and classified computational approaches in soil- structure interaction. Comparison of time- and frequency-domain analyses was also made. The first classification uses as criterion the behaviour (linear or nonlinear) of the structure and of the unbounded soil which determines for the analysis either the familiar time domain. The originally developed for machine foundation calculations. The second classification distinguished between the direct method and the substructure method which do not necessarily lead to identical results within each method. However, the various procedures are mathematically equivalent. In the substructure method the dynamic stiffness representing the interaction forces of the unbounded soil is determined based on the boundary element method in the time or frequency domain. In the latter case various so-called realizations in the time domain are distinguished using the extent of the frequency-domain calculations as a criterion. The temporal global coupling of the interaction force-displacement relationship can be eliminated with these realizations.

Viladkar et al. [5] presented a new approach for the physical and material modelling of a space frame-raft-soil system. The beams and columns of the superstructure is discretized by a modified Timoshenko beam bending element with six degrees of freedom per node and structural slabs and raft are discretized by a modified Mindlin's plate bending element with five degrees of freedom per node. The soil media is represented by the coupled finite-infinite elements with three degrees of freedom per node. The constitutive modelling involves the use of the hyperbolic model to account for the soil nonlinearity. They compared the behaviour of the space frame-raft-soil system under the linear and nonlinear interaction.

Dobry et al. [6] describes analysis procedures and system identification techniques for evaluating inertial SSI effects on seismic structural response. The analysis procedures are similar to provisions in some building codes but incorporate more rationally the influence of site conditions and the foundation embedment, flexibility, and shape on foundation impedance. Implementation of analysis procedures and system identification techniques was illustrated using a building shaken during the 1994 Northridge earthquake. The analysis procedures predict the observed SSI effects accurately.

IV.RESEARCH METHODOLOGY

The following has been adopted for the execution of the dissertation work.

1) Foundations are considered to be resting on four different types of soil such as loose soil, medium dense soil, dense soil and hard soil.

2) Raft foundation is assumed in all the models.

3) Soil spring stiffness are being assigned to raft foundation as point spring and soil stiffness are given in all six degrees of freedom.

4) Soil properties such as Shear wave velocity, Poissons ratio, Density of soil and shear modulus are taken from Bowles [9].

5) Building models designed and checked for loads as per IS: 456:2002 [7]

6) Total 16 numbers of models have been analyzed to fulfil the objectives.

7) Analysis has been carried out for different storeys (4, 8, 12) considering fixed support and springs support representing different soil conditions.

8) Analysis has been carried out considering seismic zone IV for all models (soil conditions)

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9) Results have been demonstrated in the form of tables and graphs.

10) Finally, the seismic performance of all these R.C. buildings has been compared and conclusions have been drawn.

V.MODELLING

5.1 Statement of Problem:

In this study various numbers of structures are modelled and analyzed which are same in plan but vary in total height of building i.e. number of story variations. All columns, beams and structural slabs were included in the model of each building**.** All models are subjected to dynamic analysis with the help of ETABS 2016. The dimension of all the beams and columns are design according to IS 456-2000 .The building is designed to resist dead load, live load & seismic load.

As per IS 1893:2002 [8] the following seismic parameters were used to calculate the seismic forces and design.

Zone factor = 0.16 (Zone IV)

Importance factor = 1.0 (Residential Building)

Response reduction factor = 5 Special moment resting frame (SMRF)

The other detailed description is as follows:

1. Size of Building: 12m X 12m.
2. Floor to floor height: 3.0 m
3. Parapet height: 1 m
4. Slab thickness: 150 mm
5. Wall thickness: 230 mm
6. Grade of concrete (Beam): M20
7. Grade of concrete (Column):M25
8. Grade of steel: Fe 415
9. Density of concrete: 25 kN/m3
10. Density of masonry wall: 20 kN/m3
11. Modulus of elasticity for concrete: 22360680 k.N/m2

Plan of building is shown below fig. 5.1 and details of beams and column sizes are shown in table 5.2

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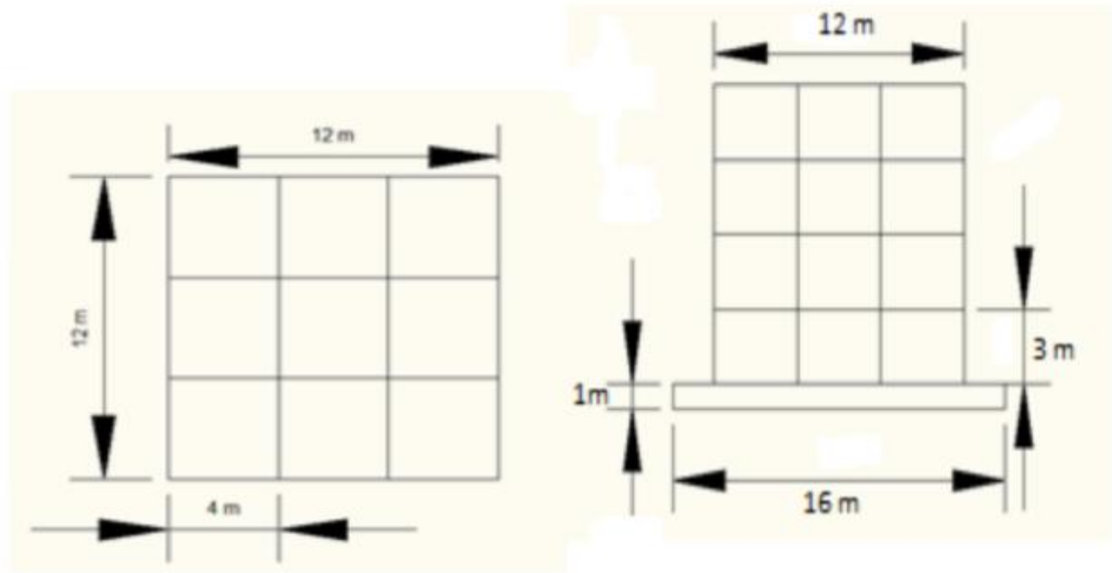

Plan Elevation

Fig. 5.1

Table 5.1 Properties of soil

.	ata	odulus of Elasticity k.N/m2	issons Ratio	ear Modulus G	it Weight N/m3
	ft Soil	000	5	375	
	dium Soil	000		000	
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	cky(Basalt)	000000		50000	
	ed				

Properties are taken from Bowles [7] as most of the researchers consider this as standard

Table 5.2 Sizes of beams and column

No. of storeys	Column size(mm)	Beam size(mm)
4 Storey	230x600	230x600
8 Storey	300x1000	230x600
12 Storey	300x1200	230x600
16 Storey	300x1500	300x750

Table.5.3. Spring stiffness formulae (Gazetas)

Degrees of freedom	Stiffness of equivalent soil spring
Vertical	[2GL/(1-ν)](0.73+1.54χ^0.75) with χ = Ab/4L^2
Horizontal (lateral direction)	[2GL/(2-ν)](2+2.50χ^0.85) with χ = Ab/4L^2
Horizontal (longitudinal direction)	[2GL/(2-ν)](2+2.50χ^0.85)-[0.2/(0.75-ν)]GL[1-(B/L)] with χ = Ab /4L2
Rocking (about longitudinal)	[G/(1-ν)]Ibx0.75(L/B)^0.25[2.4+0.5(B/L)]
Rocking (about lateral)	[G/(1-ν)]Iby^0.75(L/B)^0.15
Torsion	3.5G Ibz^0.75(B/L)^0.4(Ibz /B4)^0.2

Table.5.3. Spring stiffness formulae (Gazetas)

VI. RESULTS

A. Time Period of Modes

In ETABS 2016 there is provision to select number of modes for modal analysis. However, default 12 modes are taken for study. Graph in fig. 4.1 shows difference between fixed and spring models.

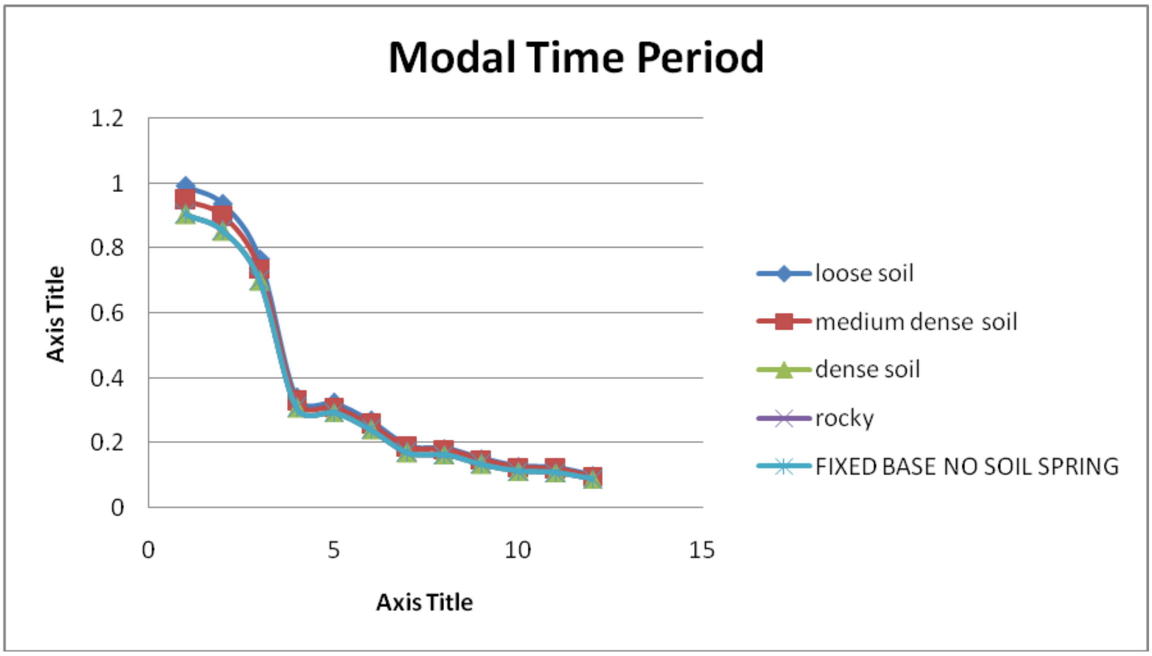

Fig. 6.1

In spring models, it is observed that the fundamental natural period for models on different soil is different. As the soil changes from hard to soft, natural periods are longer as a result of decrease in the stiffness of soil. See fig. 4.2 below

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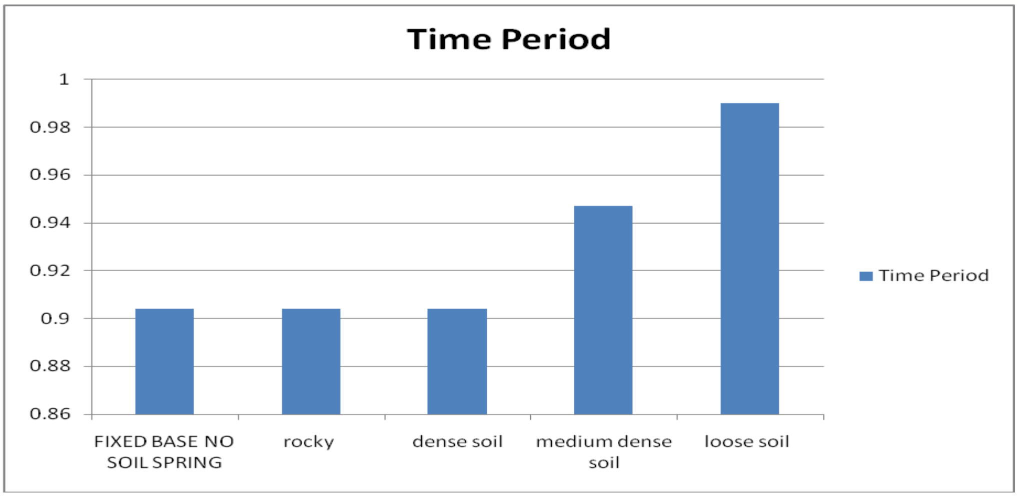

Fig. 6.2

B. Base Shear:

In ETABS 2016 there are provision to select number of modes for modal analysis. However, default 12 modes are taken for study. Graph in fig. 4.1 shows difference between fixed and spring models. Base shear increases with increase in base flexibility.

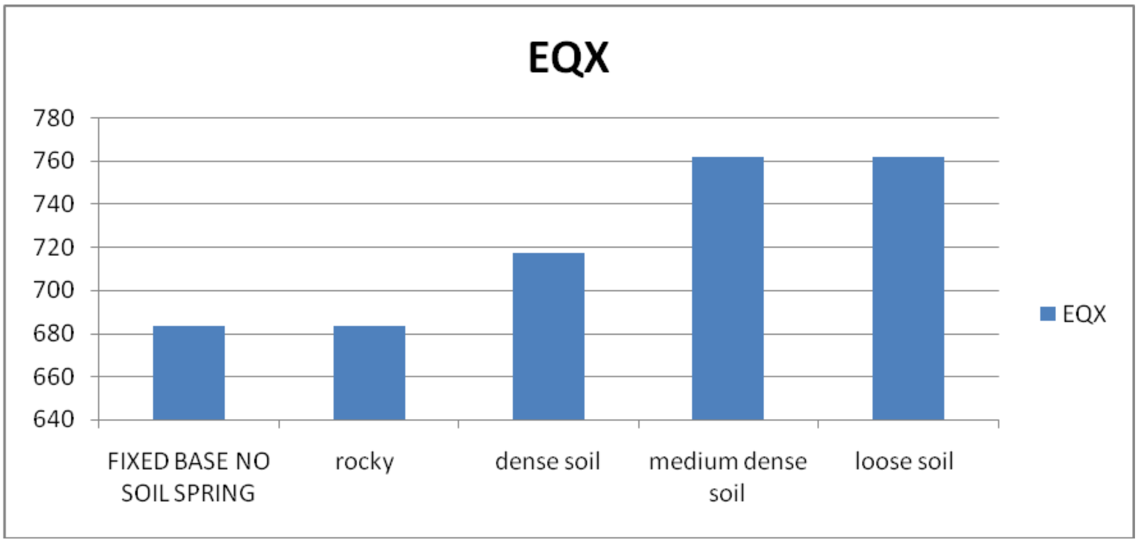

Fig. 6.3

C. Beam Moment

The variation in Beam moment of structure of fixed base and flexible base for both the models are presented in Figure 4, 5 & 6 for regular, + shape opening, C shape opening and H shape opening building frames. Each irregular model is compared with the regular model.

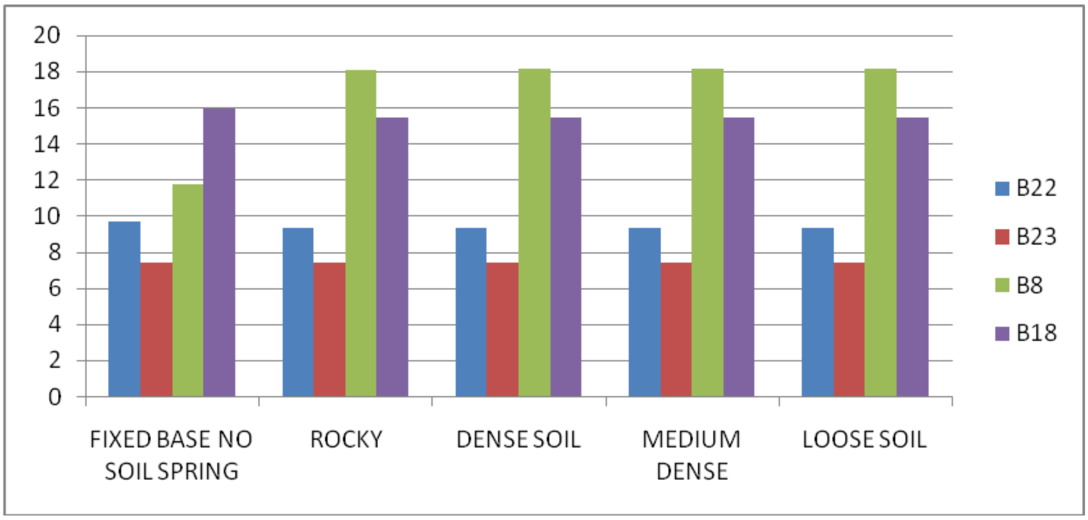

Fig. 6.4

D. Column Moment:

Graphs are plotted taking column as abscissa and bending moment as ordinate for RC building**.**

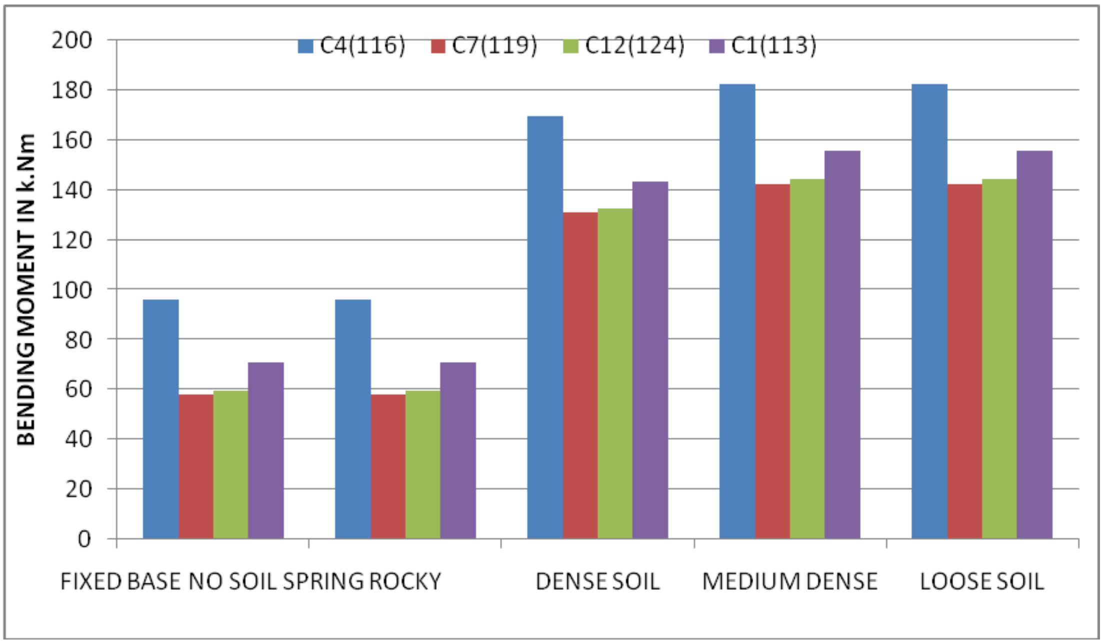

Fig. 6.5

VII.CONCLUSION

1) Increase in soil flexibility increases the response of the structure. Beam moment, Column moment and Base shear are found to be increasing as soil flexibility increases.

2) The moments in column and beam are high in models with soil structure interaction when compared with models without soil structure interaction.

3) As the stiffness of the subsoil decreases, the effects of the soil structure interaction become more dominant and detrimental to the seismic behaviour of RC building frames.

4) Results from FEM model are more effective for soft soil, hence this method can be adopted for analysis of structure resting on soft soil.

5) It is necessary to consider soil-structure interaction effect when structures rest on loose soils.

6) The results shows that including soil in a model of structure does not always have beneficial effects, as often believed. Analyses conducted shows that structure models with soil included have much higher values of storey displacements, when the soil is modelled with Winkler Springs.

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