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RELIABILITY ASSESSMENT OF A REINFORCED CONCRETE CHIMNEY UNDER EARTHQUAKE LOADING

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ABSTRACT

This paper presents the reliability assessment of a 100.5m reinforced concrete chimney at a glass factory under earthquake loading. Uncertainties in the input motion, material properties and also modeling assumptions affect the reliability of the chimney. The influence of all these uncertainties was investigated. In order to describe the uncertainties due to input motion, a moderate-size earthquake occurring close to the site and a large earthquake occurring far from the site were considered. Aside from uncertainties due to input motion, influence of uncertainties in structural parameters and modeling assumption were also investigated. For this purpose, finite element models (FEM) were built up by considering different modeling assumptions and structural parameters. It was concluded that the fundamental period of the chimney has different values due to above mentioned uncertainties. In this study, time history analyses were carried out to obtain base reactions of two cases that consider a moderate-size earthquake occurring close to the site and a large earthquake occurring far from the site separately. Probability density function of over-turning moments and a specified threshold value were used to estimate the failure probability. It was observed that the failure probability of the chimney is more under the large earthquake motions occurring far from the site.

1. INTRODUCTION

Uncertainties in both input motion and structural properties should be taken into consideration. These uncertainties affect the reliability assessment process of a structure. Load and resistance factor approach based on the fundamental principles of reliability have been investigated for decades. (Shinozuka, 1983). This approach caused the development of a statistical framework for reliability-based design. Furthermore, some studies have been conducted to determine resisting factor for probability-based design of the tubular reinforced concrete sections (Kareem, Hsiesh, 1988). Seismic reliability analyses considering the uncertainty in the input motion were also carried out (Shinozuka, 1983). Modeling assumptions such as considering soil condition is crucial for tower-like structures since they have longer periods. The effect of soil condition on the fundamental mode of a chimney has been investigated in the literature (Halabian, Kabiri, 2011). Performance-based assessment of a concrete chimney has been the subject of many researchers. Goyal & Maiti examined inelastic seismic resistance of reinforced concrete stack-like structure (Goyal, Maiti, 1997). They presented a procedure that quantifies the difference between inelastic seismic resistance and elastic seismic resistance in terms of displacement ductility factors. Furthermore, Huang and others also investigated performance of a collapsed chimney during Izmit earthquake in 17 August 1999 (Huang et al., 2004). They had demand-capacity comparisons after completing linear and non-linear analyses. Few studies have been

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done to investigate the reliability of a reinforced concrete chimney under wind loading (Kareem, Hsiesh, 1986).

This paper starts by describing chimney characteristics, followed by a summary of uncertainties and their influences on the chimney. Next, the earthquake analysis results briefly were summarized. Finally, probability density function of responses was constructed for over-turning moment at the base. The failure probability was found under a certain threshold. Reliability assessment of the chimney was presented.

2. CHIMNEY CHARACTERISTICS

The chimney has been commissioned and is in service nowadays. The chimney is located in Bozuyuk, in the south east of the Marmara Region in Turkey and it is approximately 250-300 km far away from Istanbul. The chimney is 100m tall and outer diameter is 9700 mm at base and 5750 at top. The wall thickness starting from the base 30 cm decreases by 20 cm. It was constructed by ENDEM Construction Co. in 2012 .The concrete class used in construction is C 30 (fc'=30 MPa). Fig.1 presents the view of the chimney.

Figure1. View of the chimney at a glass factory located in Bozuyuk.

3. UNCERTAINTY IN THE MATERIAL (STRUCTURAL) PROPERTIES

Young's modulus of concrete for specified concrete class is computed by different equations in accordance with codes.

TS 500 gives,

$$E_c = 3250\sqrt{f_c} + 14000 \text{ (MPa)} \quad (1)$$

ACI 318 gives,

$$E_c = 4700\sqrt{f_c} \text{ (MPa)} \quad (2)$$

Eurocode (EN 1994) gives,

$$E_c = 22\left[\frac{(f_c + 8)}{10}\right]^{0.3} \text{ (GPa)} \quad (3)$$

Furthermore, in calculating time dependent deformations, the modulus of the elasticity is reduced. The reduced value is a function of the level of loading, age of concrete, humidity, temperature and time.

However, it can be said that for a specimen kept under load for two years, Young’s modulus of concrete can be decreased to ½ or even 1/3 of its initial values (Ersoy et al., 1984).

Finite element models (FEM) of the chimney have been built up by means of SAP2000. 18000 shell elements are used in the model and the structure is fixed supported at the base. Finite element model of the chimney is presented in Fig.2.

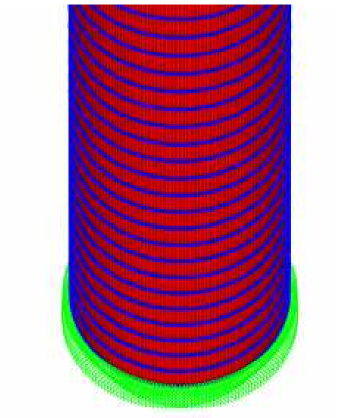

Figure2. Finite Element Model (FEM) of the chimney built up by shell elements.

Finite element models (FEM) were built up for different Young’s modulus values and analyzed. The first and second period values were obtained for all models and presented in Table.1.

Table1. 1st&2nd period values obtained for different Young’s Modulus

1st & 2nd Periods		
PERIOD (sec)		
TS500	ACI 318	EC1994
E =31800	E =25743	E =32840
1.246	1.385	1.226
0.278	0.309	0.274
E/2=15900	E/2=12872	E/2=16420
1.763	1.959	1.735
0.394	0.437	0.387

Table.1 indicates that the period of the chimney has different values for the equation of each Young’s modulus given in the codes.

Generally, there is an opening near the base of the chimney for the liner (flue duct) that is the part of the chimney which gases are exhausted to the outside air. The effect of openings on first and second period of the chimney was investigated and values were tabulated in Table.2.

Table2. 1st & 2nd period values obtained for the model w/ and w/o openings

1st & 2nd Periods (w/o) openings
TS500
E =31800
1.246
0.278

1st & 2nd Periods (w/) openings
TS500
E =31800
1.282
0.285

The difference was found 3% in percentage between two cases. In accordance with results obtained from analyses above, uncertainties in material properties affect the fundamental period of the structure.

4. UNCERTAINTY IN THE MODELING ASSUMPTIONS

Different types of finite element modeling assumptions were also used. Structural models have been built up by using frame elements and shell elements separately. The properties of the model built up shell elements were presented previous section.
Table.3 presents the 1^{st} period values of model built up shell and frame elements. The difference between two values is 2.25%

Table3. 1^{st} & 2^{nd} period values obtained for the model w/ and w/o openings

1^{st} Period (Beam Model)	1^{st} Period (Shell Element Model)
PERIOD (sec)	PERIOD (sec)
TS500	TS500
E=31800	E=31800
1.274	1.246

On the other hand, in order to include the influence of soil conditions, a model including a foundation with soil springs was built up. Soil springs are assigned to the points of the mesh beneath foundation. Soil spring values were calculated by multiplying the subgrade modulus of soil with unit area. Besides, another model that soil layers were represented by solid elements was built up. There are two layers under the foundation presented as in Fig.4. The properties of soil layers were tabulated and presented in Table.4.

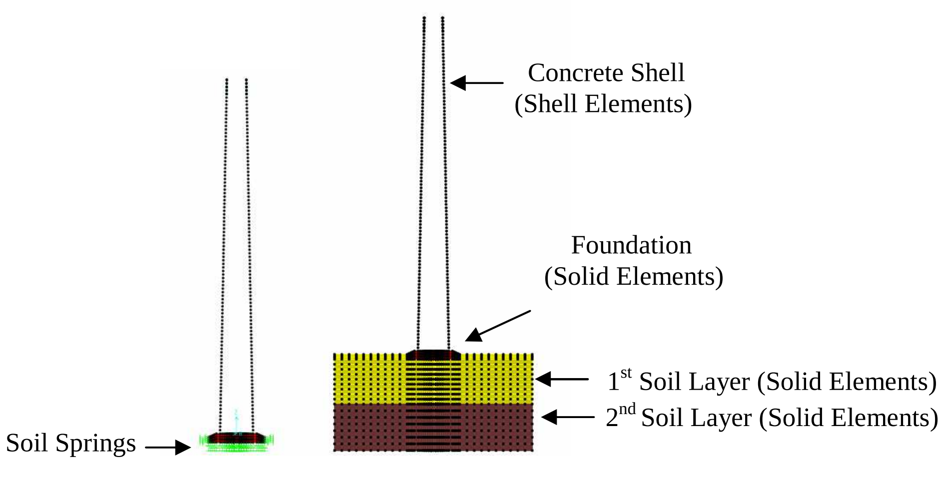

Figure4. Finite element models (FEM) of the chimney that soil conditions are represented by using different modeling assumptions

Shear modulus and elastic modulus were calculated by using equations

$$G = \rho V_s^{\,2} \tag{4}$$

where ρ is specific density of soil, V_s is shear velocity

$$E = 2G(1+\upsilon) \tag{5}$$

Table4. Properties of soil layers

Soil Type	Height (m)	Shear Velocity(m/s)	Specific Weight (kN/m^3)	Poisson Ratio	Shear Modulus (kN/m^2)	Elastic Modulus (kN/m^2)
Soil Layer 1	15	300	16	0.45	144000	417600
Soil Layer 2	15	600	22.4	0.35	806400	2177280

Soil spring forces assigned beneath the foundation were also calculated by using the formula

$$q_{\lim 1} = \rho v_{s1} \tag{6}$$

$$k_{soil} = 40 q_{\lim 1} \tag{7}$$

k_{soil} represents the soil spring force and was founded as 20000 kN/m. The 1st period values for soil spring model and soil solid model were obtained separately and presented as in Table5.

Table5. 1st period values obtained for different modeling assumptions for soil

1st Period (sec)-Shell Model
Foundation Solid Elements
ksoil=20000
1.85

1st Period (sec)-Shell Model
Foundation Solid Elements
1.91

Table.5 points out that there are two separate values which were obtained by using different modeling assumptions. For soil spring model 1st period was found as 1.85 sec. and for soil solid element model it was also found as 1.91 sec. Comparing those results with fixed supported model, 1st period values were higher 48.4 %, 53.4% than fixed supported model, separately. That is to say, modeling assumptions have a remarkable effect on the calculation of the period values.

5. UNCERTAINTY IN THE INPUT MOTION

Spectral accelerations at longer periods are more critical for chimneys as they are tall structures. For this reason, a moderate-size earthquake occurring close to the site and a large earthquake occurring far from the site were considered. 37 earthquake records which have magnitudes between 6.5 and 8 were selected and mean spectra were plotted for two cases. Mean spectra of earthquake records were plotted for close distance- 0 to 30 km from the source (fault)-and far distance -30 to 100 km from the source Fig. 6 presents the mean and individual spectrum plots for both cases. The fault locations around the chimney are indicated as in Fig.5. The basic characteristics of some selected records were also given in Table.6.

Table 6. The basic characteristics of some selected records

EQ	Record	Magnitude	PGA(g)	Epicentral Distance (km)
Duzce	Bolu	7.14	0.7662	41.27
Duzce	Duzce	7.14	0.4273	1.61
Duzce	Lamont 1062	7.14	0.2101	29.27
Duzce	Lamont 362	7.14	0.0348	43.54
Imperial Valley	El Centro	6.95	0.2584	12.99
Kobe	Kakogawa	6.9	0.2668	24.2
Kobe	Nishi-Akashi	6.9	0.4862	8.7
Kobe	Osaj	6.9	0.0762	47.49
Kobe	Shin-Osaka	6.9	0.2293	45.79
Kobe	Takarazuka	6.9	0.7069	38.6
Kocaeli	Duzce	7.51	0.3255	98.22
Kocaeli	Izmit	7.51	0.2037	5.31
Kocaeli	Ambarli	7.51	0.2228	112.26
Loma Prieta	Anderson	6.93	0.2385	26.57
Loma Prieta	BRAN	6.93	0.5263	9.01

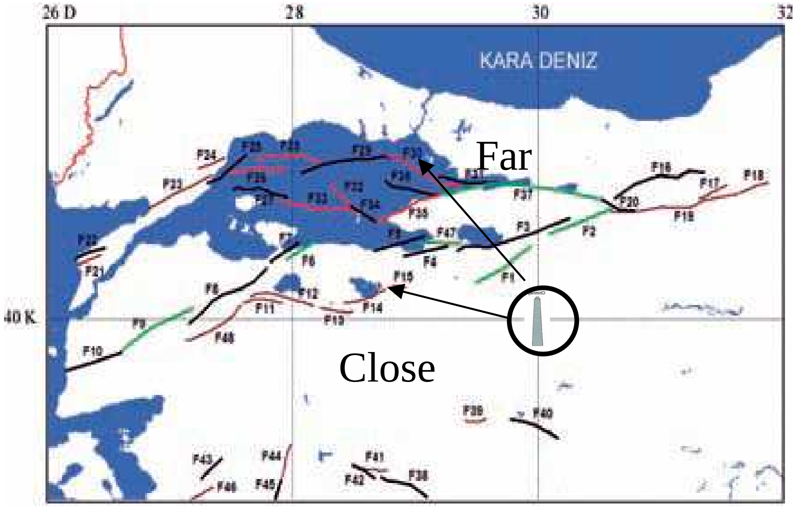

Figure5. Active faults in Marmara Region and segmentation of faults and the location of the chimney (Kalkan E., Gülkan P.)

The mean spectra of earthquake occurring at close and far distance were plotted. Furthermore, seismic hazard maps (KOERI) are utilized to get spectral acceleration values of T= 1.0 sec and T=0.2 for a design earthquake which has a 10% probability of exceedance in 50 years in TSC were obtained.Fig.7 shows the seismic hazard map for a design earthquake which has a 10% probability of exceedance in 50 years.

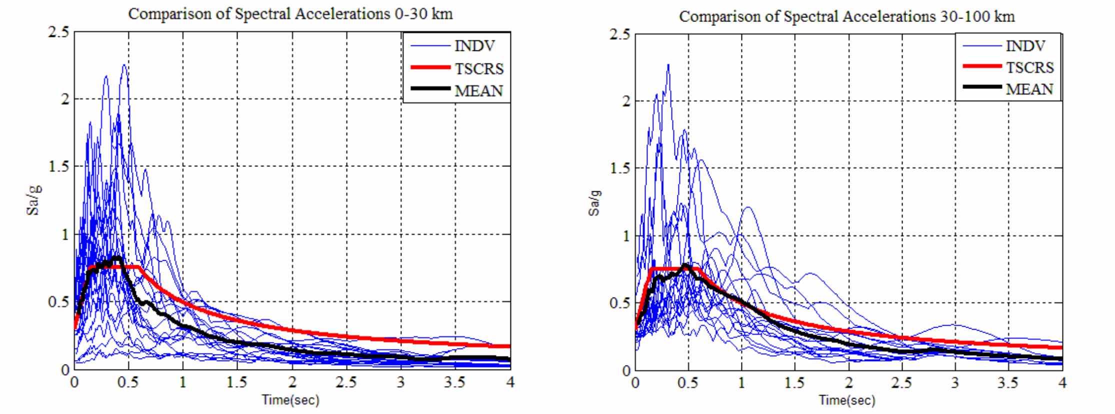

Figure6. Mean and individual spectrum for close and far distances

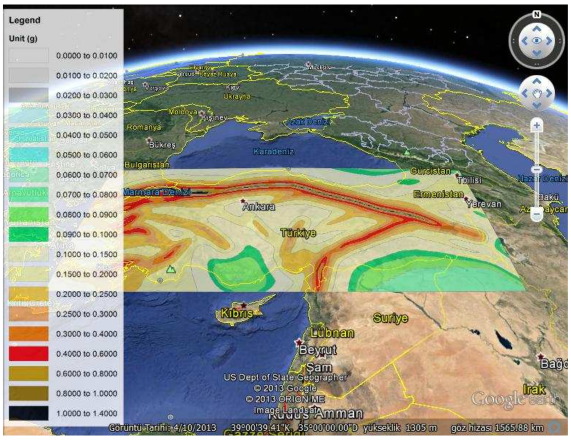

Figure7. Seismic hazard map for a design earthquake which has a 10% probability of exceedance in 50 years.(KOERI)

Besides, spectral acceleration values were obtained for T= 1.0 sec is b/w 0.25 g and for T=0.2 sec is 0.60 g by using seismic hazard map. Eventually, Fig.8 provides that three different approaches give different result in terms of spectral acceleration values.

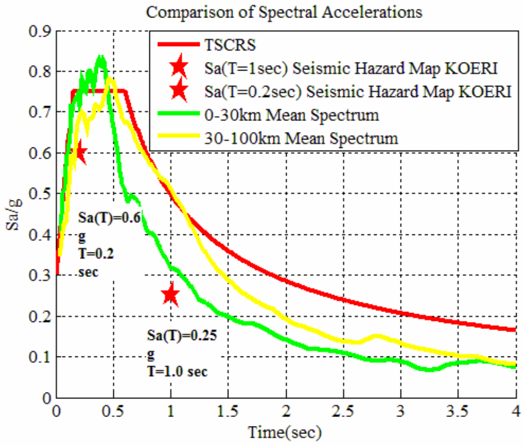

Figure8. Comparison of spectral accelerations

6. EARTHQUAKE ANALYSIS

As indicated in previous chapter, mean spectra were plotted for a moderate-size earthquake occurring close to the site and a large earthquake occurring far from the site. A detailed finite element model (FEM) of the chimney was built up and earthquake analyses were carried out for 37 records.

Over-turning moment responses at the base were obtained for some selected records and were tabulated as in Table.7.

Table7. Over-turning moment responses at the base for some records

EQ	Record	Overturning Moment(kNm)
Duzce	Bolu	287709
Duzce	Duzce	277107
Duzce	Lamont 1062	64240
Duzce	Lamont 362	38400
Imperial Valley	El Centro	143006
Kobe	Kakogawa	138885
Kobe	Nishi-Akashi	224298
Kobe	Osaj	90706
Kobe	Shin-Osaka	146829
Kobe	Takarazuka	542265
Kocaeli	Duzce	201814
Kocaeli	Izmit	176502
Kocaeli	Ambarli	144752
Loma Prieta	Anderson	115239
Loma Prieta	BRAN	299351

7. RELIABILITY ASSESSMENT OF THE CHIMNEY

Probability density function of responses were constructed for over-turning moment at the base obtained in earthquake analysis for two cases. The threshold value for the over turning moment at the base is the yield moment carrying capacity in accordance with CICIND. Yield moment carrying capacity was determined by using moment-curvature analysis as shown in Fig.9.

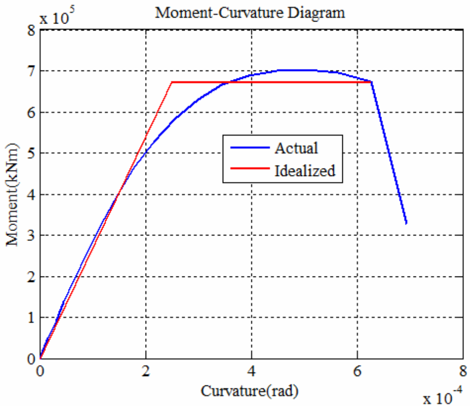

Figure9. Moment-curvature diagram of the chimney section at the base

In accordance with Fig.9,the yield moment capacity of section was found as My = 670000 kNm and yield curvature was found as $\phi_y = 0.00025 rad/m$.

Lognormal probability density functions for over-turning moment at the base for two cases were plotted as presented in Fig.10.

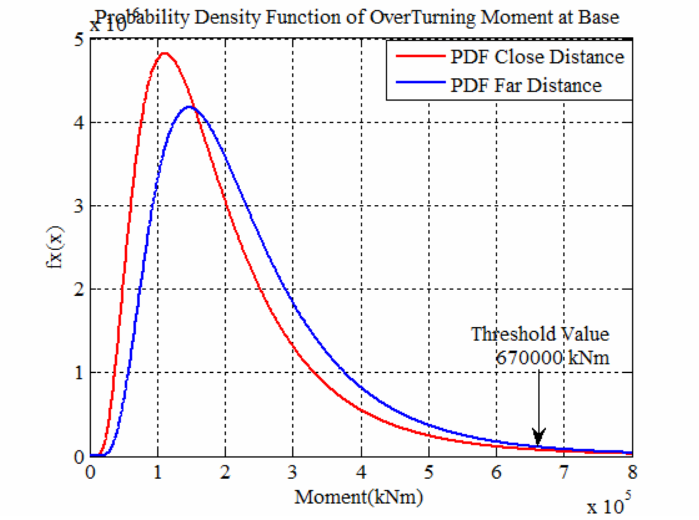

Figure10. Lognormal probability density function for over-turning moment at the base for two cases

The failure probability under earthquakes with moderate magnitude occurring at near distance is to be $0{,}28.10^{-5}$, and the failure probability under earthquakes with larger magnitude occurring at far distance is $44.\ 10^{-5}$. The maximum allowable failure probability value is given as 0.0001 for these types of structures in accordance with CICIND. Therefore, it was concluded that the reliability of system is good enough considering the maximum allowable failure probability.

CONCLUSIONS

Uncertainties in the input motion, material properties and also modeling assumptions affect the reliability of the chimney. The influence of all these uncertainties was investigated.

Firstly, a moderate-size earthquake occurring close to the site and a large earthquake occurring far from the site were considered.

Finite element models (FEM) were built up for different Young’s modulus values and analyzed. The period of the chimney has different values for the equation of each Young’s modulus given in the codes. The effect of openings on first and second period of the chimney was also investigated. Uncertainties in material properties affect the fundamental period of the structure.

Different modeling assumptions were used in order to take into account soil condition. For soil spring model the first period was found as 1.85 sec. and for soil solid element model this value turns out to be 1.91 sec. Comparing those results with fixed supported model, the first period values were higher 48.4 %, 53.4% than fixed supported model, separately. Modeling assumptions have a remarkable effect on the calculation of the period values.

The failure probability under earthquakes with moderate magnitude occurring at near distance is to be $0{,}28.10^{-5}$, and the failure probability under earthquakes with larger magnitude occurring at far distance is $44.\ 10^{-5}$. The main reason for this difference is that spectral acceleration values close to the first structural period are higher for large magnitude earthquakes occurring at far distances. The maximum allowable failure probability value is given as 0.0001 for these types of structures in accordance with

CICIND. Therefore, it was concluded that the reliability of system is good enough considering the maximum allowable failure probability.

There is also an on-going component of this study which is related with the structural health monitoring of the chimney. Vibration measurements will be taken and modal identification of the chimney will be carried out. FEM updating procedures will also be applied to the chimney by using the results of experimental measurements, vibration-based modal identification is important in terms of representing existing conditions. Uncertainties in the structural properties can be decreased by updating the finite element model FEM. Eventually, reliability assessment of the chimney can be obtained more accurately by using updated FEM.

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