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Effect of Soil-Structure Interaction on Regular and Irregular, Medium RC Framed Structure

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*Abstract— **In conventional seismic design of building frame, building base is assumed to be fixed but in reality the soil beneath the structure deforms to some extent as it has ability to deform. Due to this response of soil the seismic response of the structure gets altered. It may cause reduction in overall stiffness of structure and increases natural periods of the structure. In this study the effect of soil flexibility on performance of building frame system from fixed base analysis to flexible base analysis is studied. Winkler model approach and Elastic continuum approach is adopted to study effects of soil flexibility on 6 storey(medium raised) RC frame building with regular and different types of irregular plans (Diaphragm discontinuity) resting on three types of soil such as hard, medium hard and soft are considered. Winkler model is developed using spring stiffness equations and elastic continuum is developed by finite element method using SAP 2000. Response spectrum method is used for seismic analysis as given in IS1893-2002.Parameters such as beam moment, column moment and base shear are obtained and compared with regular building frame. Results show that as flexibility of soil increases the response of the structure increases.***

Index Terms— **Soil structure interaction, Winkler model, Elastic continuum and Finite element method.**

I. INTRODUCTION

Due to rapid urbanization and increase in population one has compelled to build structures on all available types of soils. In past construction of structure on soft soil were considered to be unsuitable. As all structures are directly in contact with the soil, interaction among the structure, foundation and soil medium beneath the foundation alter the real behavior of structure considerably as obtained by the consideration of structure alone. The structures with irregularity have to be designed at most care by understanding detrimental effects of irregularities to full fill the requirements. Hence the effects of soil flexibility have to be considered in seismic design of structures to ensure the seismic safety of structure. In this paper the effect of soil flexibility is accounted through the consideration of springs of specified stiffness to represent soil. Winkler's idealization represents the soil medium as a system of identical but mutually independent, closely spaced, discrete, linearly elastic springs. Finite element method is very useful to study the complex interactive behavior of

structure. Finite element method can be used to model many complex conditions with high degree of realism including nonlinear stress-strain behavior, non-homogeneous material conditions and so on.

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II. OBJECTIVE OF STUDY

Objective of present study is to determine the effects of soil structure interaction on dynamic properties of medium rised RC framed structure with various plan irregularities (Diaphragm discontinuity) resting on different types of soil. To achieve objective of study two methods of soil structure interaction are considered i.e. Winkler method and Elastic continuum method.

III. STUDY METHODOLOGY

Foundations are considered to be resting on three different types of soil namely, Hard, Medium hard and Soft soil. Parameters required for analysis are Shear wave velocity (Vs), Poisson's ratio (μ), Density of soil (ρ) and Shear modulus (G).
Shear wave velocity (Vs) for different types of soil is obtained from IBC CODE 2006.
The value of the spring stiffness of the varieties of soil, thee shear modulus (G) is estimated to use the following expression

$$G = Vs^2 \times \rho$$

The Modulus of elasticity of soil is estimated using following expression.

$$Vs = \sqrt{E/(2\rho(1+\mu))}$$

ρ = Mass density of soil in kN/m^3

μ = Poisson's Ratio

Properties of different types of soil are tabulated in Table 1.

Table 1. Details of soil Parameters

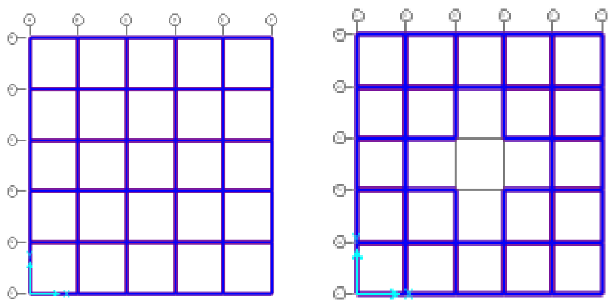
Types of soil	Shear wave velocity (Vs) m/sec	Poisson's ratio (μ)	Density of soil (ρ) kN/m^3
Hard soil	750	0.3	18

Medium Hard soil	360	0.4	16
Soft soil	180	0.4	16

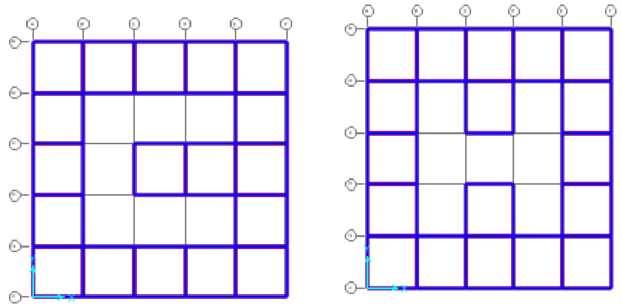
Symmetric building space frame of 5 bay by 5 bay 6 storey with regular and irregular plans are considered as show in figure 1. The details of building frames, foundation and soil mass considered for the study are given in table 2.

Table 2. Geometric and material properties of frame, footing and soil mass.

Component	Description	Data
Model details	Number of storeys	6
	Number of bays in X direction	5
	Number of bays in Y direction	5
	Storey Height	3.2m
	Bay width in X direction	5m
	Bay width in Y direction	5m
	Size of beam	0.3m x 0.4m
	Size of column	0.3m x 0.4m
	Thickness of slab	0.125m
Soil (FEM)	Block of soil mass	75m x 75m - 38m depth
Seismic parameters	Type of structure	OMRF
	Seismic zone	V
	Importance factor	1
	Response reduction factor	3



(a) Regular (b) + shape Opening



(c) C shape opening (d) H shape opening

Fig 1. Different Types of Plans

A. *Idealization of Winkler Model*

Effect of soil flexibility is incorporated by considering equivalent spring with 6 degree of freedom. The stiffness along these 6 degrees of freedom is determined using the spring stiffness equations are given in table 2.Winkler model is shown in figure 2.

Table 3. Spring Stiffness Equations

Degrees of freedom	Stiffness of equivalent soil spring
Vertical	$[2GL/(1-\nu)](0.73+1.54\chi^{0.75})$ with $\chi = Ab/4L^2$
Horizontal (Lateral direction)	$[2GL/(2-\nu)](2+2.50\chi^{0.85})$ with $\chi = Ab/4L^2$
Horizontal (Longitudinal direction)	$[2GL/(2-\nu)](2+2.50\chi^{0.85})-[0.2/(0.75-\nu)]GL[1-(B/L)]$ with $\chi = Ab/4L^2$
Rocking (about longitudinal)	$[G/(1-\nu)]I_{bx}^{0.75}(L/B)^{0.25}[2.4+0.5(B/L)]$
Rocking (about lateral)	$[3G/(1-\nu)]I_{by}^{0.75}(L/B)^{0.15}$
Torsion	$3.5G\, I_{bz}^{0.75}(B/L)^{0.4}(I_{bz}/B^4)^{0.2}$

Ab= Area of the foundation considered; B and L= Half-width and half-length of a rectangular foundation, respectively; Ibx, Iby, and Ibz = Moment of inertia of the foundation area with respect to longitudinal, lateral and vertical axes, respectively.

The values of stiffness for three types of soil are calculated as per the equations given in table 3 and are presented in table 4.

Table 4. Spring Stiffness for Different Types of Soil.

Stiffness of equivalent soil spring (kN/m)			
Soil type	Hard soil	Medium hard soil	Soft soil

Horizontal (Longitudinal direction)	80404412	17496000	4374000
Horizontal (Lateral direction)	80404412	17496000	4374000
Vertical	98501786	23535360	5883840
Rocking (about Longitudinal)	175659976	41971024	10492756
Rocking (about lateral)	181717217	43418300	10854575
Torsion	55355842	11336876	2834219

B. Idealization of Elastic continuum

It is a common experience that in the case of the soil media, surface deflections will occur not only immediately under the loaded region but also within certain limited zones outside the loaded region. Analysis is carried out by considering elastic continuum below foundation. This is assumed to be at a lateral offset of width of building on all four sides and depth equal to 1.5 times the width of building. Considering this, soil block of 75m x 75m in plan and having 38m depth is used for the study. Super structure, foundation and soil mass system are modeled in to 3 dimensional forms by FEM. Beams and columns are modeled as frame element with 2 nodes having 6 degree of freedom at each node, foundation is modeled as 8 noded concrete element and soil mass beneath the foundation is modeled as 8 noded solid element with 2 degree of freedom at each node. Elastic continuum model is in figure 3.

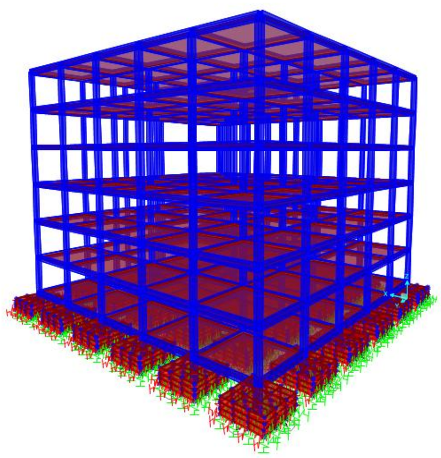


Figure 2. Winkler model (Regular)

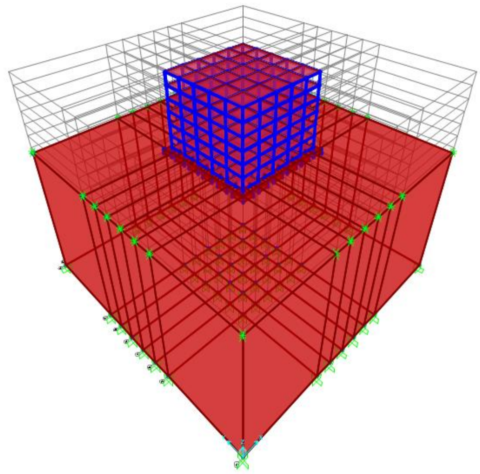


Fig 3. Elastic Continuum model (Regular)

IV. PARAMETRIC STUDY

A symmetric space frame of 5 x 5 6 storey with isolated footing along with two soil structure interaction models viz. Spring Model and Elastic Continuum Model are considered. The effect of different soil and structural parameters on seismic performance of building is studied considering and without considering soil structure interaction.

A. 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.

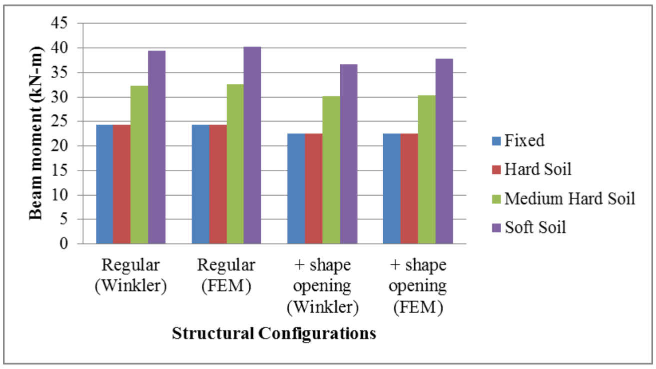


Fig 4. Variation of Beam moment for Regular model & + shape opening model for different support conditions

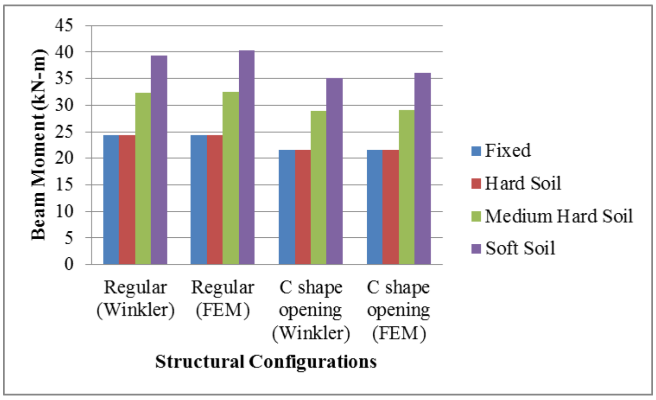


Fig 5. Variation of Beam moment for Regular model & C shape opening model for different support conditions

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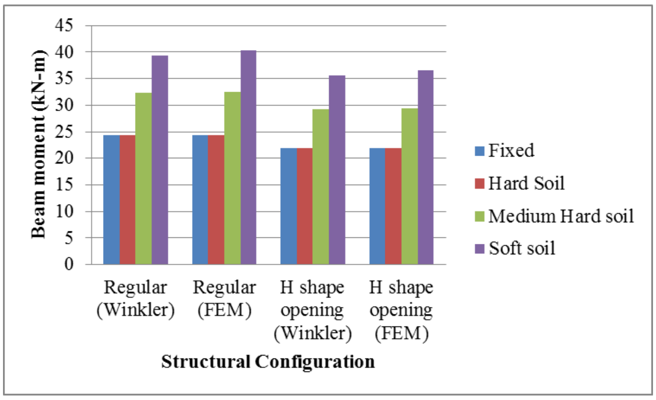

Fig 6. Variation of Beam moment for Regular model & H shape opening model for different support conditions

From figure 4 to 6 it is observed that as flexibility of soil incrases, beam moment of structure increases. It is observed to be same in all models . For fixed base condition the beam moment of structure is same when compared with structure on hard soil, there after as flexibility of soil increases the response of structure also increases. There is increment in beam moment in a range of 30- 40% from fixed base condition to flexible base condition. Beam moment in FEM model is higher than winkler model. Increment in beam moment is due to differential settlement of foundation which results with soil flexibility.

B. Column Moment

The variation in Column moment of structure of fixed base and flexible base for both the models are presented in Figure 7, 8 & 9 for regular, + shape opening, C shape opening and H shape opening building frames. Each irregular model is compared with the regular model.

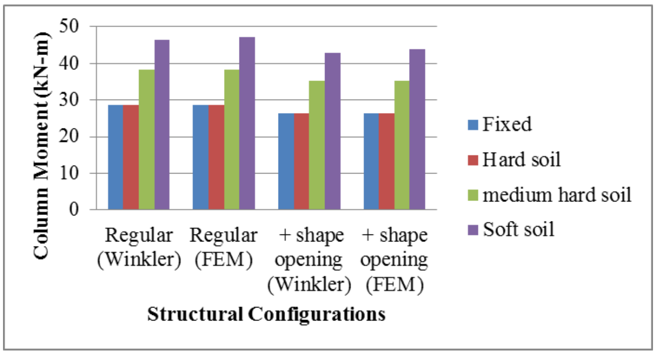

Fig 7. Variation of Column moment for Regular model & + shape opening model for different support conditions

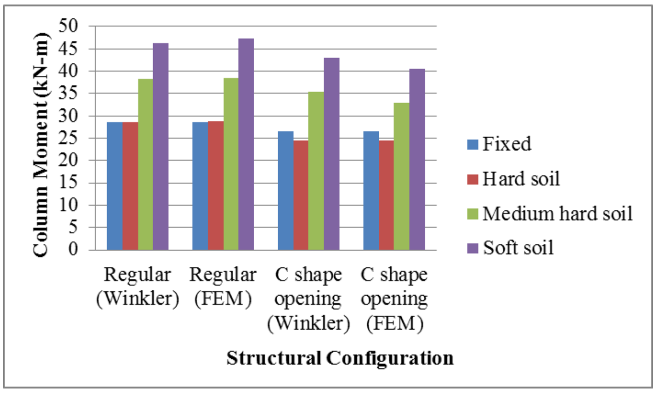

Fig 8. Variation of Column moment for Regular model & + shape opening model for different support conditions

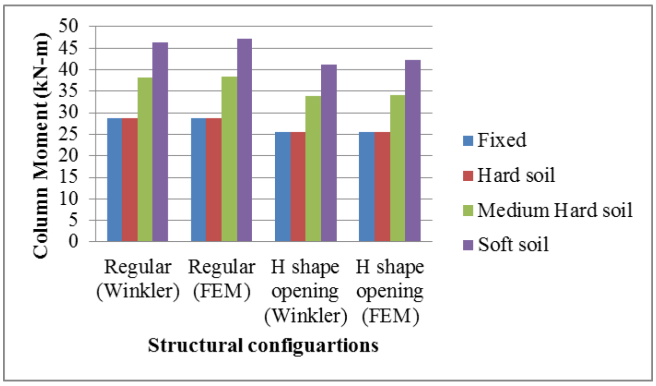

Fig 4. Variation of Column moment for Regular model & + shape opening model for different support conditions

From figure 7 to 9 it is observed that column moment increases as flexibility of soil increases.There is incremnet in column moment in range of 40-50% from fixed base to flexible base (Soft soil). Column moment in FEM model is higher than Winkler model.

C. Base Shear

The variation in Column moment of structure of fixed base and flexible base for both the models are presented in Figure 10, 11 & 12 for regular, + shape opening, C shape opening and H shape opening building frames. Each irregular model is compared with the regular model. The combined representation for all frames for all support conditions for Winkler and FEM is shown separately in Figure 13 & 14.

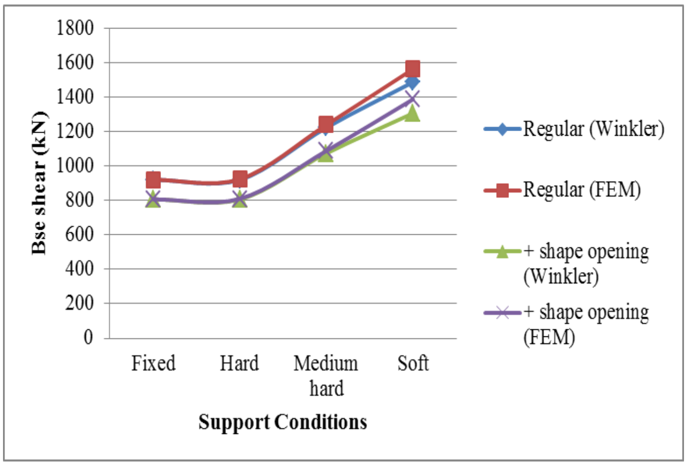

Fig 10. Variation of Base shear for Regular model & + shape opening model for different support conditions

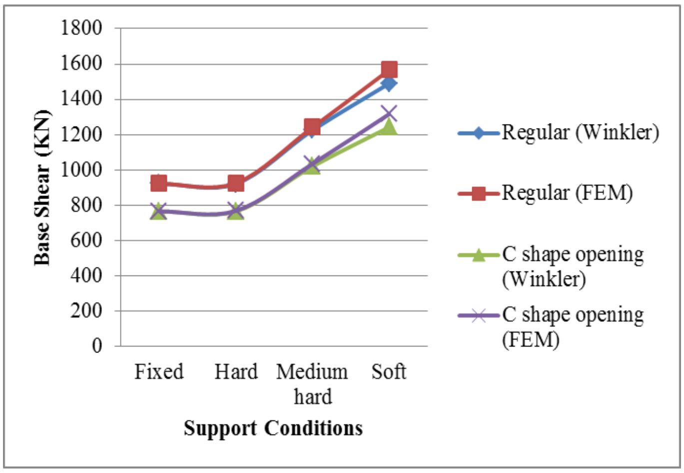

Fig 11. Variation of Base shear for Regular model & C shape opening model for different support conditions

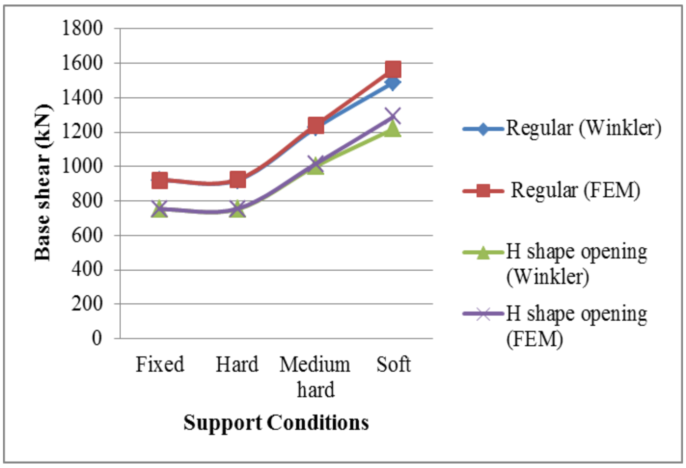

Fig 12. Variation of Base shear for Regular model & H shape opening model for different support conditions

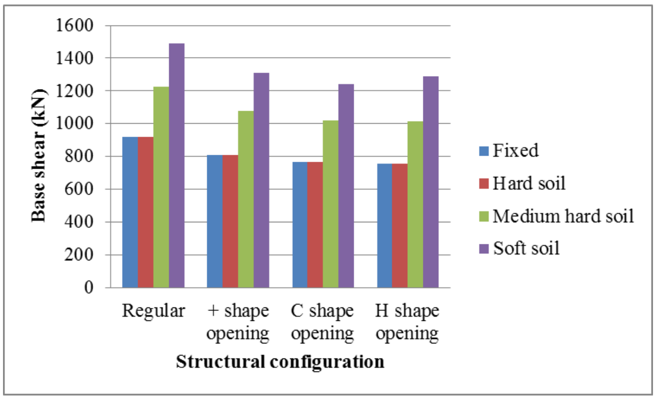

Figure 13. Variation of Base shear with different support condition for Winkler model

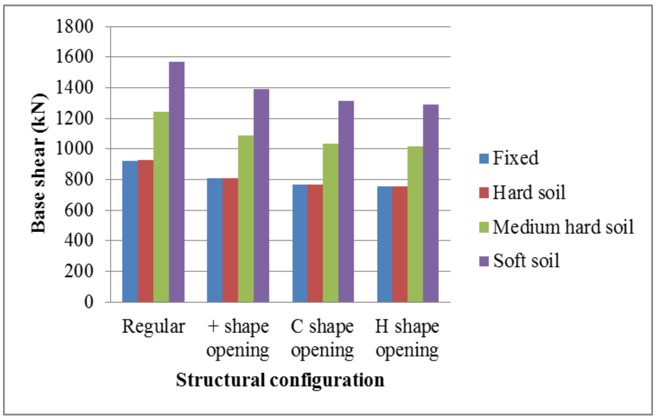

Fig 14. Variation of Base shear with different support condition for FEM model.

Base shear increases with increase in base flexibility. Base shear increaes in range of 30 to 40% from fixed base condition to flexible base condition for all models. Base shear in FEM model increases up to 42% and in Winkler model it increases up to 38% when compared with fixed model in both regular and irregular configuraton. FEM model gives higher base shear values compared to winkler model for soft soil.

V. 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 response of framed structure with regular and irregular configuration has not varied much.
3) The moments in column and beam are high in models with soil structure interaction when compared with models without soil structure interaction.
4) Idealization of supporting soil by Winkler method does not reflect the flexibility of soil precisely compared to Elastic continuum method as realistic idealization is possible by FEM. Hence results obtained from FEM method are more accurate than Winkler method.
5) Results from FEM model are more effective for soft soil, hence this method can be adopted for analysis of structure resting on soft soil.
6) It is necessary to consider soil-structure interaction effect when structures rest on loose soils.

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