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An Evaluation of Impressionableness Structural Systems under the Condition of Foundation and Bed Resistance

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ORIGINAL ARTICLE

ABSTRACT

The analysis of the structures under the influence of the earthquake load is usually done independent of the conditions and the soil variable under them. In other words, the bed of the structure location is supposed to be rigid. In these conditions seismic excitation in the bed of the structure is conducted in the form of a displacement with acceleration with time (or equivalent force). What happens in reality is that the structure is situated on the soil environment as a flexible bed, and from the view point of dimension as semi-infinite and earthquake vibrations from its source reach the foundation of the structure by passing from this environment which results in soil-structure interaction. The flexibility of the structure foundation and the emission of system energy by the waves in the infinite environment of soil (radiation depreciation) are two important results of soil-structure interaction phenomenon. One of the methods of considering the above-mentioned phenomenon in the analysis of the structure-supposing the elastic linear behavior of the soil environment-is by using SSI equivalents by which we have analyzed frame structures and shear wall frame structures under the earthquake load by considering SSI. By extraction of base shear amounts and displacement of the head of the structures under the influence of different earthquakes quantitative and different results have been obtained in a way that mentioned amounts strong dependence on the stiffness of the structure, stiffness of the soil, the kind of the earthquake ,etc. For this reason, the amount of the base shear and displacement in shear wall frame structures is more different from frame structure system in a way that these variations have twofold decrease or increase in a shear wall frame structure comparison with a frame structure system. This matter and the subsequent results reveal the necessity of paying attention to SSI in analysis and design of important structures from the view point of safety factor economic issues.

Keywords: Soil–structure interaction, frame structure, shear wall, stiffness

INTRODUCTION

Research on seismic response of the buildings against earthquake is not only one of the important issues in the field of civil engineering but also because of the location of some countries on seismic belt, there is a possibility of great earthquakes occurrence, therefore the exact study of seismic response of buildings with precise attention seems logical and of course essential.

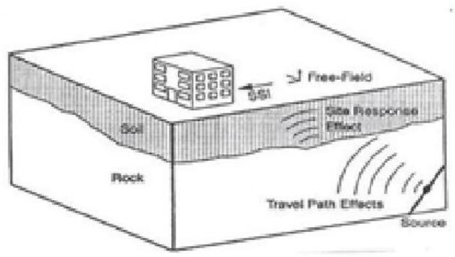
Therefore, during the last decades, much effort has been made to the seismic designs of buildings as precise as possible and in this course, paying attention to soil-structure interaction is one of the cases that has attracted much curiosity and attention in the field of earthquake and structural engineering.

But the calculation of the structure response with soil by taking into account their mutual influence on each other is not as easy and simple as the analysis of a free multi-degree system.

In the meanwhile , contrary to the structure which is a limited environment and can be analyzed simply with a limited number of freedom degree and with a relative precision and exactness , soil is a semi-infinite space .for this reason since 3 pas decades up to now , different methods for the analysis of soil-structure interaction have been proposed .

Seismic vibration which influences the structures is a function with different parameters such as: the effect of earthquake source, the effect of the course of passing of waves, the effect of building site and the effect of soil-structure interaction shown in figure 1.

Figure 2. Specification engineering of the soil-structure interaction



The final result of the first 3 parameters is known as free-field seismic movement which indicates the earth's

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response in absence of any effects of the structures vibration. The effects of soil-structure result from the flexibility of the soil under the foundation and relative vibrations between the foundation and the free field [1].

During the last quarter of the twentieth century, the importance of considering the effect of soil-structure interaction in dynamic analysis of a large specterm of the structures built on soft soil has attracted much attention and the analysis of soil- structure interaction has turned into a major issue in earthquake and structural engineering.

Seismic response has exerts influence on the structures in different aspects such as decrease of natural frequency of the system , damping increase of lateral displacement and decrease of structures base shear. For this reason, making use of appropriate and precise methods of analysis plays an important role in the study of the effect of soil-structure interaction on seismic response of the structures. For the structures built on soft soil, the movement of foundation is usually different from the movement of free field and a rotational component resulting from the flexibility of support is added to horizontal movements of foundation. This rotational component can be importance for high-rise structures. The presence of soil layer changes the content of the frequency of the earth's movement and filters higher frequencies [1].

In general methods of SSI are divided into two categories: direct method and substructure method. Each one of these methods can be used in frequency or time domain each of which has its own privileges. The major difference in these two fields is that non-linear behavior can only be studies in time domain [2].

The main objective of this research is to study the effect of soil interaction on concrete structures with different specifications such as height, system type etc. Then the results brought forth frame these kinds of structures are studies and analyzed. For this purpose, we have used the strong and widely-used structural program sap2000 in this research.

Introduction of the structure

In the first phase, we have modeled the geometry of the structure in a way that the structure has four different 2-dimentional spans with 10 and 5 stories. The mass of the structure in the stories is 640kg/m^2(DL+0.2LL). The two structures have been designed in two moment-frame structural systems of medium reinforced concrete and hybrid concrete system (moment frame structure + shear wall) and according to Iran's 2800 code and soil type III.

The kind of analysis and interaction of the records

The records used for analysis in this paper are Tabas wave and Loma prieta with specifications presented in table 1. The kind of analysis is dynamic analysis of time history and non-linear static analysis of push over has been selected for different kinds of modeling structures.

Introduction of the soil

Soil models used have been selected according to Iran's 2800 code and table 2 in a way that soils with different stiffness have been used for better and move tangible results.

For modeling of the soil and taking into account of its interaction with soil, it must be equated with stiffness coefficient of the spring. For this purpose, in addition to the specifications of the soil according to the specific structure, it depends on the foundation specification [2].

For example: Spring Coefficientfor strip Foundation:

$Kv = G\,(1-5\upsilon^2)$

$Kh = G\,(1-4\upsilon^2)$

The way of modeling

At first the mentioned structures are modeled according to the specifications stated in this paper. Then after the design of the ideal model according to Iran's concrete code (aba) on rigid and fixed support, they are studied and analyzed.

In the next step, we model the foundation and for assigned the springs, divide the related foundation (figure 2).

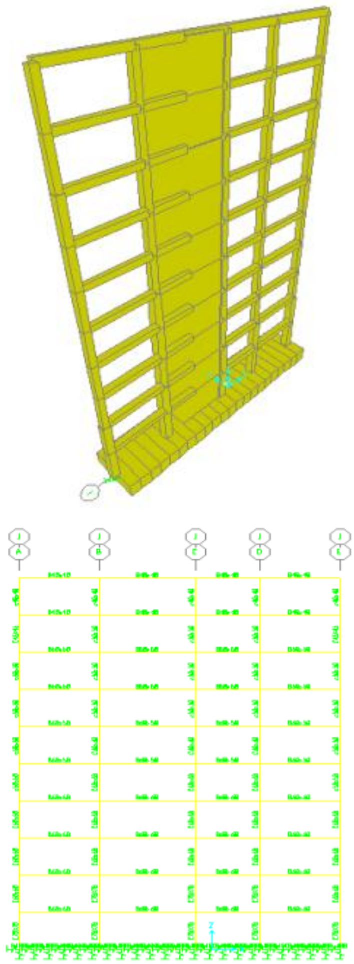

Figure 2. The modeling structure, foundation and bed

The analysis of the results and outcomes

After modeling of the structure and considering soil-structure interaction, in the first step, the ratio of natural period of the structure under the flexible bed ($\frac{\tilde{T}}{T}$) for different cases has been presented in detail in table 3.

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Table 1. Specification of the records

Wave	Year	Station	Direct	PGA(cm/s2)	PGV(cm/s)	PGD(cm)	Km	Kind of soil	Ms
Tabas	1978	9101	H1	819.9	97.78	39.92	3	III	7.4
			H2	835.6	121.4	94.58			
Loma prieta	1989	1652	H1	239.3	20.3	7.73	21.4	II	7.1
			H2	235.4	18.4	6.73			

Table 2. Specification of the soils

Soil tupe	Vs(m/s)	Description of the land according to Iran's 2800 code	γ (KN/m3)	υ	G(N/m2)	E(N/m2)
II	560	Soft igneous stones, soft stones, stiff soils, compacted sand, very stiff clay with the thickness less than 30 meters	21	0.35	658.56×106	1778.112×106
IV	150	Soft deposits with high moisture due to highness of the level of underground water	17	0.4	38.25×106	107.1×106

Table 3. Ratio of natural period

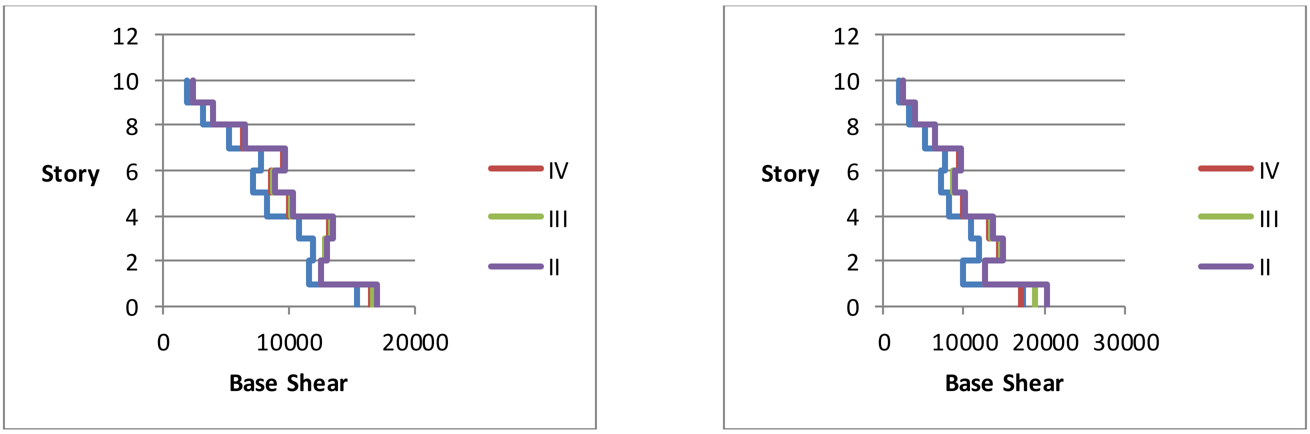
Natural period / Structure	Soil	$\bar{T}1/T1$	$\bar{T}2/T2$	$\bar{T}3/T3$	$\bar{T}4/T4$	$\bar{T}5/T5$	$\bar{T}6/T6$	$\bar{T}7/T7$	$\bar{T}8/T8$	$\bar{T}9/T9$
Frame structure	IV	1.073	1.042	1.000	1.048	1.154	1.112	1.341	1.296	1.167
	III	1.006	1.006	1.000	1.043	1.038	1.000	1.113	1.066	1.000
	II	1.002	1.002	1.000	1.012	1.013	1.000	1.031	1.026	1.000
Shear wall + frame structure	IV	1.187	1.506	1.556	1.727	2.100	1.887	1.691	2.314	1.785
	III	1.012	1.026	1.000	1.330	1.505	1.206	1.117	1.490	1.458
	II	1.004	1.009	1.000	1.076	1.236	1.088	1.016	1.480	1.079

The study of the base shear has been measured according to the ratio of base shear with flexible point of support to rigid bed $(\frac{\bar{Q}}{Q})$.

The results have been mentioned in table 4 and figure 3 by considering the type of the structural system, soil type and different records.

Table 4. Ratio of base shear

Type Of Structure	Seismic Waves	Base shear \ Soil	IV	III	II
Frame structure	Tabas Wave	$\bar{Q}x/Qx$	0.863	0.902	0.960
	Loma perieta Wave	$\bar{Q}x/Qx$	0.955	0.964	0.941
Shear wall + frame structure	Tabas Wave	$\bar{Q}x/Qx$	1.350	0.892	0.834
	Loma prieta Wave	$\bar{Q}x/Qx$	1.578	0.939	0.986



Tabas wave

loma prieta wave

Figure 1. Curve of base shear (frame structure)

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The next important parameter in movement control of the mentioned structures. For this purpose, movement over foundation and the last story has been presented in table 5 as follows:

Table 5. The amount the movement of the modeled structures

Type of Structure	Seismic wave	Soil	Displacement at Top Floor U (m)	Displacement at Foundation U0 (m)
Frame Structure	Tabas Wave	Rigid Soil	0.10695	0
		IV	0.10682	0.2124×10^{-2}
		II	0.10693	0.1264×10^{-3}
	Loma prieta Wave	Rigid Soil	0.1321	0
		IV	0.1085	0.2147×10^{-2}
		II	o.1286	0.8002×10^{-4}
Shear wall + frame structure	Tabas Wave	Rigid Soil	0.0643	0
		IV	0.0711	0.1761×10^{-2}
		II	0.0661	0.1435×10^{-3}
	Loma prieta Wave	Rigid Soil	0.0214	0
		IV	0.0227	0.1606×10^{-2}
		II	0.021	0.1138×10^{-3}

Overturning moment is one of the other evaluated subjects which are strongly influenced by soil-structure interaction. For this purpose, Table 6 is presented as follows:

Table 6. Overturning moment

Type Of Structure	Seismic Waves	Soil / Overturning moment	IV	III	II
Frame structure	Tabas Wave	$\bar{M}x/Mx$	0.873	1.005	1.003
	Loma prieta Wave	$\bar{M}x/Mx$	0.896	1.068	0.996
Shear wall + frame structure	Tabas Wave	$\bar{M}x/Mx$	0.958	0.909	0.959
	Loma prieta Wave	$\bar{M}x/Mx$	0.607	0.898	0.915

RESULTS

- ✓ By considering the SSI, the time of natural period increases and this increase grows by increase of the flexibility of soil.
- ✓ By comparing natural period coefficients ($\frac{\tilde{T}}{T}$), we can understand that these coefficients in hybrid system (moment frame + shear wall) is greater that frame structure. Because hybrid system in comparison with moment frame is much stiffer especially when situated on flexible soil.
- ✓ By taking into account of the effect of SSI (soils becoming more flexible) the movement in moment frames increase while this movement may decrease or increase in hybrid system frames.
- ✓ On the whole, increase or decrease of shear force depends on different factors such as the stiffness of the structure, stiffness of soil, foundation type etc. But in this research, shear force for moment frame varied from -15 to +10 percent while the variation of shear force for hybrid system is from -30 to +20percent.
- ✓ Factors which are effective in overturning moment variations are:
  1-degree of structure stiffness
  2-degree of stiffness of soil
  3-earthquake type
  As an example overturning moment for extremely soft soils is Vs =150m/s and for structural systems with moment frame fluctuates up to 10 percent (-10 to +10) and for hybrid systems fluctuates between -15 and +10 percent.

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