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Spectral Acceleration Amplification Effects on The Ductility Demand of Self Standing R.C. Chimneys

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ABSTRACT

According to construction of industrial structures in developing countries, current research is carried out on Self Standing Reinforced Concrete Chimneys, which are a sort of special structures and is used in several types of factories. For this purpose, the 3D model of an existing Reinforced Concrete chimney of 80.0 m high and a diameter of 4.0 ~5.0 m in Armenia, is modeled and analyzed using spectral analysis procedure according to 4th revision of Iranian 2800 seismic code, taking into account the spectral acceleration level to Sa=0.4g. On the next step, the finite element model is analysed by the means of Time History Analysis method, using 3 pairs of accelerograms recorded on each soil categories of Rock (Vs>750m/s), Dense Soil (375<Vs<750m/s) and Loose Soil (175<Vs<375m/s) and Very Loose Soil (Vs<175m/s) respectively, taking into account the spectral acceleration level of Sa=0.2g ~1.0g. The Modal Pushover Analysis is carried out as well in order to determine the Yielding Displacment Δy. Finally the ductility demand for all soil categories are computed.

Keywords:

Spectral Acceleration, Self Standing R.C. Chimneys, Ductility Demand, Time History, Analysis, Yielding Displacement

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1. Introduction

Structures designed to resist moderate and frequently occurring earthquakes must have sufficient stiffness and strength to control deflection and to prevent any possible damage. Selecting a good structural system requires understanding seismic behavior of the systems available. Since stiffness and ductility are generally two opposing properties, it is desirable to devise a structural system that combines these properties in the most effective manner without excessive increase in the cost. For the seismic analysis of overground and underground structures, consideration of the soil–structure interaction becomes extremely important when the soil or the foundation medium is not very firm. During earthquake excitation, the structure interacts with the surrounding soil imposing soil deformations. These deformations, in turn, cause the motion of the supports or the interface region of the soil and thestructure to be different to that of the free field ground motion.

These interactions substantially change the response of the structure. For very stiff soil, this change is extremely small and can be neglected. Therefore, consideration of base fixity remains a valid assumption for overground structures constructed on firm soil. Similarly, the effect of soil–structure interaction on long buried structures. Such as pipelines, within firm soil is negligible as it takes the same profile as that of the soil during the earthquake motion. In order to understand the soil–structure interaction problem properly, it is necessary to have some knowledge of the earthquake wave propagation through the soil medium for two main reasons. Firstly, the dynamic characteristics of the input ground motion to the structure depend upon the modification of the bedrock motion as it propagates through the soil. Thus, the knowledge of wave propagation through the soil medium is essential to understand ground motion modifications due to soil properties. Secondly, the knowledge of the vibration characteristics of the soil medium due to wave propagation is important in relation to the determination of the soil impedance functions and fixing the boundaries for a semi-infinite soil medium, when the wave propagation analysis is performed by numerical techniques.

2. Ductility Factor Theoretical Basis

Both structural and non-structural collapses during severe earthquakes, usually occur due to lateral displacements. So the determination of the "Lateral Displacement Demand" in performance based design method is of much importance.

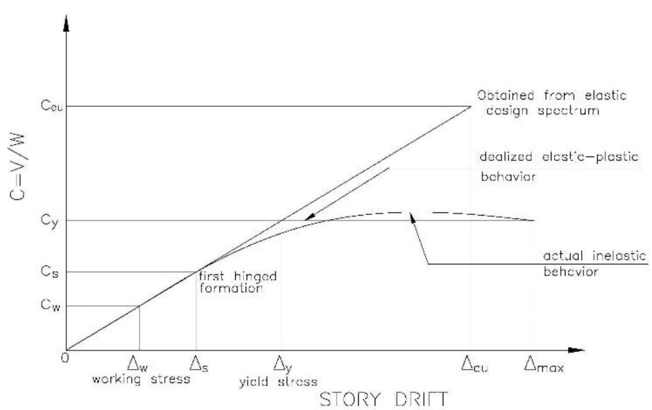

Figure 1. General seismic response of structures.

According to the reduced lateral forces, the lateral displacements computed through a linear analysis, should be increased in order to estimate the real displacements during a severe earthquake.

In Figure 1, Δmax is the maximum inelastic displacement, Δe is the maximum linear displacement. In Figure 2 the real behaviour of the structure is replaced by a bilinear elasto-plastic model. In equation 2, μ is the Ductility Factor and is described as follows:

$$\mu = \Delta_{max} / \Delta_y \tag{1}$$

3. Finite Element Model and Assumptions

The 3D model of a reinforced concrete chimney of 80.0 m high and a diameter of 5.0 m at the bottom and 4.0 m at the top. The wall thickness of the chimney is varying from t=0.8 m at the botoom to t=0.4m at the top. Both thickness and diameter reduction type from bottom of the chimney to the top of it are linear and according to Figure 2 demonstrates the finite element model, which is to beanalyzed and designed due to Iranian 2800 seismic code, for soil types I~IV and Sa=0.20g~1.0g spectral acceleration levels. Time History analyses are also performed on model. Later, by performing a "Modal Push-over Analysis" the Yielding Displacement Δy of the structure due to FEMA 356 guideline is achived. By using achieved results of Time History analyses, demanded ductility factors are computed for model using equation (1), according to records based on estimated site specifications and mentioned spectral acceleration levels. The structural concrete is estimated to have a 28 days strength of f'c=240 kg/cm2 and the reinforcing rebars are AIII type with a yielding stress of Fy=4000 kg/cm2 .

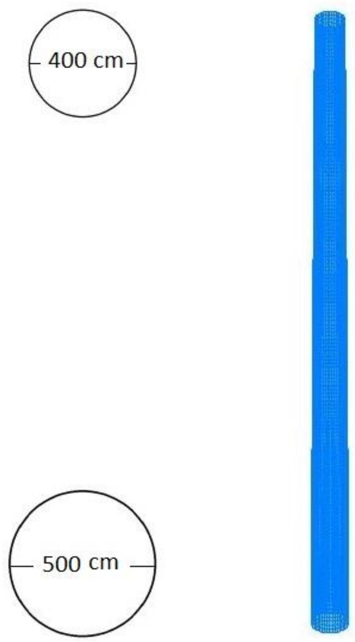

Figure 2. Conceptual analytical model.

Nonlinear Pushover analyses are completed using Perform-3D analysis software. For analysis purposes, the lumped mass method is used for determination of the total mass of the material inside of the model. The computed mass of the material is uniformly distributed on the framework of the model. In order to illustrate the structural concrete nonlinear behavior, the "Takeda" model is taken into account.

4. Time History Analyses

In order to perform the time history analyses, 3 pair of accelerograms of earthquakes listed in Table 1 are selected. Accelerograms are recorded on each soil type, based on Iranian 2800 seismic code requirements, then scaled to spectral acceleration level of Sa= 0.20g ~ 1.0g respectively.

Table 1. Characteristics of used Earthquake Records

Event	Year	Mag.	Mechanism
Irpinia-Italy	1980	6.9	Normal
Tabas-Iran	1978	7.35	Reverse
Loma Prieta	1989	6.93	Reverse-Oblique
Northridge	1994	6.69	Reverse
San Fernando	1971	6.61	Reverse
Landers	1992	7.28	Strike-Slip
Hector Mine	1999	7.13	Strike-Slip
Westmorland	1981	5.9	Strike-Slip
Imperial Valley	1979	6.53	Strike-Slip

Later the scaled records were applied to the finite element models due to the soil type and spectral acceleration levels mentioned above. For Time history analyses, the " Direct Integration" technique was used and for both models were completed using Newmark – β method, using $\gamma = 0.5$ & $\beta = 0.25$. Due to structural characteristics, the damping ratio was determined equal to 0.05 for the first two modes of vibrations.

5. Analysis Results

In Figure 3 Push-over diagrams of estimated three dimensional finite element model of reinforced concrete chimney is shown. According to this diagram, the R.C. chimneys mainly dissipate the seismic induced energy in linear range.

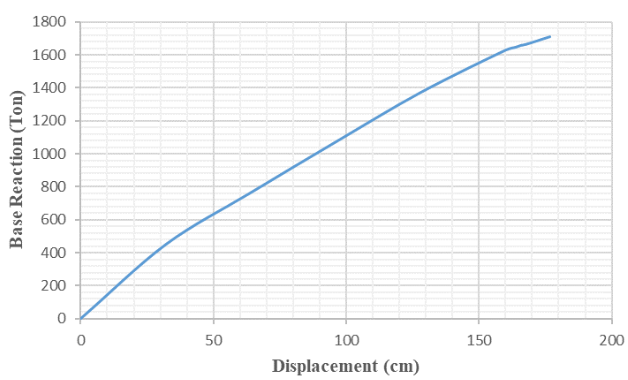

Figure 3. Push-over Diagram of the Model

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The results of ductility demands are based on soil specifications and spectral acceleration levels as shown in Table 2 and Figure 4 respectively.

Table 2. Summarized Mean values of Ductility Demand factors.

Soil Type	Mean Values				
	0.20g	0.40g	0.60g	0.80g	1.0g
Rock	------	1.76	2.17	1.63	3.72
Dense Soil	------	1.46	1.81	1.60	3.10
Loose Soil	------	1.59	2.32	1.74	3.97
Very Loose Soil	------	1.85	2.70	2.02	4.63

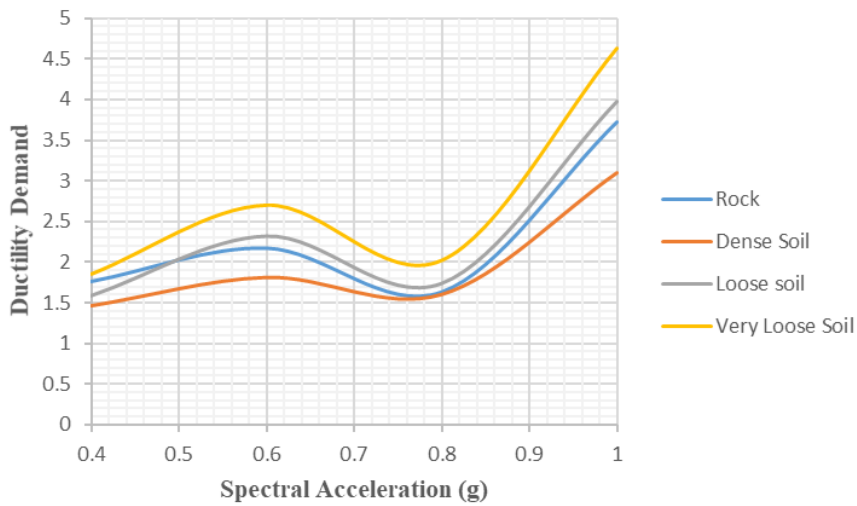

Figure 4. Diagrams of Mean Ductility Demand versus Spectral Acceleration.

6. Conclusions

The computational results of finite element analysis of estimated structure illustrate that by degrading the soil category the ductility demand increases, regardless of the frequency content effects of the earthquake records. All diagrams of ductility demand versus spectral acceleration show two turning points at 0.60g and 0.75g. Generally the randomness of results decrease while the soil category degrades, regardless of frequency contents of earthquake records. Ductility demand amplification due to soil category degradation, illustrates the effect of the nonlinear structural behaviour in filtering of low frequency content of selected accelerograms. As could be seen in Figure 4, the results for Rock and Loose Soil are almost the same which also coincides with the result of Dense Soil only at the turning point with 0.75g spectral acceleration. This fact indicates on demonstrating the same Ductility Demand for two mentioned soil types which is also applicable on Dense Soil on turning point. Due to this fact, it could be indicated that the combination of duration, frequency content and peak ground acceleration (PGA) of the used records are to be the main causes of this special event, which could be changed for another sets of records.

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