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Dynamic Seismic Spectrum Analyses of a 120 m High Reinforced Concrete Chimney According to Turkish Building Earthquake Code 2018 (TBEC-2018)

Zeki KARACA[1a], Erdem TÜRKELİ[*2b], Aslı ÇİÇEK[1c]

[1]Ondokuz Mayıs University, Faculty of Engineering, Civil Engineering Department, 55139, Samsun
[2]Ordu University, Vocational School of Technical Sciences, Construction Department, 52200, Ordu

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Abstract: Reinforced concrete chimneys are tall and slender structures that are more vulnerable to seismic actions. In recent earthquakes, many of them severely damaged or totally collapsed. Therefore, it is an inevitable duty to analyze the structural response of these tall and slender structures under different seismic codes. In this study, the structural response of a 120 m high RC chimney under the seismic spectrum provided in Turkish Building Earthquake Code 2018 is determined. At the end of the analyses, the top displacement and base shear is obtained and the top displacement is compared with the limit value provided in ACI 307/98 that this comparison showed that the considered chimney is safe (only on the basis of top displacement comparison). Also, other linear and nonlinear seismic analyses should be performed to verify the structural response results obtained in this study.

1. Introduction

Reinforced concrete (RC) chimneys are tall and slender structures that are used in industrial facilities having the responsibility of waste gases to be thrown away. Nowadays, due to the limitations in environmental regulations, their heights are increasing that is responsible for slenderness and vulnerability to earthquakes. The height of RC chimneys are ranging from 60 m. up to 350 m.

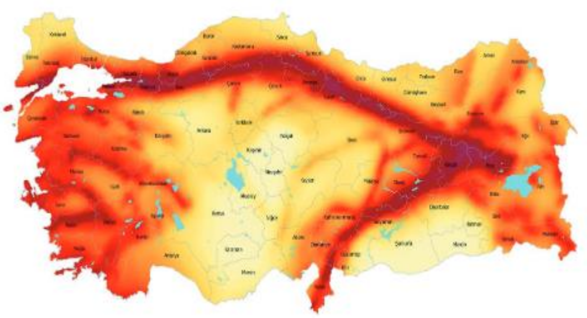

Figure 1. Earthquake hazard map of Turkey [1]

Also, Turkey can be counted as one of the active tectonic region in the World (Fig.1). From Fig.1 [1], the red zones indicated the active tectonic regions. Therefore, the dynamic seismic analyses of RC chimneys should be executed carefully.

There are some linear and nonlinear analyses methods that can be utilized in the seismic analyses of RC chimneys. Linear analyses are consisting of equivalent earthquake method, response spectrum method and time history analyses. Other than these, nonlinear seismic methods i.e. pushover (static) and nonlinear time history analyses. In the nonlinear methods, the real dynamic behavior of the constituting materials should be known. For example, in the case of RC chimneys, the real nonlinear behavior of RC should be known. To do that some of the theories were provided in the technical literature [2,3]. However, in the case of linear modelling, there is no need to analyze the nonlinear response of the constituting materials. In this study, the linear elastic behavior of the representative RC chimney is considered in the dynamic seismic spectrum analyses.

In the technical literature, there are some studies dealing with the dynamic seismic response of RC chimneys. Wilson [4] dealt with nonlinear seismic response of RC chimneys by conducting an experimental program. At the end of these

**Corresponding Author: erdemturkeli@odu.edu.tr ORCID: 0000-0002-4293-4712*
a ORCID: 0000-0003-1130-5259
b ORCID: 0000-0002-4293-4712
c ORCID: 0000-0001-8659-0600

experiments, some of the code recommendations were suggested. Zhou et. al [5] dealt with the fragilities of a 240 m. high RC chimney by considering lumped mass beam. Karaca et. al [6] studied about the effect of FRP strengthening on the dynamic seismic response of RC chimneys. To do that the stress and displacement comparison of strengthened and unstrengthened RC chimneys were performed. Türkeli et. al [7] studied about the effect of body spacings on the seismic and wind response of RC chimneys. In the study, it was shown that these spacings considerably increased the percentage of tensile and shear stresses. Jiang et. al [8] presented a numerical algorithm to analyze earthquake response of tall RC chimneys based on stick multidegree-of-freedom models.

From technical literature search, it is clearly seen that there is no any other study that deals with the dynamic seismic spectrum analysis of RC chimneys by using Turkish Building Earthquake Code 2018 (TBEC-2018) [9]. Therefore, this study is believed to be beneficial for engineers in practice and academicians.

In this study, the dynamic seismic spectrum response of a 120 m high RC chimney is investigated by using the spectrum provided in Turkish Building Earthquake Code 2018 (TBEC-2018). To do that a RC chimney is selected from the technical literature [10] and the spectrum cited above is applied to the chimney. At the end of the study, the top displacement, base shear, modal parameters of the chimney are presented.

2. Structural Information and Finite Element Model (FEM) of the Chimney

As indicated in the introduction part of the study, a 120 m high RC chimney is selected for the dynamic seismic response investigation. The outer diameter of the chimney at the bottom and top are 12.00 m and 8.50 m, respectively. Also, the wall thickness at the bottom and top are 0.60 m and 0.26 m, respectively. The bottom of the chimney is accepted as fixed to the ground as no soil-structure interaction is taken into account. Moreover, the spacing for the flue entrance is not taken into account.

In the FEM (Fig.2) of the cited RC chimney, 10 equal 12 meters high non-prismatic circle-sectioned concrete bars are utilized by using SAP2000 structural analysis software [11]. There are two translational and one rotational degree of freedom (total three) in the nodes that joins the concrete bars.

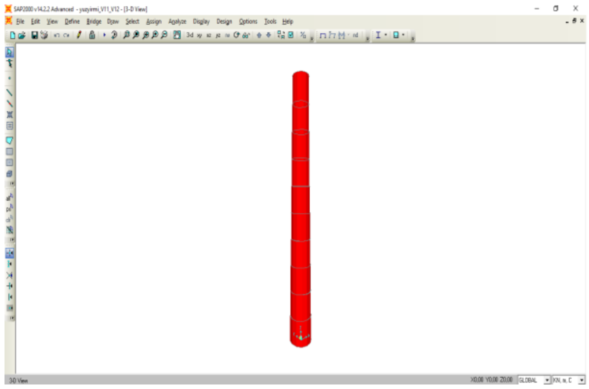

Figure 2. FEM of the chimney considered in this study produced in SAP2000 [11]

The cited chimney is constructed from RC that has unit weight, module of elasticity and Poisson's ratio are 25 kN/m³, 30.000.000 kN/m² and 0.2, respectively. With the information provided above, two-dimensional linear dynamic analysis is performed by utilizing the structural analysis software SAP2000.

4. Design Spectrum according to Turkish Building Earthquake Code 2018 [9]

The ordinate of the horizontal elastic response spectrum is provided with Eq.(1)-(4).

$$S_{ae}(T) = \left(0.4 + 0.6\frac{T}{T_A}\right)S_{DS} \qquad (0 \le T \le T_A) \qquad (1)$$

$$S_{ae}(T) = S_{DS} \qquad (T_A \le T \le T_B) \qquad (2)$$

$$S_{ae}(T) = \frac{S_{D1}}{T} \qquad (T_B \le T \le T_L) \qquad (3)$$

$$S_{ae}(T) = \frac{S_{D1}T_L}{T^2} \qquad (T_L \le T) \qquad (4)$$

In these equations, S_{DS} and S_{D1} are the design spectral acceleration coefficients. Also, T is denoting the natural vibration period. The corner points of the horizontal design spectrum, T_A and T_B, can be given in Eqs.(5) and (6) depending on the coefficients S_{DS} and S_{D1}.

$$T_A = 0.2\frac{S_{D1}}{S_{DS}} \qquad (5)$$

$$T_B = \frac{S_{D1}}{S_{DS}} \qquad (6)$$

By this way, the horizontal design spectrum is given in Fig.(3).

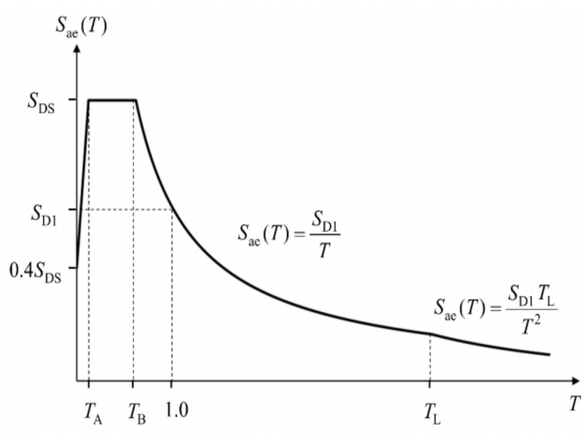

Figure 3. Horizontal design spectrum according to TBEC-2018 [9]

5. Dynamic Spectrum Analysis of the Chimney according to Turkish Building Earthquake Code 2018

In order to analyze the chimney, before dynamic spectrum analyses according to Turkish Building Earthquake Code, a structural modal analysis is performed. According to this modal analysis, the modal frequencies (also the modal periods) and the mode shapes of the first five modes are provided in Fig.4.

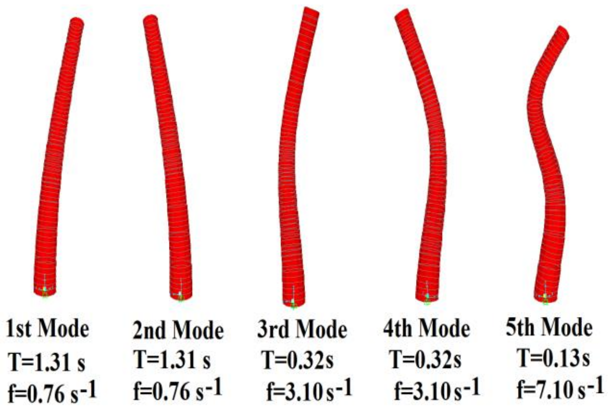

Figure 4. Modal information of the 120 m. high chimney considered in this study

In technical literature [12], it is emphasized that the modes that have cumulative mass ratios over 90 % is enough for the dynamic analyses. Therefore, the 120 m high considered is analyzed for 24 modes in the dynamic analysis. In Table 1, the sum of the total mass participations of first eleven modes are represented. It can be clearly seen that even in the first 11 modes, the sum of total mass is over 90 %. Therefore, it is enough to analyze the first 24 modes of the considered chimney in the dynamic analysis.

Table 1. Total participating mass ratios of the considered 120 m high chimney

Mode Number	Sum (X)	Sum (Y)
1	0,14007	0,38537
2	0,52544	0,52544
3	0,59509	0,70083
4	0,77048	0,77048
5	0,77948	0,87102
6	0,88002	0,88002
7	0,88002	0,88002
8	0,92613	0,89035
9	0,93645	0,93645
10	0,96620	0,93727
11	0,96701	0,96701

In order to determine the relevant parameters for constructing the horizontal design spectrum according to Turkish Building Earthquake Code 2018 [9], the exact coordinates of the structure on the earth should be known. In this study, it is accepted that the location of the considered chimney is in the Tüpras Refinery in Kocaeli, one of the largest petroleum refinery in Turkey (Note: There is no any real chimney in Tüpras Refinery like the one considered in this study). From the interactive web application of the Turkey Earthquake Risk Map (Fig.5) [13], the parameters relevant for the dynamic analysis of the 120 m high RC chimney is obtained.

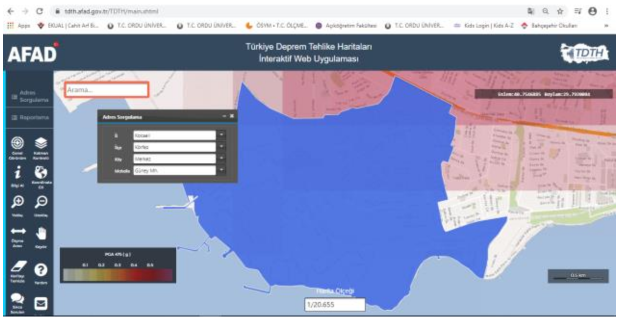

Figure 5. Turkey Earthquake Risk Map Web Application [13]

From the reporting part of this application cited above, for DD-2 earthquake ground motion level and ZA local site class, a detailed report is obtained. DD-2 is denoting the earthquake ground motion level that have the probability of exceedance 10 % (repetition period 475 years) over 50 years. Also, for the considered chimney, soil-structure interaction is not taken into account. Therefore, ZA soil type (sound, hard rock) is preferred for the dynamic analysis. For the soil and earthquake ground motion level cited above, the parameters S_{DS} and S_{D1} are determined as 1.336 and 0.364, respectively. The obtained horizontal design spectrum is provided in Fig.6.

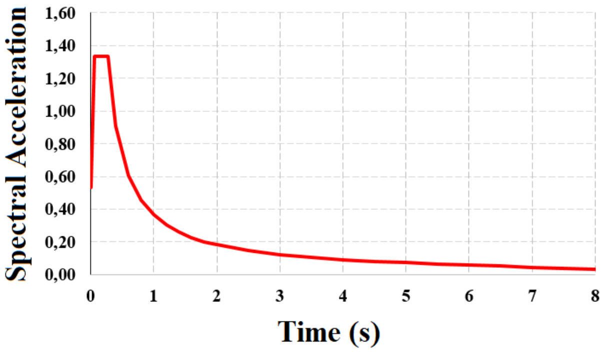

Figure 6. Horizontal design spectrum obtained for 120 m high chimney

The horizontal design spectrum given in Fig.6 is applied to 120 m high chimney by using SAP2000 structural analyses software. The modes are combined with complete quadratic combination (CQC) method. At the end of the dynamic horizontal design spectrum analysis, the displacement at the top of the chimney is obtained as 0.23 m (23 cm). Also, the reaction at the base of the considered chimney is obtained as 14764 kN.

ACI 307/98 [14] specifies a deflection criterion for the maximum lateral deflection of the top under all service conditions prior to the application of load factors. This is represented in Eq.(7).

$$Y_{max} = 3.33 \cdot h \quad (7)$$

In Eq. (7), Y_{max} is denoting maximum deflection in mm and h is denoting the height of the chimney in meters. According to ACI 307/98, the maximum deflection limit of the chimney can be calculated in Eq.(8).

$$Y_{max} = 3.33 \cdot 120 = 399.60\ mm = 39.96\ cm \quad (8)$$

It can be clearly identified that the top deflection of the considered chimney under the spectrum defined in Turkish Building Earthquake Code (2018) is lower than the top deflection limit provided in ACI 307/98.

6. Conclusions

In this study, the dynamic horizontal seismic spectrum analysis of a 120 m high RC chimney is performed by utilizing a recently published code, Turkish Building Earthquake Code (2018) [9]. The novelty of this code is to provide earthquake accelerations on the basis of the location that the structure is constructed. To do that, firstly, the location of the structure is determined on the interactive web application of the Turkey Earthquake Risk Map [13]. After that, the relevant parameters such as S_{DS} and S_{D1} are determined for constructing the horizontal seismic design spectrum. At the end, the spectrum analysis is performed by using the structural analysis software SAP2000.

On the basis of the dynamic seismic spectrum analysis, the displacement at the top and the reaction at the base of the considered chimney is obtained as 0.23 m (23 cm) and 14764 kN, respectively. Also, the top displacement obtained from the dynamic seismic spectrum analysis (Turkish Building Earthquake Code 2018) is compared with the one (limit deflection) provided in ACI 307/98. Depending only on the top deflection comparison, the considered 120 m high RC chimney can be considered as safe. However, as these kind of tall and slender structures, these linear dynamic seismic analyses should be compared and supported with nonlinear seismic analyses.

Acknowledgement

This study is dedicated to the venerable memory of our greatest and wise teacher Prof. Dr. Ing. Ahmet Durmuş.

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