INTERNATIONAL
EARTHQUAKE SYMPOSIUM KOCAELI 2007
22 - 26 OCTOBER 2007

A STUDY ON SEISMIC BEHAVIOR OF MINARETS CONSIDERING SOIL-STRUCTURE INTERACTION

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Key Words: Minaret, soil-structure interaction, seismic analysis.

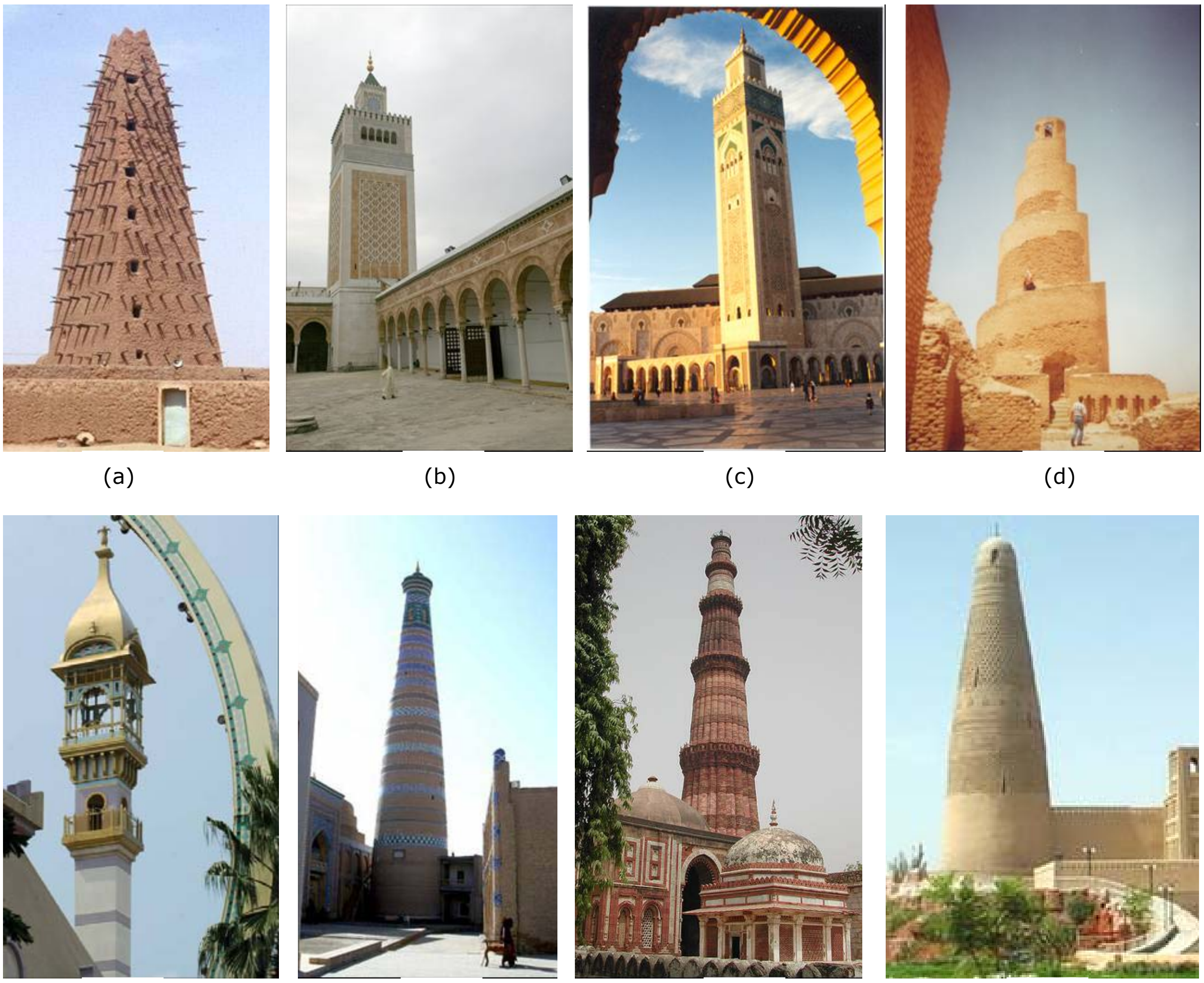
ABSTRACT: Minarets are special structure types used commonly in Islamic Countries. Because of structural characteristics such as slenderness, geometrical shape and supporting system etc, during an earthquake the minarets behave differently from the other structures. Especially in some Islamic country like Turkey, Iran and Pakistan, the minaret suffered many damages from earthquakes. From these damages, some imply that soil structure interaction may play important role on the seismic behavior of the minarets. Furthermore this interaction effects may change the damage pattern fully. For this purpose a typical model commonly built in Turkey are selected for this investigation. Minaret/Soil-Foundation model are performed considering three different soil type. Then these models are analyzed and some discussion and conclusion obtained form the analyses are given at the end of the study. Finally it is noted that soil-structure interaction effect cause to change on the seismic behavior of minaret considerably for especially soft soil.

INTRODUCTION

Minaret may be called as a tower near to, or built into, the structures of a mosque, which is used by the muezzin to call out the adhan in order to make people to come to prayers in Islam. It is known that during Mohammed’s lifetime, the adhan was given from a rooftop or from an elevated platform. The earliest mosques were built without minarets, and the action of adhan could be performed in many other locations such in front or the roof of the masjid.

During the period of the four rightful caliphs, there was no evidence for the existence of minarets. In Islamic architecture, it is stated that the first minarets were constructed at the corners of the Mosque of 'Amr by Fustat by Maslama (the governor of Egypt) during Mu’awiya’s reign in 673 A.D (Larousse, 2006). In the course of time, numerous magnificent minarets have been constructed with different materials and structural systems in various regions of the World as shown in Fig.1. Some other new mosques and minarets are also shown in Fig.2.

Minarets are one of the most significant architectural objects of the cultural inheritance from the period of Seljuk and Ottoman Empires. The architectural styles and structural systems of Turkish minarets vary depending on construction material, available technique facilities, abilities and background of workmen, etc. Therefore, the minarets that can be contiguous or separate the mosque, have been built stone, brick or wooden materials and as a form they can be cubic, cylindirical or polygonal.



(a) (b) (c) (d)

(e) (f) (g) (h)

Figure-1. Different minarets of various culture- (a) Agadez Mosque minaret-Nijer [2], (b) Minaret of the Zaytuna Mosque by Declan McCullagh [4], (c) Hasan II minaret-Casablanca-Morocco [9], d) Samarra ruines minaret –Iraq [5], e) Minaret Leofoo Village-Taiwan [8], f) Islam khoja minaret-Uzbekistan [1], g) Qutub Minar brick minaret.-India [11], h) Emin minaret-China [6].

(a) (b) (c)

Figure-2. Modern Mosques and minarets: a) Kocatepe mosque- Turkey [10], b) Faisal mosque- Pakistan [7], c) Pyramid mosque- Kuwait [3].

MODELING OF SOIL/FOUNDATION-MINARET SYSTEM

ANSYS (2006) is used in modeling the soil/foundation-minaret system, finite element model is used as shown in Fig.3. Body of the minaret and stairs are modeled with shell elements and soil is modeled with solid elements.

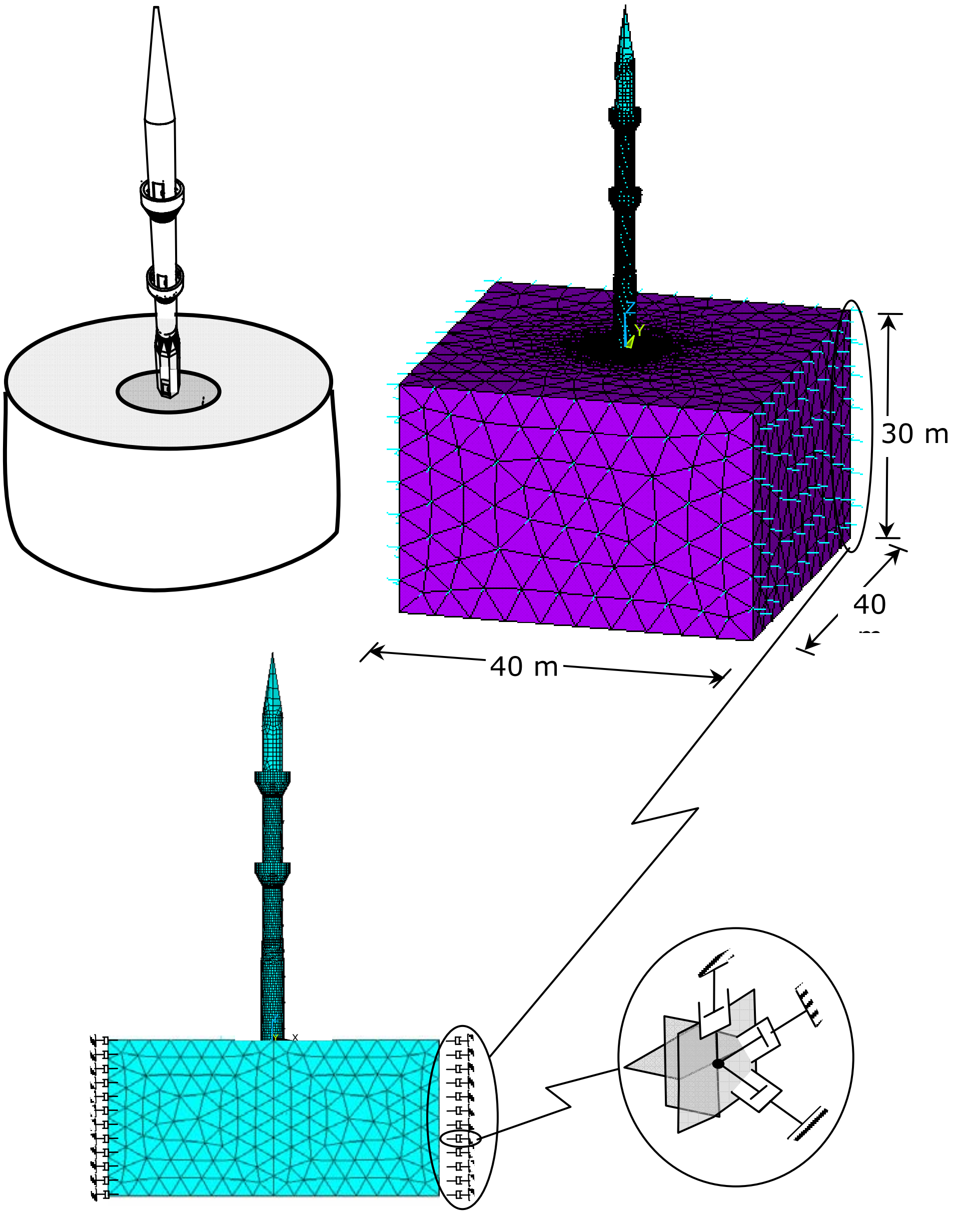


Figure-3. Considered finite element model of the soil/foundation-minaret.

On the soil-structure interaction surface, foundation is also modeled using the shell elements. In order to characterize soil/foundation-minaret model and determined the seismic behavior of the systems, transient dynamic analysis was carried out using the ANSYS. Details in modeling the fluid and the unbounded media are explained in the following titles.

Viscous Boundaries with FEM for Soil-Structure Interaction

The simulation of the infinite medium in the numerical method is a very important topic in the dynamic soil-structure interaction problems. The general method of treating this problem is to divide the infinite medium into the near field (truncated layer), which includes the irregularity as well as the non-homogeneity of the foundation, and the far field, which is simplified as an isotropic homogeneous elastic medium (Wolf and Song, 1996a). The near field is modeled using finite elements and the far field is treated by adding some special artificial boundaries or connecting some special elements. The soil is in most cases a semi-infinite medium, an unbounded domain, or so large in extent that the simultaneous modeling together with the structure may be impractical. In a dynamic problem, it may be insufficient to prescribe a zero displacement at a large distance from the structure, as is routinely done in static (Nofal, 1998). But sufficiently large soil model may prescribe the soil structure interaction as is performed in some studies (Livaoğlu, 2005, Clough and Penzien, 1993, Wilson, 2002). The other and more appropriate approximations are the artificial and/or transmitting boundaries. Furthermore, reflecting and radiation effects of the propagating waves from the structure-foundation layer may be avoided by means of these types of boundaries. There are different types in frequency or time domain with different sensitivities. Firstly Lysmer and Kuhlmeyer (1969) developed viscous boundary using one-dimensional beam theory and this theory has been commonly used with the FEM. Then more complex boundary types are used and developed like Damping-Solvent Extraction Method (Song and Wolf, 1994, Wolf and Song, 1996b). Doubly-Asymptotic Multi Directional Transmitting Boundary (Wolf and Song, 1995, Wolf and Song, 1996a), Paraxial Boundary (Anrade, 1999) and etc. In this study viscous boundary is used for three dimensions (see Fig.3).

To calculate the properties of this boundary condition, it is considered a plane wave propagating in the x-direction. The forces that cause wave propagation are shown acting on a unit cube in Fig.4.

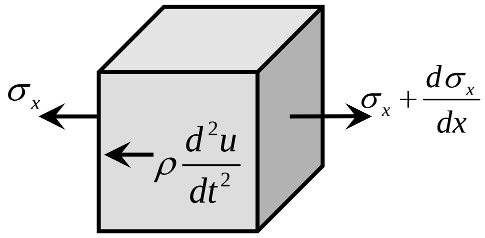


Figure-4. Forces acting on unit cube

From this figure the one dimensional equilibrium equation in this direction is:

$$CSR = 0.65 \cdot \left(\frac{\sigma_{VO} a_{\max}}{\sigma'_{VO}} \right) r_d \tag{1}$$

$$\rho \frac{d^2u}{dt^2} - \frac{d\sigma_x}{dx} = 0 \tag{2}$$

Because, the one-dimensional partial differential equation is written in the classical wave propagation form:

$$\frac{d^2u}{dt^2} - v_p^2 \frac{d^2u_x}{dx^2} = 0 \tag{3}$$

where v_p is the wave propagation velocity of the material and is given by $v_p = \sqrt{E_c / \rho}$ in which ρ is the mass density and E_c is the bulk modulus. The solution of Equation for the harmonic wave propagation in the positive x-direction is a displacement $u(t,x)$ and velocity $\dot{u}(t,x)$ of the following form:

$$u(t,x) = U\left[\sin\left(\omega t - \frac{\omega x}{v_p}\right) + \cos\left(\omega t - \frac{\omega x}{v_p}\right)\right] \tag{4}$$

$$\dot{u}(t,x) = U\omega\left[\cos\left(\omega t - \frac{\omega x}{v_p}\right) - \sin\left(\omega t - \frac{\omega x}{v_p}\right)\right] \tag{5}$$

The strain in the same direction and the corresponding stress can be expressed in the following simplified form (Wilson, 2002). Same results were obtained by Lysmer and Kuhlmeyer, (1969):

$$\varepsilon(t,x) = \frac{du}{dx} = -\frac{\dot{u}(x,t)}{v_p} \qquad \sigma_x = E_c \varepsilon(t,x) = -\rho v_p \dot{u}(x,t) \tag{6}$$

Where ρ, v_p and v_s are mass density, dilatational and shear wave velocity of the considered medium, respectively. Finally these viscous boundaries can be used with the FE mesh as shown in Fig.5. In this figure A_n, A_{t1} and A_{t2} are the fields that controlled viscous dampers, σ and τ are the normal and shear stresses occurred in the boundaries of the medium and the end n and t are the subscripts represent normal and tangent directions in the boundary.

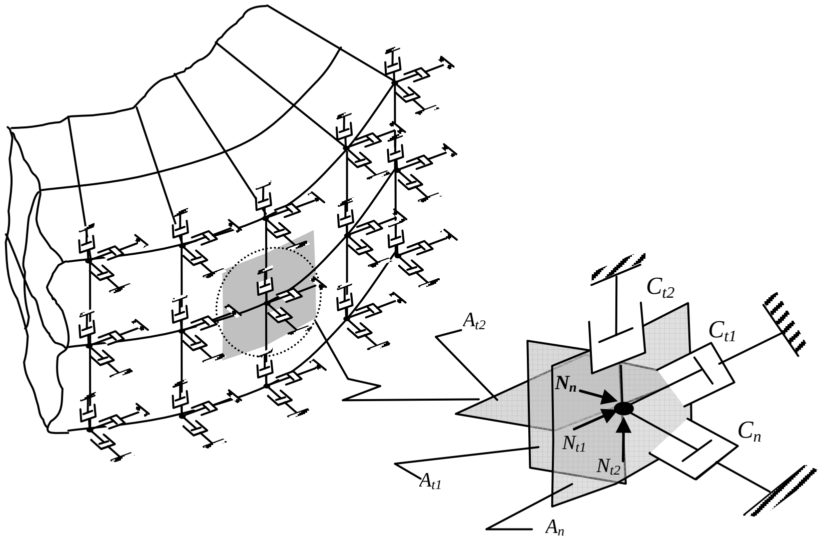


Figure-5. Viscous boundary considered in the 3D finite element model

When the viscous boundary is taken into considerations, well-known equation of motion can be written as below:

$$\left[\mathbf{M}_{\mathbf{ss}}\right]\left\{\ddot{u}(t)\right\}+\left[\mathbf{C}_{\mathbf{ss}}\right]\left\{\dot{u}(t)\right\}+\left[\mathbf{C}_{\mathbf{i}}^{*}\right]\left\{\dot{u}(t)\right\}+\left[\mathbf{K}_{\mathbf{ss}}\right]\left\{u(t)\right\}=\left\{R(t)\right\} \tag{7}$$

where $\mathbf{C}_{\mathbf{i}}^{*}$ is the special damping matrix and that is:

$$\left[\mathbf{C}_{\mathbf{i}}^{*}\right]=\begin{bmatrix} A_{n}\rho v_{p} & 0 & 0 \\ 0 & A_{t1}\rho v_{s} & 0 \\ 0 & 0 & A_{t2}\rho v_{s} \end{bmatrix} \tag{8}$$

Finally equation of the motion concerning the fluid-elevated tank-soil/foundations system is

$$\left[\mathbf{M}_{\mathbf{ss}}\right]\left\{\ddot{u}(t)\right\}+\left(\left[\mathbf{C}_{\mathbf{ss}}\right]+\left[\mathbf{C}_{\mathbf{i}}^{*}\right]\right)\left\{\dot{u}(t)\right\}+\left(\left[\mathbf{K}_{\mathbf{s}}\right]+\left[\mathbf{K}_{\mathbf{ss}}\right]\right)\left\{u(t)\right\}=\left\{R(t)\right\} \tag{9}$$

Where $\mathbf{M}$, $\mathbf{K}$ and $\mathbf{C}$ are the mass, stiffness and damping matrix, subscript of ss, i and s indicate the soil-structure, boundary surface and soil.

Details of Representative Minaret

The architectural, geometrical and material properties of minarets vary widely. For example, the height of a typical minaret can be between 10 m and 55 m. The minaret may have one or more balconies. The representative reinforced concrete minaret investigated in this study is assumed to be 30 m high, including a 6 m boot or base, 2 m transition segment, 17 m cylindrical body, and 5 m spire (cap). The assumed outer diameter and thickness of the cylinder is 1.76 m and 0.18 m, respectively. Foundation is circular and its dimensions are 3 meters depth and 3 meters diameters. The plan view at the balcony level and elevation of the representative minaret are shown in Fig.6. Young's modulus and the weight of concrete per unit volume are taken to be 32,000 MPa and 25 kN/m^3, respectively.

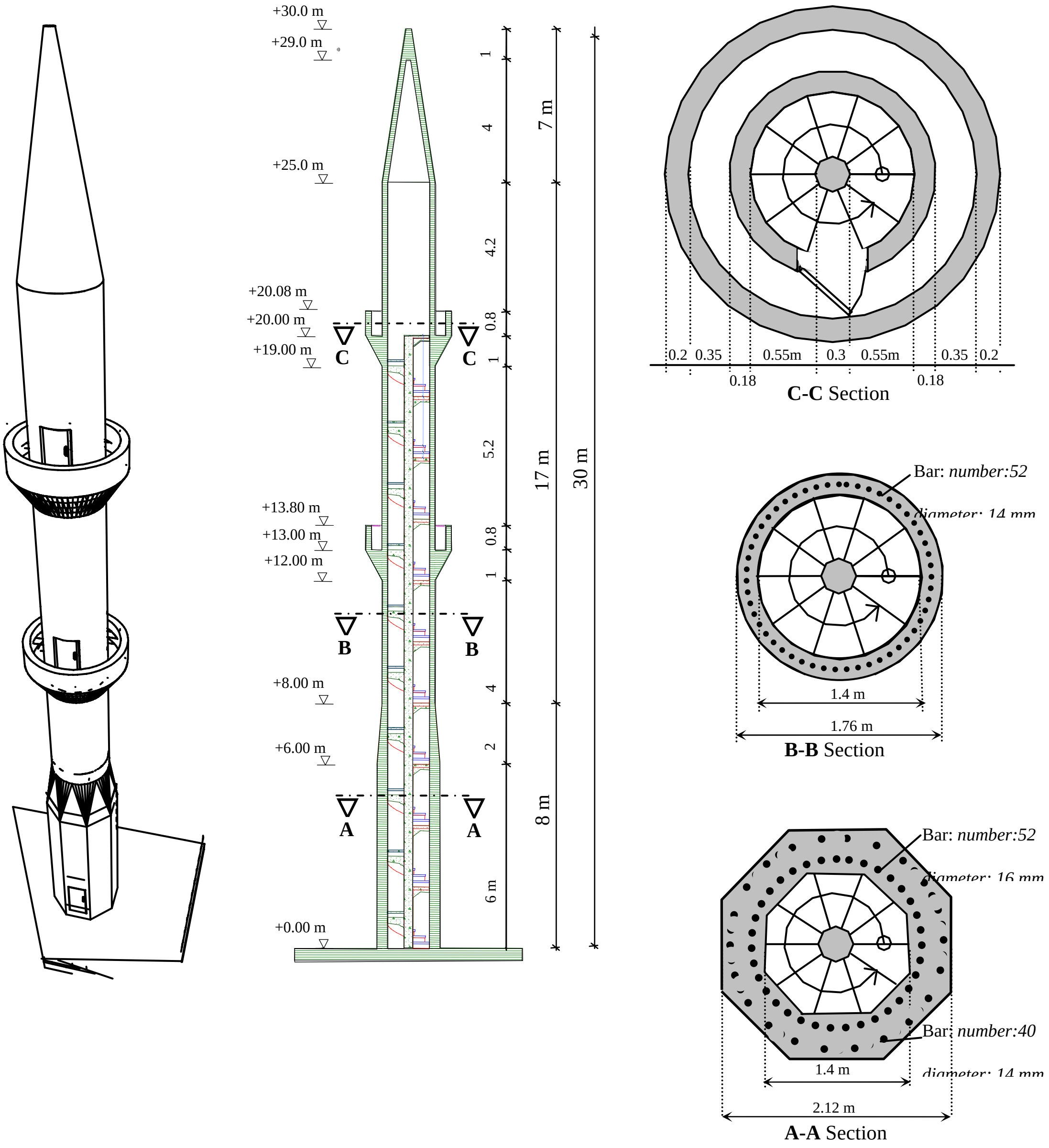


Figure-6. Vertical cross section of the reinforced concrete minaret considered for the seismic analysis.

In the seismic analysis, it is assumed that the representative minaret is subjected to North-South component of the August 17, 1999 Kocaeli Earthquake in Turkey. The ground acceleration of North-South component of this earthquake as shon in Fig.7 was taken into consideration for approximately twenty seconds.

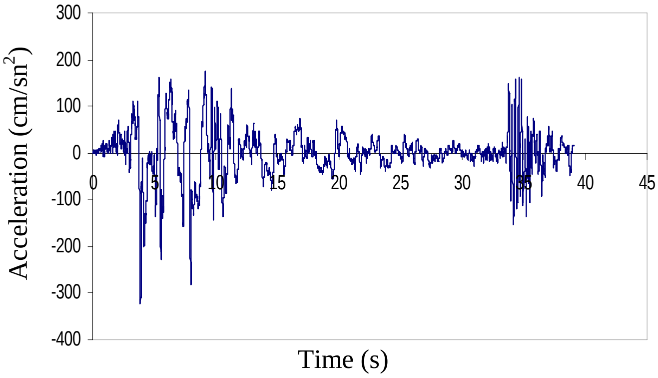


Figure-7. N-S Components of 17 August, 1999 Kocaeli earthquake.

To evaluate variations of the dynamic parameters in the minaret depending on soil conditions, three soil types as shown in Table 1 were considered. Soil conditions recommended in the literature are considered in the selection of soil types and their properties (Bardet, 1997, Coduto, 2001).

Table-1. Properties of the considered soil types

Soil types	ζ_g	Young's modulus E (kN/m^2)	Shear modulus G (kN/m^2)	Bulk modulus E_c (kN/m^3)	Unit weight γ (kg/m^3)	Poisson ratio, υ	Shear wave velocity v_s (m/s)	P wave velocity v_p (m/s)
Firm soil	5.00	7000000	2692310	9423077	2000	0.30	1149.1	2149.89
Mid-soft soil	5.00	500000	192310	673077	1900	0.35	309.22	643.68
Soft soil	5.00	35000	12500	75000	1800	0.40	82.54	202.18

As an example, first twenty seconds part of North-South components of August 17, 1999 Kocaeli Earthquake in Turkey is applied simultaneously to the system along the y-direction. All models are analyzed considering them situated on three different soil types given in Table 1. The soil medium beneath the minaret foundation is modeled with 91382 solid elements that the element has eight nodes with three degrees of freedom at each node. The viscous boundaries are modeled by using 324 elements for three dimensions per node. Full transient analyses with Rayleigh damping are performed to estimate the result of the analyses.

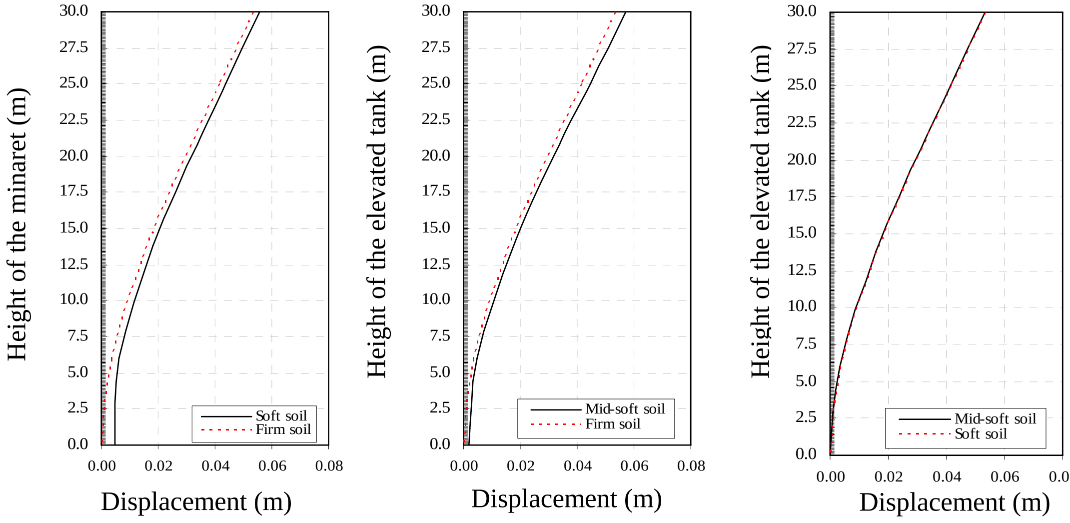
Discussion of the Analysis Results

The obtained peak values and their times for the maximum roof displacements are given in Table 2 respectively. As can be seen, these maximum responses of systems obtained about 9.15 seconds and maximum responses are calculated for the systems in soft soil type around 0.06 meters (60 mm). The best way the of the exhibits soil-structure interaction is the displacement. Therefore the displacement deviations are illustrated comparatively.

Table-2. Results obtained from seismic analysis

Soil types	Maximum roof displacement. *u*	
	time (s)	value (m)
Firm Soil	9,15	0.05
Mid-Soft Soil	9.15	0.06
Soft Soil	9.15	0.06

Maximum displacement along the height of the minaret systems are illustrated in Fig.8. From the results carried out can be seen that for the all soil type, maximum displacements are obtained at the top of the minaret systems. Over all maximum displacement however obtained for soft soil as 0.06 m. Because of the rocking response and additionally horizontal response of the soil/foundation system for softer soil type, one can easily observe the behavior. But it is worth to note that when the relative displacement are investigated, actually all system displacement coincided.



(a) (b) (c)

Figure-8. Comparisons the deviations of the maximum displacements along the height of the minarets for (a) soft and firm soil , (b) mid-soft and firm soil (c) mid-soft and soft soil types.

When the systems are evaluated for displacement history due to soil type, for almost all, it is assigned that deviations do not affects the roof displacement considerably. As can be seen from Fig.9, roof displacements of systems in soft soil type are not significantly affected by the soil type. In these models soft soil only causes 9 % increases. This is not important increases, because a big part of this increase results from horizontal response of soil/foundation response.

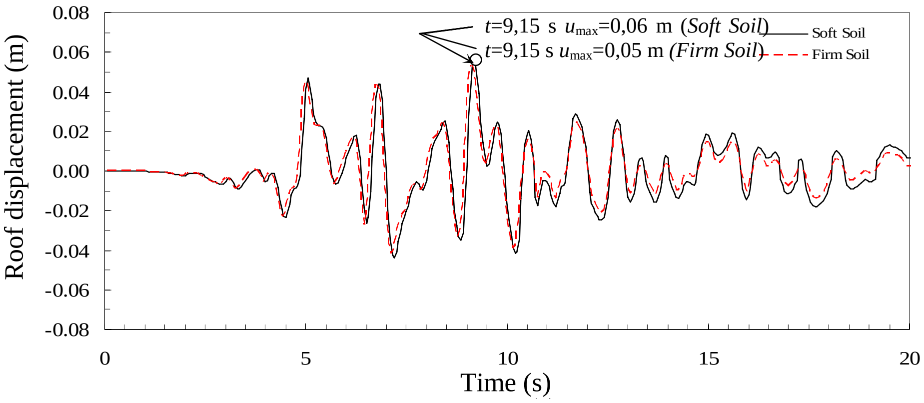


Figure-9. Deviations of the roof displacements in time for Soft and Firm soil comparatively.

Similarly, Fig.10 gives a comparison between Mid-Soft soil and Firm soil. This figure illustrated that Mid-soft soil causes also same increases with the soft soil defined in this study. Displacement obtained finally as can be seen from Fig.10 easily that the system on soft soil and the system mid-soft soil considered in this study gave almost same result. In the other words, displacement histories are coincided for these soil types.

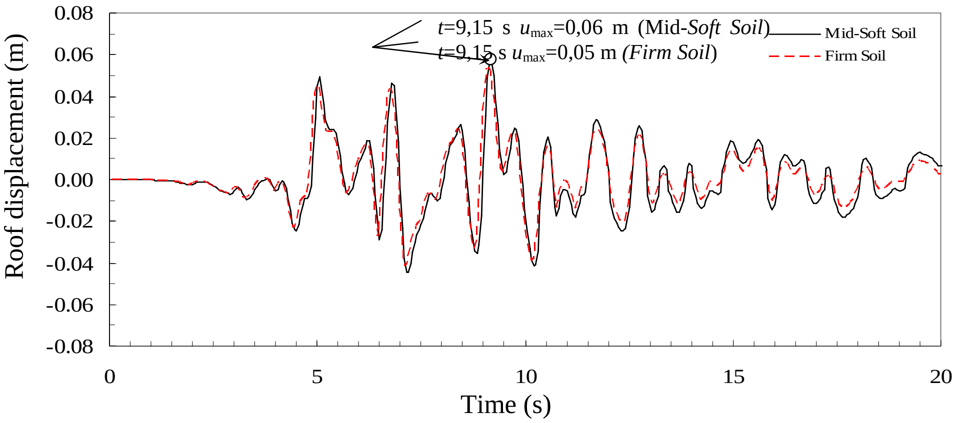


Figure-10. Deviations of the roof displacements in time for Mid-Soft and Firm soil comparatively.

CONCLUSIONS

Considering the soil interaction effect, a model is presented to determinate the effects of the interaction on minarets for seismic analysis of minaret-foundation/soil systems. The model provides to determine structural response of the system.

Generally, when soil gets softer, it is assumed that displacement considerably affected such a type of structure that is slender and based a small area. But for the minarets investigated in this study and soil type considered here, it is observed that interaction not cause significantly significant increases of displacement.

It is recommended that more numerical examples should be analyzed for different soil types and foundation conditions such as embedment ratios. After that these results presented here can be generalized.

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