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Determination of the Most Effective Location of Environmental Hardenings in Concrete Cooling Tower Under Far-Source Seismic Using Linear Spectral Dynamic Analysis Results

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ABSTRACT

The feeling of the need to build longer cooling towers increases with the development of the capacity of hydropower plants. So the engineers are trying to design leaner towers, with more buckling resistance using environmental hardening rings. Several studies have investigated the effect of wind strength on these structures, but the effect of seismic acceleration on these structures has been less studied. In this study, by investigating the results of linear spectral dynamic analysis, the optimum location of environmental hardening rings is determined under the influence of earthquake acceleration. The effect of thickness and number of hardening rings on the performance of the tower is also investigated, and the optimum relationship between these two parameters is extracted technically and economically. Different analytical methods can be used to investigate this issue, but using the spectral analysis method besides considering the buckling effects of the tower crust is the most appropriate analytical method for these types of structures.

1. INTRODUCTION

The hardening ring is an environmental hardening incorporated into the inner part of the concrete cooling tower shell. The increase in the capacity of the power plants and consequently the need to increase the height of these towers led to maintaining the stability of the shell as it is one of the most important issues in the design of the structure and therefore the designers used environmental Hardening rings to solve this problem [1, 2].

However, as with other structures, the embedded hardener must be adapted to all aspects of the design. It is also important to think about the most suitable location for these rings to reduce interference in the operation of the tower.

When designing hardening rings, wind energy is generally considered as the main external factor, and also, given the great importance of seismic acceleration in high seismic regions, the influence of this factor on the location of the hardening ring must also be evaluated. There are various methods for analyzing this structure, such as spectral analysis and time history methods. The design spectral method is the most logical and economical method for analyzing seismic cooling towers [3].

2. SOFTWARE MODEL SPECIFICATIONS

In this study, there is a cooling tower located in an area of high relative risk with a height of about 130 meters, and the following table specifications are taken into consideration.

Table 1. Geometrical characteristics of cooling tower structure

d_F	d_B	d_I	d_T	H_F	H_B	H_I	H_T
106.366	89.58	61.18	63.06	0	27.65	113.25	133.25

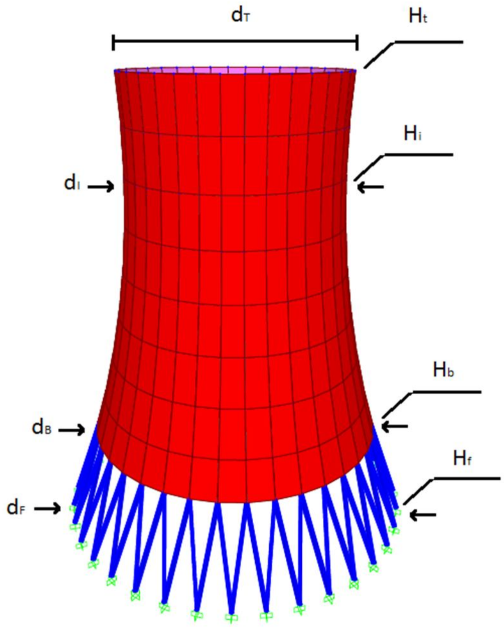

Figure 1. Geometric characteristics of the tower

The tower has 36 pairs of V-Leg shaped rectangular columns with a cross section of 0.77 square meters. In this study, 15th version of Sap 2000 software was used for modeling and analysis.

The Frame element is used for column modeling and the Shell element for shell modeling. The staple joint is considered for the columns connection to the ground. The shell is divided into eight levels in height and 36 in the area. The thickness of the tower shell is 120 cm in the lower part, which gradually decreases as the upper part

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reaches 20 cm. Also the compressive strength of concrete in columns and shell is 28 MPa. Also, regardless of the thermal effects on the tower crust and cracks in the crust, when calculating the main periodicity of the crust, the crust is taken into account without cracking, because the crust does not crack in the first seconds of the earthquake and therefore a lot of lateral force is applied.

In this study, hardening rings with a thickness of 30, 60, 90 and 120 cm thick and six times the minimum thickness of the crust (120 cm) were used. Also, the hardening ring element was similar to the shell element and the type of concrete ring was also considered in terms of compressive strength according to the shell [5, 6, 7].

3. SHELL BUCKLING ANALYSIS

In order to determine the best location of hardening rings, the shell buckling analysis was initially performed without any hardening rings under unit load caused by seismic acceleration in the X direction. Then, the location with the most deformation in the shell was selected as the location of the first hardening ring. Thereafter, in addition to the first ring, the second hardening ring was positioned at different elevation levels of the shell.

The criterion for determining the most suitable location for the second ring was obtaining the highest buckle positioning factor. Then the most suitable site for the third and fourth hardening rings was determined according to the results of the buckle analysis of the shell. This was repeated for all four thicknesses of the hardening ring.

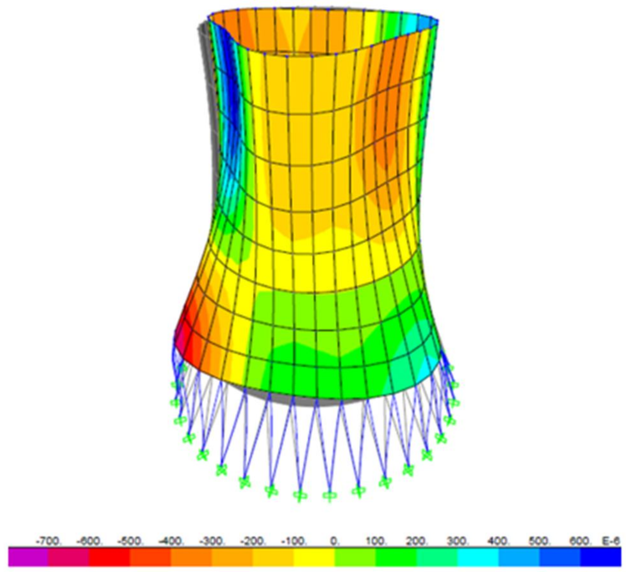

Figure 2. The amount of deformation in the tower shell without the presence of hardening ring

According to the results of the buckling analysis of the tower shell, the best location for the environmental hardening rings was found for 1 to 4 rings and four different thicknesses according to Table 2.

Table 2. The most appropriate location for hardening rings (height in meters from base level)

	Single ring	Double Rings	Three Rings	Four Rings
Thickness of 30 cm	27.65	38.64	106	119.6
Thickness of 60 cm	27.65	38.64	106	119.6
Thickness 90 of cm	27.65	38.64	106	51.9
Thickness of 120 cm	27.65	38.64	106	51.9

It was also shown in Figure 3 that as the number of hardening rings increased, the increase rate of the first buckling mode factor decreased. This means that increasing the number of hardening rings from a reasonable amount based on engineering calculations does not necessarily mean obtaining a buckle mode factor. Secondly, increasing the thickness by assuming a constant number of rings will give a better result than increasing the number of rings with constant thickness. That is, if there is a need to increase the strength of the tower crust against buckling caused by the earthquake acceleration, considering the minimum number of hardening rings with the required thickness is a better method and considering this by the designer, with respect to the running cost of each hardening ring, helps make the design more economical.

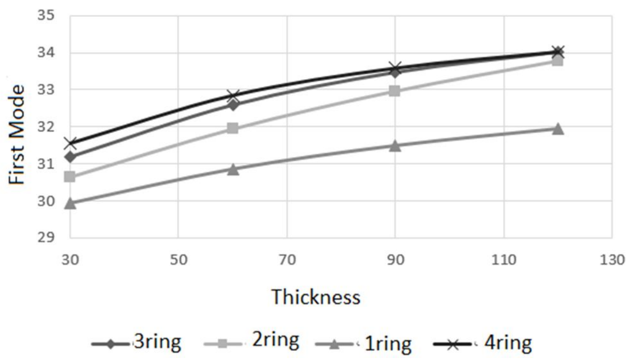

Figure 3. The Thickness and Number of Hardening Rings - First Buckling Mode Factor

4. SPECTRAL DYNAMIC ANALYSIS

Spectral dynamic analysis was performed using the standard design spectra 2800 as well as the seismic design regulations of the oil industry installations and structures. In order to evaluate the effect of the presence of peripheral hardening ring on the behavior of the tower according to the results of the dynamic analysis, the parameter of the nodal displacement parameter of the tower shell was used. In preparing the spectra obtained from each hazard level, the effect of uncertainty on earthquake recognition parameters, such as geographic location of the earthquake center, focal depth, fault displacement rate, orientation and diffusion rate, and mechanical properties of the seismic source environment, must be taken into account. In this paper, considering the effect of the far-source seismic on the cooling tower, there is no need to carry out site studies and specify the above parameters. After modal analysis, it was found that the main mode of structure with 46% mass participation was the sixth mode and the main periodicity of the structure was 0.74 seconds.

After dynamic analysis of the number of four hardening rings of four different thicknesses, it was found that with increasing number and thickness of the hardening ring, the rate of nodal displacement in the tower shell increases with a very small amount. That is, considering the hardening ring to any number and any thickness does not have a positive effect on reducing the displacement of the cooling tower shell. It was also found that increasing the thickness of the hardening ring assuming a fixed number of rings would have a greater effect on increasing the maximum displacement in the tower shell.

Figure 1-4 shows the results of the maximum displacements obtained from spectral analysis for the modes of 1 to 4 hardening rings for all four thicknesses of 30, 60, 90 and 120 cm.

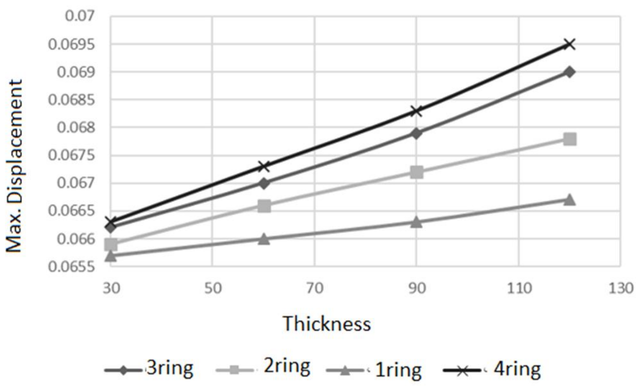

Figure 4. Thickness and number of hardening rings - Maximum displacement in tower shell

5. CONCLUSION

The following results were obtained from the conducted studies:

- The best location for the environmental hardening rings will vary depending on the number of hardening rings.

- Consideration of more than 4 environmental hardening rings due to the force of the seismic acceleration does not have a significant effect on increasing the buckling strength of the cooling tower shell.

Installation of more than 3 hardening rings for tower under wind power is not suitable for concrete cooling towers [4].

- Increasing the thickness of the hardening ring is more effective than increasing the number of rings in increasing the buckling strength of the tower shell.

- Considering the hardening rings to any number and to any thickness has no effect on reducing the nodal displacement of the tower shell.

In this paper, the influence of the presence of an environmental hardening ring on the cooling behavior of the cooling tower under the force of earthquake acceleration was investigated using the results of the spectral dynamic analysis as well as shell buckling analysis. However, considering only the extent of the displacement of the tower shell as a control parameter, precisely identifying the behavior of these hardening rings against seismic requires careful consideration of other effective control factors that will be discussed in future research.

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