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Effect of Soil Structure Interaction on Frames with Different Base Conditions

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Abstract: **In conventional modeling of frame structures, soil structure interaction is usually not taken into account. This leads to differences in the response of the structure. But the interaction among the structure, foundation and soil medium below the foundation alter the actual behavior of the structure considerably as obtained by the consideration of the structure alone. Flexibility of soil medium below foundation decreases the overall stiffness of the building frames resulting in an increase in the natural period of the system. Soil-Structure Interaction (SSI) is a collection of phenomena in the response of structures caused by the flexibility of the foundation soils, as well as in the response of soils caused by the presence of structures. Analytic and numerical models for dynamic analysis typically ignore SSI effects of the coupled in nature structure-foundation-soil system. It has been recognized that SSI effects may have a significant impact especially in cases involving heavier structures and soft soil conditions. In this project the effect of soil structure interaction on the dynamic behavior of buildings is studied by analyzing:**

- **A bare frame**
- **A base isolated frame**
- **A symmetric frame with under designed footing**

Keywords— Rocking isolation; Soil-structure interaction; Foundation design; seismic isolation; Improved foundation ; Uplifting

I. INTRODUCTION

Soil structure interaction is generally not taken into account in the conventional modelling of frame structures. This leads to differences in response of the structure. The interaction among the structure, foundation and soil medium below the foundation alter the actual behaviour of the structure considerably ass obtained by the consideration of the structure alone. The conventional design of framed structures resting on ground usually involves assumption of fixity at the base of foundation, neglecting the flexibility of the foundation and the deformation response of ground. The foundation settlement can alter the distribution of forces in the framed structure. Hence, assessing the structural response in conjunction with the ground response becomes important. Taking flexibility of the soil medium can result in increase in natural period of the system.

In this paper the effect of soil structure interaction on the behavior of buildings is studied by analyzing

- A conventional bare frame
- A base isolated frame
- A symmetric frame with under designed footing

Base isolation is aimed at uncoupling the upper structure from the foundation. To study the effect of SSI on a base isolated frame, a base isolated frame structure which includes the influence of the soil medium is analyzed.

Intentionally under designing the foundation advocates the intense rocking response of the superstructure as a whole, instead of flexural column deformation. Studies have shown that the overall performance of the rocking isolated design alternative is superior to that of the conventionally designed system.

In this paper the effect of soil structure interaction on a symmetric frame with under designed footing along with the above mentioned frames is studied and the results are compared to arrive into a conclusion**.**

II. OBJECTIVE

To study the soil structure interaction on frames by analyzing

1. A conventional bare frame
2. A base isolated frame
3. A non conventional symmetric frame with under designed footing

Types of soil:

1. Soft
2. Medium
3. Hard

III. IDEALIZATION OF FRAME

The study consists of analysis of three models of 2- D frames: a conventional bare frame, a base isolated frame and a symmetric frame with under-designed footing.

2 bay frames with two storeys on isolated footing, resting on three different types of soil namely, soft, medium and hard, have been considered for analysis. The height of ground floor is taken as 4m and first floor as 3m. Bay length is taken as 5m. The present study also considers bare frame without the effect of soil medium to see the influence of soil structure interaction on the response of the structure. The dimensions of all beams are taken as 200x500mm and that of columns as 400x400 mm. The analysis is carried out using ANSYS 14.5.

IV. IDEALIZATION OF SOIL

Three types of soil – soft, medium and hard- are taken for analysis to properly understand the effect of soil structure interaction on the response of building frame. The properties of the soil are given below:

TABLE 1: PROPERTIES OF SOIL

Sl. No	Type of soil	N value	Shear modulus (kN/m^2)	Unit weight (kN/m^3)	Poisson's ratio
1	Soft	3	30502.57	16	0.4
2	Medium	6	53018.1	18	0.35
3	Hard	30	192458.23	20	0.3

Soil medium is modeled as half space. As noted by Tabatabaiefara and Massumi (2010), the distance of the structure centre to the soil finite element model boundaries should be within three to four times the foundation radius in horizontal direction and two to three times the foundation radius in the vertical direction, to make the effects of the reflexive waves negligible. Therefore, horizontal distance between soil boundary and centre of building has been adopted equal to 20 m, while vertical distance between soil boundary and foundation of building has been adopted equal to 30m.

Flexibility of soil medium below foundation may alter natural frequencies resulting in elongated time period of the structure. Analysis is carried out in ANSYS 14.5 to obtain the results. Bare frame without soil medium is also carried out to understand the effect of soil structure interaction on the behaviour of the structure.

V. ROCKING FOUNDATION OVER CONVENTIONAL FOOTING

Rocking isolation consists of intentionally under dimensioning of the footing to respond to earthquake shaking through rocking. Thus inertia forces are transmitted to superstructure. Rocking isolation advocates intense rocking response of the superstructure as a whole, instead of flexural column deformation.

Studies have shown rocking isolation is superior to conventional foundation design in many aspects. F. Gelagoti(2012) carried out analysis on a simple one bay frame and a complex symmetric two bay frame and concluded that rocking isolation is superior to the conventional design in terms of structural stability and foundation settlement. I. anastasopoulos et.al. (2014) analyzed an asymmetric frame and observed superiority of rocking isolation.

To obtain rocking isolation for the frame, footings are under designed. For conventional design of footing, 1.8m width is provided whereas for under designed footing, a width of 1.3m is provided.

VI. BASE ISOLATED FRAME

Through base isolation, upper structure is uncoupled from the foundation thus reducing the structural internal forces. Base isolation introduces a flexible layer between the foundation and the building. Flexibility in horizontal direction increases the fundamental period of the building. In this study base isolated frame is modeled by introducing bearings between foundation and the superstructure. Stiffness of the bearing is provided as 300 kN/m.

VII. TIME HISTORY ANALYSIS

Acceleration time history of Kobe earthquake, 1995 is used for time history analysis. This time history is used as an input to assess the seismic performance of the structure at earthquake scenario. The peak ground acceleration of Kobe earthquake is 0.85g indicating strong seismic shaking.

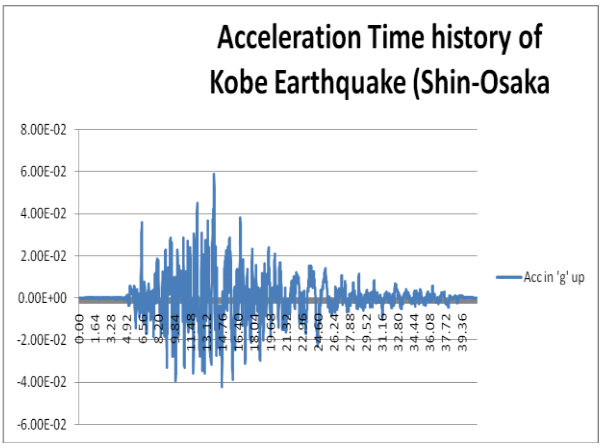

Fig 1: Acceleration time history of Kobe earthquake

VIII. RESULTS AND DISCUSSIONS

The study is aimed to understand the effect of soil structure interaction on the structural response of the frame and also to assess the performance of the frame with different base conditions and soil types. Results are presented as time period of the structure, acceleration at the top of structure and base shear.

TABLE 2: SUMMARY OF NATURAL PERIOD FOR THE FRAMES

Soil	Conventional frame (s)	Base isolated frame (s)	Frame with underdesigned footing (s)
Soft	0.56	9.3	0.6
Medium	0.45	8	0.47
Hard	0.42	10	0.45

TABLE 3: SUMMARY OF TOP ACCELERATION FOR FRAMES

Soil	Conventional frame (m/s^2)	Base isolated frame (m/s^2)	Frame with underdesigned footing (m/s^2)
Soft	10.1	0.232	1.28
Medium	3.08	0.20	0.66
Hard	2.92	0.20	0.43

Since soft soil is more affected by SSI , base shear values for frame on soft soil and for bare frame are presented in table 4.

TABLE 4: SUMMARY OF BASE SHEAR FOR FRAMES

Soil	Conventional frame (kN)	Base isolated frame(kN)	Frame with underdesigned footing(kN)
With SSI	113.5	156.06	120.1
Without SSI	121.1	159.4	126.2

TABLE 5: PROPERTIES OF FRAME WITHOUT SOIL STRUCTURE INTERACTION

Properties	Conventional frame	Base isolated frame	Frame with underdesigned footing
Natural period(s)	0.21	0.75	0.2
Top acceleration(m/s^2)	0.1	0.232	0.248
Base shear(kN)	121.1	159.4	126.2

Table 4 and table 5 show the variation in base shear value of frame over varying soil types and base conditions. The base shear values obtained are different for different ground types and base conditions. When the effect of SSI is observed it is seen that as flexibility of soil increases the value of base shear decreases, since base shear is dependent on the primary factor, natural period. With the increase in flexibility of soil, the natural period of the building increases and base shear decreases. However this variation is more in high rise buildings.

The transfer functions at the top of the structure are shown below. Results are shown for frame with and without soil medium. For convenience, frame resting on soft soil has been shown in results since SSI affect soft soil most.

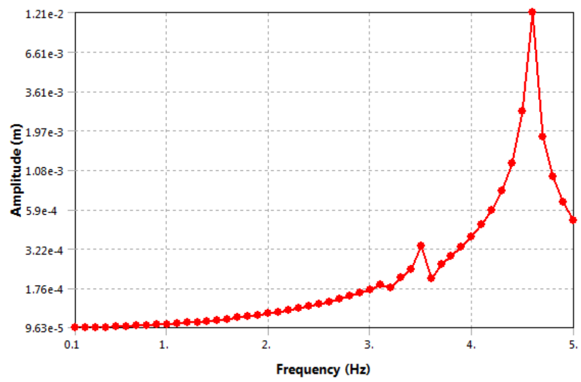

Fig 2: Transfer function of top of frame for conventional frame(with SSI)

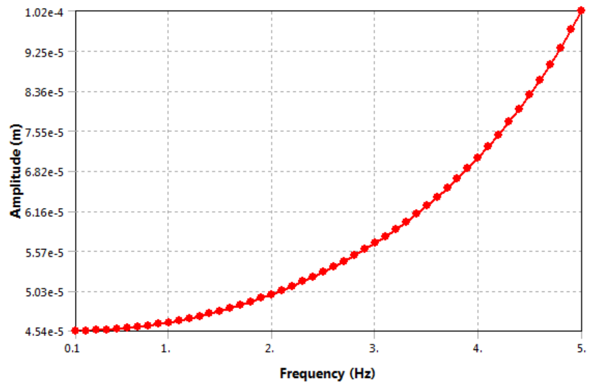

Fig 3: Transfer function of top of frame for conventional frame(without SSI)

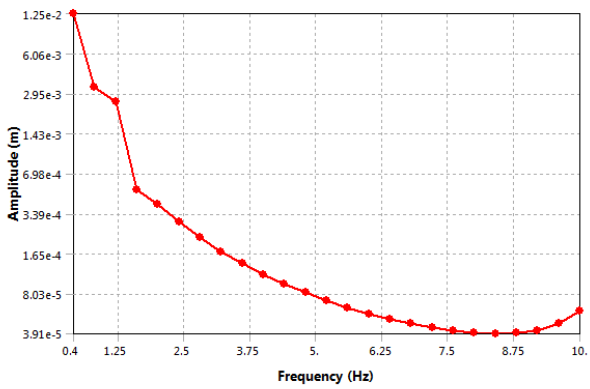

Fig 4: Transfer function of top of frame for base isolated frame(with SSI)

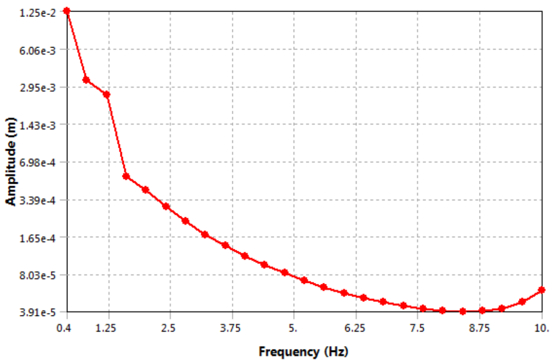

Fig 5: Transfer function of top of frame for base isolated frame(without SSI)

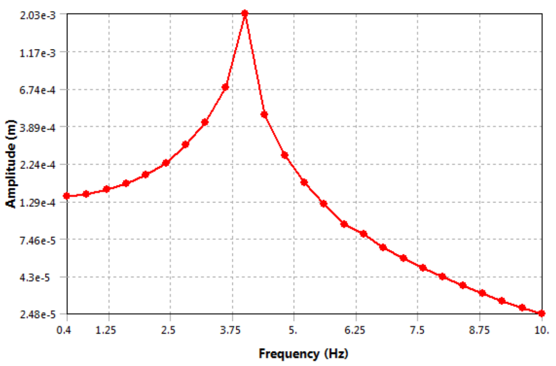

Fig 6: Transfer function of top of frame for frame with underdesigned footing(with SSI)

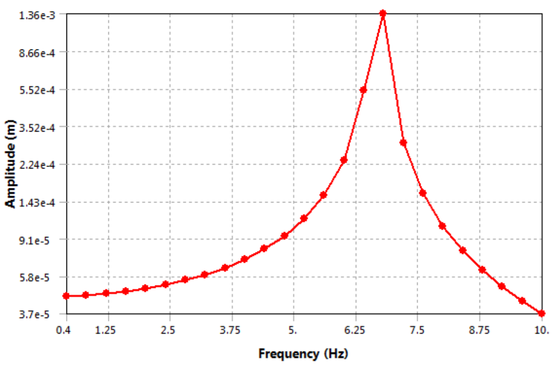

Fig 6: Transfer function of top of frame for frame with underdesigned footing(without SSI)

IX. CONCLUSIONS

In this paper, analysis wass carried out to study the effect of soil structure interaction on behaviour of frames with different base conditions. Three types of soil- soft, medium and hard – were considered. Following conclusions can be drawn from the study:

1. Soil structure interaction increases the natural period of the structure considerably.
2. Acceleration at the top of the frame is significantly increased with consideration of soil structure interaction.
3. Effect of soil structure interaction is greater for soft soil.
4. Base shear of the frame is observed to decrease when soil structure interaction is considered.

It is evident from the study that soil structure interaction is significant in design of structures.

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