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SEISMIC EFFECT OF SOIL STRUCTURE INTERACTION ON PLANE FRAME STRUCTURE

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ABSTRACT : *Earthquake is a sudden violent shaking of the ground and can cause destruction of structures. The behavior of a structure under earthquake forces depends not only on its stiffness but also on the supporting foundation and soil. The phenomenon in which the response of the soil influences the motion of the structure and the motion of structure influences the response of the soil is termed as soil structure interaction (SSI). In conventional studies, structure is assumed as resting on rigid soil and SSI effect is neglected. However, for the realistic analysis of structure, the soil and foundation are to be considered as an integral part of the structure. For the present study a plane frame structure subjected to earthquake is analyzed considering SSI effect so as to investigate the effects of SSI on the response of a structure subjected to earthquakes. The structure is subjected to four earthquake ground accelerations and the response of the structure obtained from the analysis without considering SSI is compared with the response obtained from the analysis considering SSI.*

Keywords – *acceleration, base shear, bending moment, earthquakes, soil structure interaction*

1. INTRODUCTION

In conventional analysis and design of super structure and foundation, the superstructure is assumed as fixed at base and its behavior is assumed to be completely independent of foundation and supporting soil. The foundation is assumed to be stiff and stiffness of foundation and structure is not taken into account. It is well-known that the actual behavior of superstructure depends not only on the stiffness of super structure but also on the stiffness of foundation and soil system. Similarly behavior of foundation depends on behavior of superstructure and soil system. The super structure, foundation and supporting soil forms integral unit of load carrying system and for proper evaluation of displacement and forces in superstructure and foundation it is necessary to consider them as a single system. Rational analysis of structure and foundation requires interaction between superstructure, foundation and supporting soil medium to be accounted by treating them as single continuous system. Soil structure interaction analysis considers super structure, foundation and soil system as a single unit.

Studies [1], [2] and [3] considering soil structure interaction for dynamic load condition reports that consideration of soil structure interaction in dynamic analysis reduces overall stiffness of structure and increases the period of the system. In addition the damping of the soil also has the effect on the response of the structure. Hence, to obtain the realistic response of the structure subjected to earthquakes the effect of soil is to be considered in the analysis.

Several studies have been carried out to investigate the effects of SSI for the structure subjected to earthquake ground motion considering SSI effect. However in these studies the foundation system is modeled with frequency dependent springs and dashpots. Soil is a continuous system and it is more appropriate to model it as an elastic half space rather than simple spring and dashpot. It has been observed that frequency independent mass - spring model could well represent the kinematic interaction between foundation and soil only at low frequencies [4] and these models may tend to produce overly conservative results [5]. Finite element method which treats the soil as elastic continuum is generally used to model the soil. Finite element model provides a reasonable representation of the soil – structure system and the associated acceleration distribution in the foundation soil. The versatility and ease of use of commercially available finite element programs have contributed to their popularity. The method is suitable for the analysis of nonlinear materials and complex geometry. These procedures would allow greater flexibility in terms of geometric and material characterization of the soil medium.

However most of the software's developed using finite element method applies the seismic loading to all mass degrees-of freedom within the computer model and cannot solve the SSI problem. This lack of capability has motivated the development of the massless foundation model. This allows the correct seismic forces to be applied to the structure; however, the inertia forces within the foundation material are neglected [6]. In the proposed study, a plane frame structure subjected to earthquake is analyzed considering SSI effect. Soil is modeled as a continuous system and finite element method is used to model the soil. Seismic loading is applied only to the structure degree of freedom rather than at all the degrees of freedom. To study the effect of stiffness of soil on the response of a structure, three types of soils namely soft, medium and hard are considered for the analysis. The structure is subjected to four earthquake ground accelerations: Imperial Valley, Chi Chi, Northridge and El Centro and the response obtained by considering SSI effect is compared with the response obtained without considering SSI effect.

2. METHODOLOGY

A typical five story plane frame structure considered for the study is shown in figure 1.

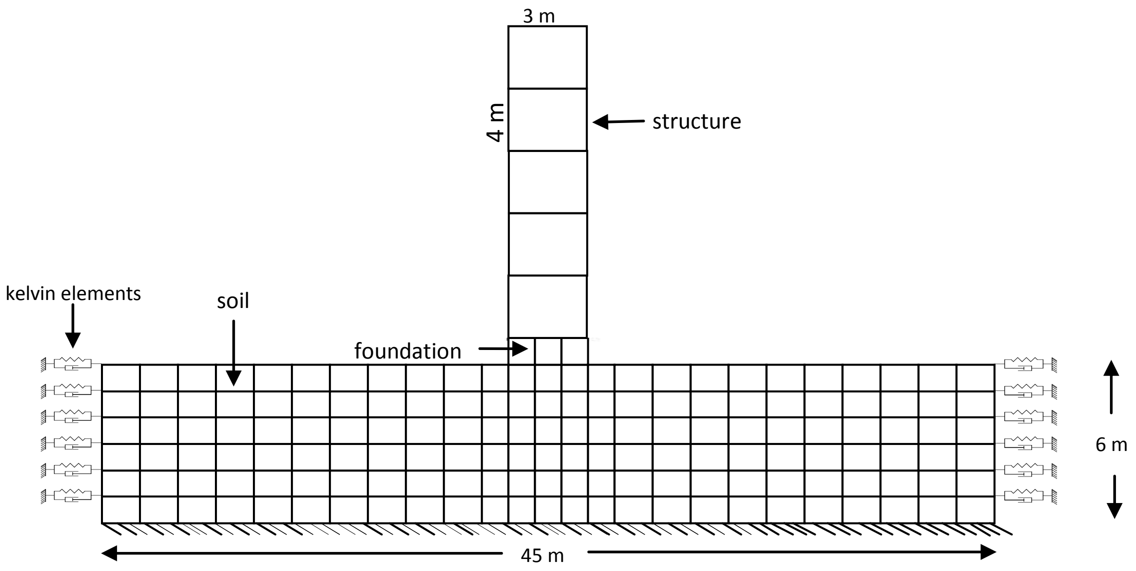


Figure 1 **Model** of structure with SSI

The structure is divided into beam and column connected at the nodes. Foundation soil is modeled using four noded plane strain rectangular element. The soil mass is assumed to be elastic, homogeneous and continuous. The base of the soil is assumed to be resting on hard rock and is assumed to be fixed. To simulate an infinite soil medium, artificial boundary [7] are attached to the edges of soil. These boundaries are modeled using springs and dash pot as suggested by [7]. The overall dynamic equation of equilibrium for structure-foundation-soil system can be expressed in matrix form as

$$[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} = \{F(t)\} \quad (1)$$

Where [M] is the mass matrix, [K] is the stiffness matrix and [C] is the damping matrix of both structure and soil. $\{\ddot{u}\}$, $\{\dot{u}\}$, {u} are acceleration, velocity and displacement vectors. {F(t)} is the nodal load vector and is given by the equation.

$$\{F(t)\} = -[Ms]\{I\}\ddot{u}_g(t) \quad (2)$$

where Ms is the mass matrix corresponding to structural degrees of freedom only

The resulting equations are solved using Newmark's method. In this method, from the response at the time *t* the response at time $t+\Delta t$ is determined. Owing to its unconditional stability, the constant average acceleration scheme (with β=1/4 and γ=1/2) is adopted. Equation of motion 3.1 incremental form can be written as,

$$M\Delta\ddot{u}_i + C\Delta\dot{u}_i + K\Delta u_i = \Delta F_i \quad (3)$$

Where Δ denotes the variations of each parameters from t to Δt, and index i indicates the i^{th} time step.

$$\Delta\dot{u} = \frac{2}{\Delta t}\Delta u_i - 2\dot{u} \quad (4)$$

$$\Delta u_i = \frac{4}{(\Delta t)^2}\Delta u_i - \frac{4}{\Delta t}u_i - 2u_i \quad (5)$$

Substituting equation 3 and equation 4 into equation 2 yields,

$$\hat{k}_I \Delta u_i = \Delta\hat{F}_I \quad (6)$$

Where $\hat{k}_i$ and $\Delta\hat{F}$ are called, effective stiffness and effective load vector respectively. These are defined as,

$$\hat{k}_i = k_i + \frac{2}{\Delta t}C + \frac{4}{(\Delta t)^2}M \quad (7)$$

$$\Delta\hat{F}_i = \Delta F_i + \left[\frac{4}{\Delta t}M + 2C\right]\dot{u} + 2M\ddot{u} \quad (8)$$

By solving Equation 5 Δu_i are determined and subsequent values of displacements and velocity at the beginning of step (i+1) are calculated using Equation 2 and the following two equations,

$$u_{i+1} = u_i + \Delta u_i \quad (9)$$

$$\dot{u}_{i+1} = \dot{u}_i + \Delta\dot{u} \quad (10)$$

3. RESULTS AND DISCUSSIONS

Figure 1 shows the structure on soil mass considered for the analysis. The material and geometric properties considered for the study are as shown in the table 1 and table 2.

Table 1: properties of structure

Modulus of elasticity	2.2×10^7 kN/m^2
Size of beam	0.6 m x 0.6 m
Size of column	0.3 m x 0.6 m

Table 2: properties of soil

Properties of soil	Types of soil		
	Soft	Medium	Hard
Elastic modulus, E (kN/m²)	5000	50000	500000
Mass density of soil , ρ (kN sec^2/m^4)	2	2	2
Poisson's ration, γ	0.33	0.33	0.33

The structure resting on soil mass is subjected to the following four earthquakes

i) Imperial Valley

ii) Chi-Chi

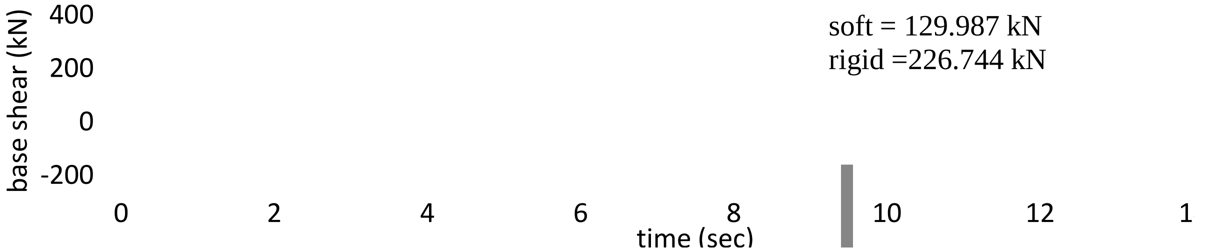
iii) Northridge

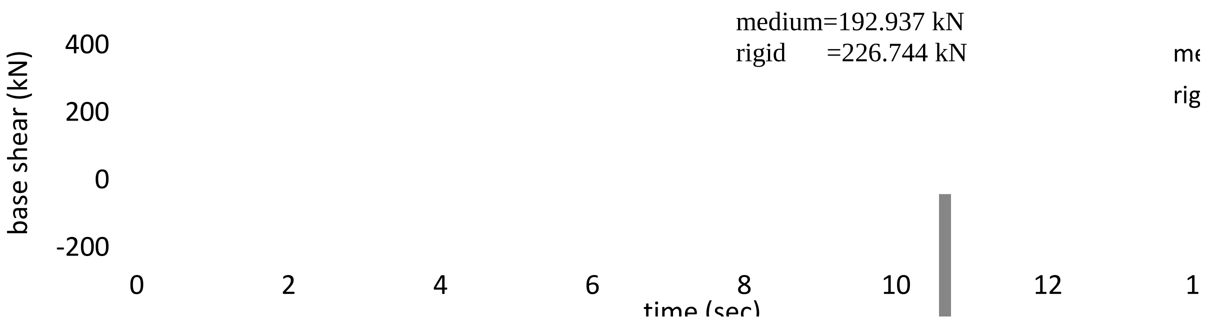
iv) El Centro

The peak base shear, peak bending moment at the base column and absolute peak ground acceleration at top of the structure are obtained. The responses obtained for the structure without considering SSI (fixed at the base) and for the structure on soft, medium and hard soils are tabulated in table 3. Figure 2 and figure 3 shows the time history response of base shear for the structure subjected to Imperial Valley and El Centro earthquakes for soft, medium and hard soils. The time history response of base shear for the structure on rigid base is also shown in the same figure. It can be observed from the figure that the response of the structure on soft and medium soil with time is different compared to the response of the structure on rigid base. It is lesser for soft soil for both the earthquakes whereas for medium soil it is more for the El Centro earthquake and less for Imperial Valley earthquake. The response of the structure on hard soil at the entire time interval is almost similar to the structure on rigid base for both the earthquakes. From the table, 3 it can be observed that the peak acceleration and peak base shear response for the structure on soft soil considering SSI is lesser than that of the structure without considering SSI for all the four earthquakes considered for the study. In the case of medium soil, the base shear, acceleration and bending moment response is lesser for the structure considering SSI for Imperial Valley and Northridge earthquakes where as it is more for Chi Chi and El Centro earthquakes compared to the corresponding responses for the structure without considering SSI effect. In the case of hard soil, the response for the structure with and without SSI effect is almost similar. Thus the SSI effect may be either beneficial or detrimental for the structures subjected to earthquake ground motions depending on the type of soil and its effect is to be considered for the realistic analysis of structure subjected to the earthquakes.

Table 3: Time history response of the structure

Earthquake	Soil	Acceleration (m/s^2)	Base shear (kN)	Bending moment (kNm)
Imperial Valley	Soft	4.005507	129.987335	225.330475
	Medium	7.784421	192.937805	335.818695
	Hard	8.778991	227.404266	396.241150
	Rigid	8.895536	226.744751	395.253296
Chi Chi	Soft	3.467529	102.039169	177.374161
	Medium	7.981914	217.959991	380.649536
	Hard	7.383483	188.787842	330.022430
	Rigid	7.440938	193.345764	338.037659
Northridge	Soft	11.431392	331.482086	577.693359
	Medium	22.213028	532.761719	935.101624
	Hard	26.903288	646.656494	1135.707520
	Rigid	27.001469	656.085754	1151.644043
El Centro	Soft	3.836126	106.200562	185.233963
	Medium	12.175265	275.815582	485.596466
	Hard	12.187210	263.116760	463.840851
	Rigid	12.098492	257.882080	454.645020





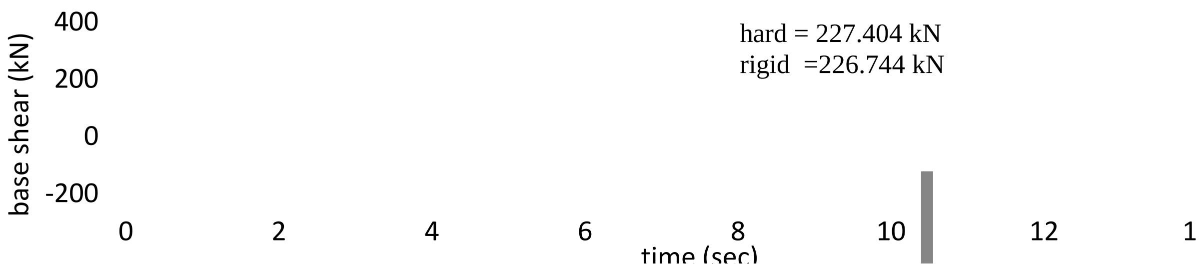
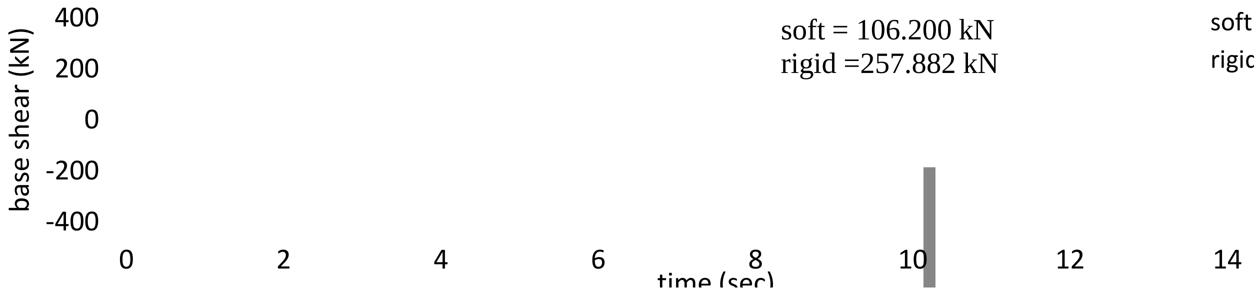


Figure 2 Response of the structure to Imperial Valley earthquake



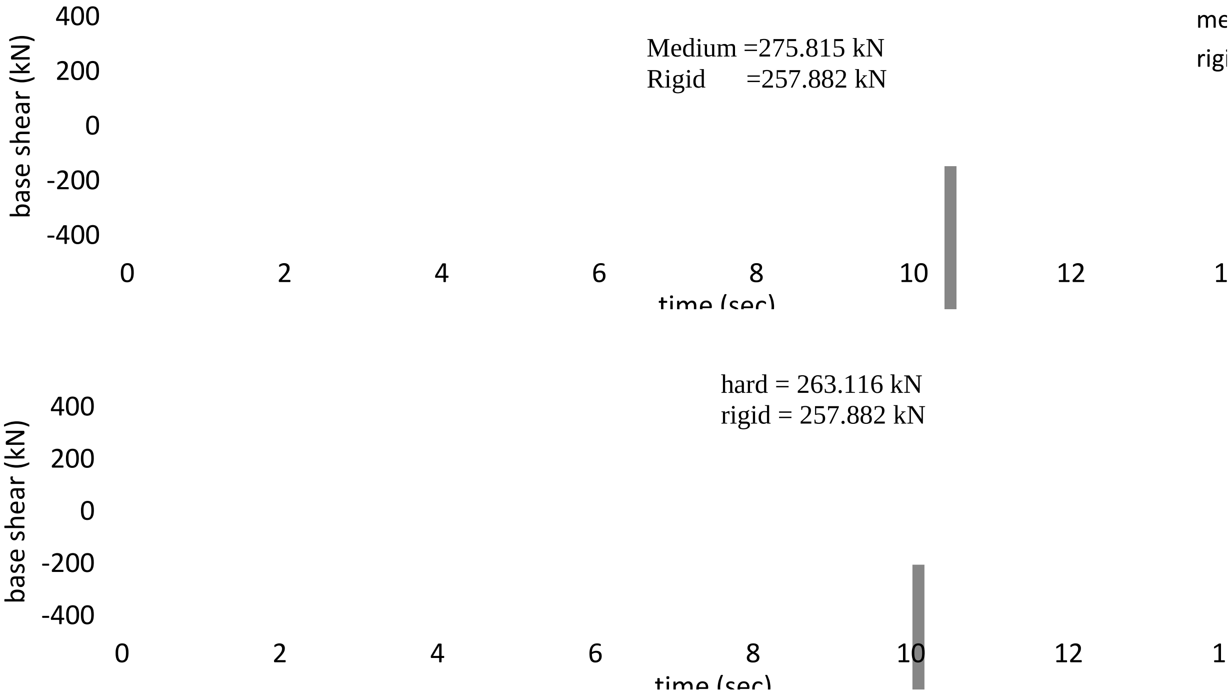


Figure 3 Response of the structure to El Centro earthquake

4. SUMMARY AND CONCLUSION

The effect of soil structure interaction for the structure subjected to earthquake ground acceleration is studied. In this the soil is considered as an elastic continuum and finite element method is used to model the soil. The response obtained from the analysis considering SSI is compared with the response obtained without considering SSI effect. From the study it is concluded that the response of the structure considering SSI is different from the response of the structure without considering SSI. Depending on the type of soil the SSI may either increase or decrease the response of structure. For the structure and soil considered for the proposed study, the response decreases for the structure on soft soil whereas for medium soil it decreases due to SSI for few earthquakes and increases for other earthquakes due to SSI effect. The SSI however has no much effect for the structure on hard soil. Thus the SSI effect may be either beneficial or detrimental depending on the type of soil and for realistic analysis, its effect is to be considered.

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