# Seismic Behavior of Column-supported and Innovative Fixed-base Cooling Towers with Ring Beam


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**SUMMARY**
The recent destructive earthquakes consequences have revealed vulnerability of cooling towers and the vital role of them in the safety and performance of power plants during and after a strong ground motion, especially in the nuclear power plants. While, in the design of traditional cooling tower system; wind load is often taken as the governing lateral load case; and usually X-shaped columns are prescribed for supporting the cooling towers at the base level, even in the high seismic zones. It can be also mentioned that some of the failures happen in connecting systems of non-structural elements to cooling towers, which are almost near to the base level; therefore, reduction or control of the seismic responses at the base level may result in improvement of the seismic performance of the cooling towers. Hence, this study focuses on seismic behavior of cooling towers and on finding solutions for reduction of earthquake effects on the system. In that regard, seismic behaviors of cooling towers have been analytically investigated. In the numerical study, iso-parametric solid element has been used for the finite element modeling, and time-integration dynamic analyses have been performed. A new model, in which the columns are replaced with a ring beam at the base, is also analyzed. The responses of the column-supported tower are obtained and compared with those of a tower is fixed at the base with the ring beam. The results show that in the column-supported cooling, potential of the buckling occurrence in the columns increases due to the compressive stresses effects, while in the ring beam supported cooling towers, stresses at the base level considerably decrease. From view of the findings, the ring beam system is proposed as an alternative structural system for the cooling towers in the high risk zones.



*Keywords: Cooling tower; Seismic load; Dynamic analysis; Fixed Base; Column Supported*


## 1. INTRODUCTION

A nine magnitude earthquake in Japan has resulted destructive disaster in the power plant, the quake occurred in what is called a subduction zone, where one of the Earth's tectonic plates is sliding beneath another. The lack of any significant activity in the design and construction of new nuclear power plants over the last two decades has resulted in a corresponding lull in the basic academic research carried out in this field. The natural draught cooling tower is very important and essential component in the thermal nuclear power stations and industrial power plant. Due to their complexities in geometry the analysis of such type of structures has been attracted by many researches throughout the world.

Due to failure of Cooling towers in UK 1965, 1984, Scotland 1973 and France 1979, the analysis of cooling tower attracted the attention of many investigators to account the proper physical, material and loading modelling of cooling towers, for example: Abbu-Sitta (1972) had presented Ring-Stiffened hyperbolic cooling towers under static wind loading. Equations for the interaction between a hyperboloidal shell of revolution and a top boundary ring beam were derived and solved with the general shell equations for two sample cooling towers. It was shown that the ring beam effect is local and influences mainly the meridional moment and the circumferential force, a typical edge disturbance. Karisiddappa (1995) carried out the analysis of column supported cooling towers for unsymmetrical wind loads. Improved 3D finite element formulation of column supported hyperbolic cooling towers and the realistic circumferential wind pressure distribution which is unsymmetrical had been carried out. Consequently for different wind pressure distribution profiles meridional membrane forces exhibit more sensitivity towards the pressure variations.

Gran (1983) employed a doubly curved memberane quadrilateral shell finite element to obtain the static response of a fixed base cooling tower under dead load only. This element has been developed with the intention of its application to study the response of the column supported cooling towers. Gupta (1985) had an Investigation on hyperbolic cooling tower ultimate behaviour. It was shown that a significant redistribution of meridional stresses occurs after yielding of the reinforcement, thus, increasing the ultimate strength beyond that predicted from the elastic analysis.

Rao (1994) presented the Stress resultants in hyperbolic cooling tower shell subjected to foundation settlement. The effect of differential settlement of columns supporting a natural draught hyperboloid cooling tower on the stress resultants in the tower shell was analyzed using discrete finite element modeling of the shell and the supporting base. It is shown that the stress concentration can be severe up to seven times the average stress resultants for dead load, and up to five times the average stress resultants for the foundation settlement. Chaojin Xu (1996) developed soil-structure interaction and partial foundation uplift for tower structure. Parametric studies were performed to evaluate the effects of soil stiffness, ratio of tower height to foundation width and partial separation of the foundation from the soil. It was demonstrated that the effects of soil stiffness on a short tower are greater than slender one. The height-width ratio affects the seismic response of the tower significantly, the allowance of foundation uplift my substantially reduce the seismic response of moment and also uplift is not always beneficial and its effects could be significant for structures under strong seismic motions.

P.Bazzurro (1996) presented a methodology for the evaluation of the annual probability of occurrence of post-elastic seismic damage in realistic structures. The structural performance was investigated by conducting appropriate non-linear dynamic analyses for a limited set of real ground-motion records that might potentially pose a threat to the structure at the site. The seismic damage hazard was analyzed by coupling conventional seismic hazard analysis for the site and the structural response to earthquakes of different intensities. Karisiddappa (1998) represented the tower shell by semi-loof shell elements and the supporting columns by semi-loof beam elements, hoop forces altered significantly in the lower portion of the shell near the column- shell junction.

J.M.Roesset (1998) presented selection of the design earthquake and its characteristics, evaluation of soil effects and soil structure interactions, dynamic analysis and design of the structures. J.Noorzaei, Ali Naghshineh (2006) investigated on physical and material modelling of a cooling tower–foundation–soil system. The physical modelling had been carried out using solid 20-noded isoparametric element to model the cooling tower, annular raft foundation and soil media. The cooling tower–foundation–soil system was analysed under vertical and lateral load generated due to self-weight and wind loads. The soil nonlinearity had been taken into consideration using hyperbolic nonlinear elastic constitutive law. The response of the structure had been investigated with respect to displacement and stresses. Moreover, an attempt was made to study the effect of the linear and nonlinear interactive analyses compared with conventional analysis. It was seen that the interactive analysis of the cooling tower–foundation–soil media plays a major role in releasing the stresses in the cooling tower.

## 2. PROBLEM DEFINITION

The present investigation is focused on the:

I. A comprehensive 3-D model was developed a column supported hyperbolic cooling tower and it's supporting annular raft and the fixed based hyperbolic cooling tower.
II. To explore the effect of ring beam on the overall response of cooling towers.
III. Linear analysis of the cooling tower under vertical and lateral loads generated due to self and seismic loads; the response of the tower has been compared with that of a tower whose supporting columns are fixed at the base.

Since, a comparative study has been made between the two cooling towers, the linear analysis could be adequate for showing the main advantages of the proposed system. The large natural draft cooling tower for a nuclear project presented by Tilak, Fig.2.1, has been considered as case study in the present investigation analysis. The details of geometry and material properties of this tower are as follows:

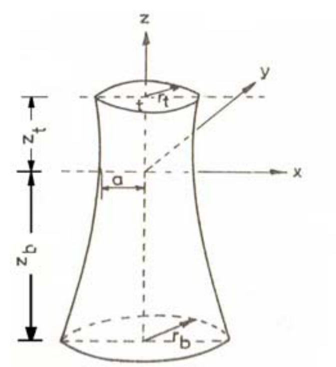



**Figure 1.** Cooling tower geometry (After Fonder and Clough, 1973)

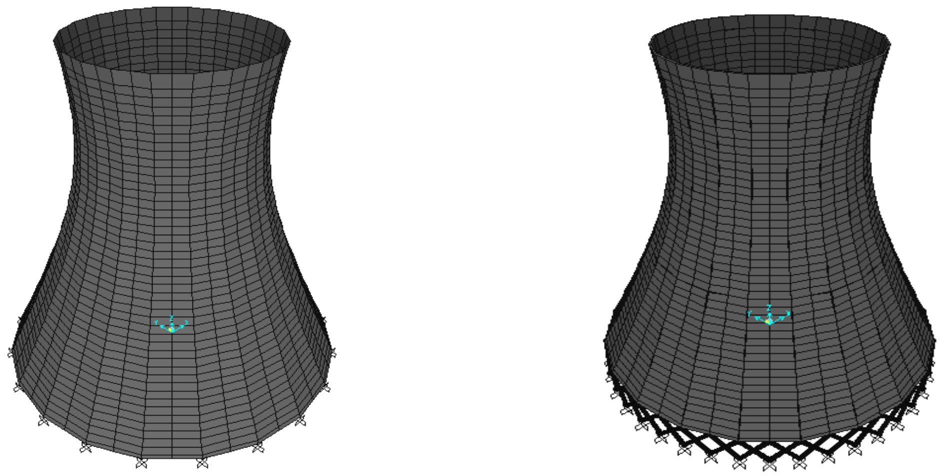
**Table 2.1.**Geometric and Material Details of Hyperbolic Cooling tower.

| No | Parameter Description | Symbol | Parametric value |
|---|---|---|---|
| 1 | Height above throat level | Z t | 24.09 m |
| 2 | Height below throat level | Z b | 91.26 m |
| 3 | Radius at top | r t | 27.535 m |
| 4 | Radius at bottom | r b | 52.877 m |
| 5 | Radius at throat level | a | 25.304 m |
| 6 | Shell thickness at top | t t | 0.5 m |
| 7 | Shell thickness at bottom | t b | 0.7 m |
| 8 | Shell thickness at throat level | t | 0.17 m |
| 9 | Young's modulus for shell | E | 285 x 104 t/ m2 |
| 10 | Poisson's ratio for shell | μ | 0.18 |

## 3. SEISMIC LOAD SIMULATION

Two hyperbolic cooling tower models have been prepared for this investigation, namely, Fig. 2.2:

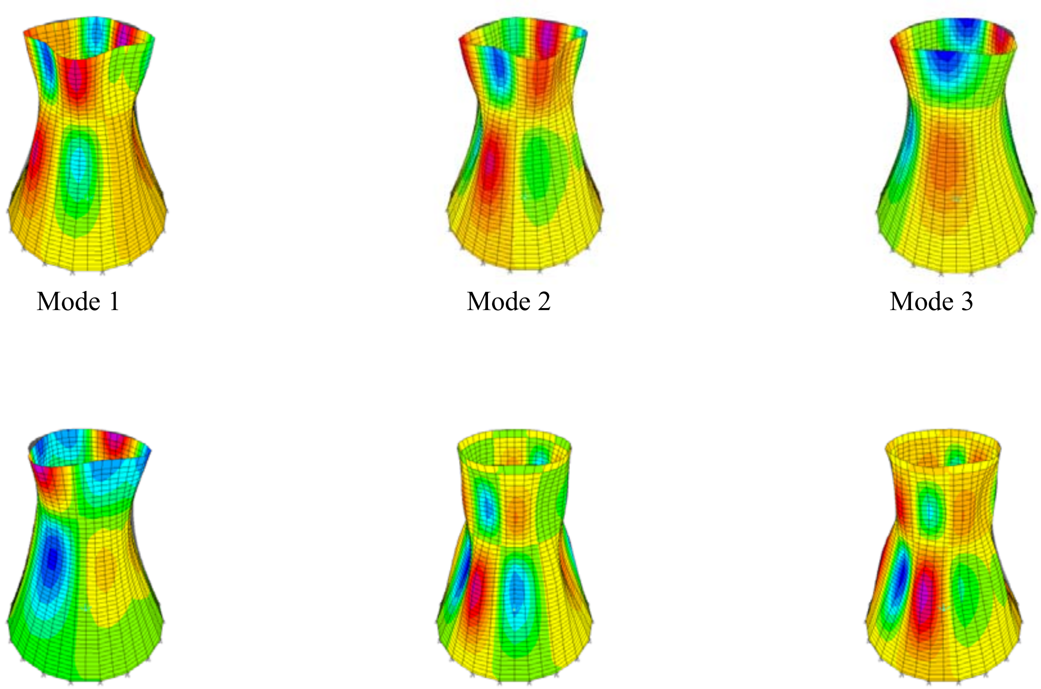
I. Model-I: Fixed Base Analysis (FBA).
II. Model-II: Column Supported Analysis (CSA).



Model-I Model-II

**Figure 2.** FBA&CSA Models of cooling towers

Variation of deformed shape for FBA and CSA models for different modes of 1 to 6 are presented in Fig.3.3 and Fig.3.4. As it appears mode shapes in FBA model are more stable in cooperation with mode shapes in CSA model. Increasing period in the first modes of CSA model, shows that function of these structures have more flexibility and can observe more energy which is not an advantage with respect the function of these structures, these differences are minimised in higher modes as demonstrated in Table 3.2.



Mode 1 Mode 2 Mode 3

Mode 4 Mode 5 Mode 6

**Figure 3.** Variation of Deformed Shape FBA Mode 1,2,3,4,5,6

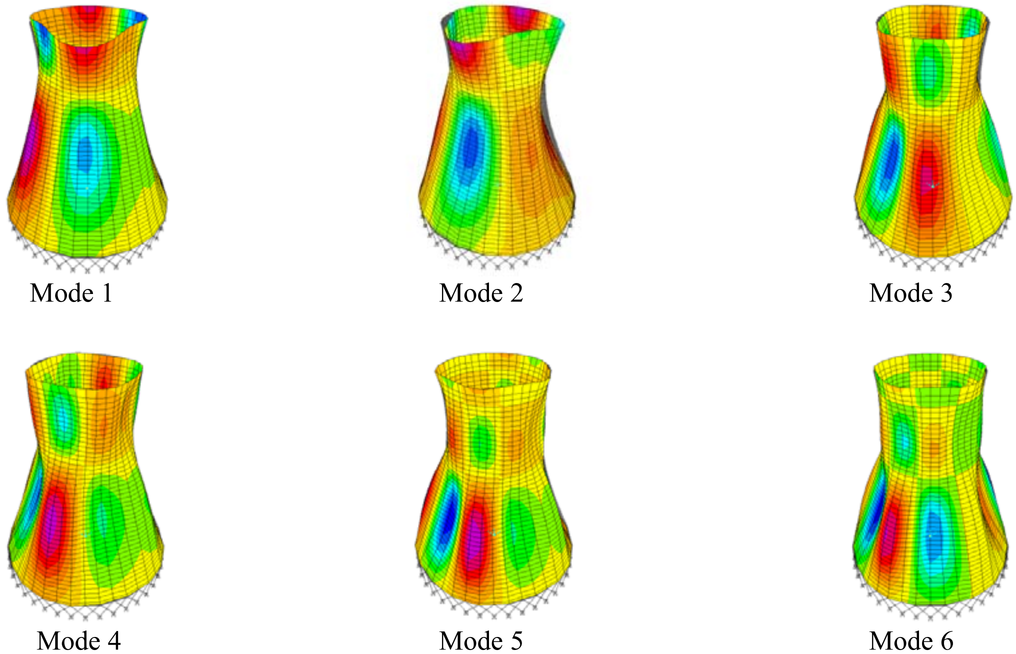


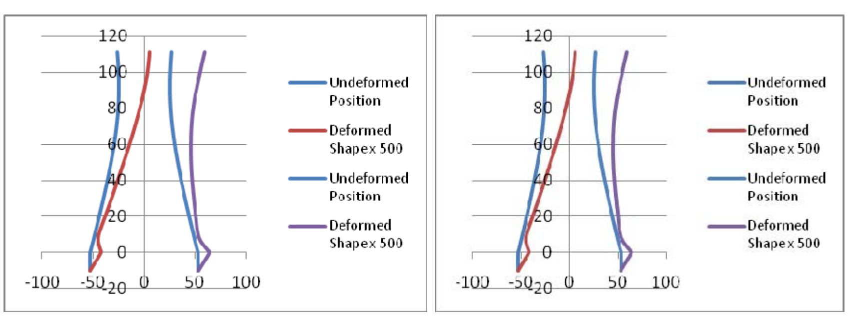

**Figure 4.** Variation of Deformed Shape CSA Mode 1,2,3,4,5,6

**Table 3.2.** Periods and Frequencies

| OutputCase | StepNum | Period(FBA), sec. | Period(CSA) |
|---|---|---|---|
| MODAL | 1 | 0.608019 | 1.064584 |
| MODAL | 2 | 0.608019 | 1.064582 |
| MODAL | 3 | 0.5662 | 0.946665 |
| MODAL | 4 | 0.5662 | 0.946664 |
| MODAL | 5 | 0.521057 | 0.695933 |
| MODAL | 6 | 0.521057 | 0.695932 |

## 4. RESULTS AND DISCUSSION

The variation of radial displacements along the height of the tower at different meriodinal angles are exhibited in Fig.4.5 and Fig.4.6. The maximum displacement was calculated CSA model which is 44mm as FBA model yield the maximum displacements of 20mm. The Column Supported Analysis gave the total radial displacement which is about two times of that of the Fixed Base Analysis. All the two models predict the maximum displacement at throat level.




FBA Model CSA Model

**Figure 5.** Radial displacements along the height of the tower for FBA, CSA

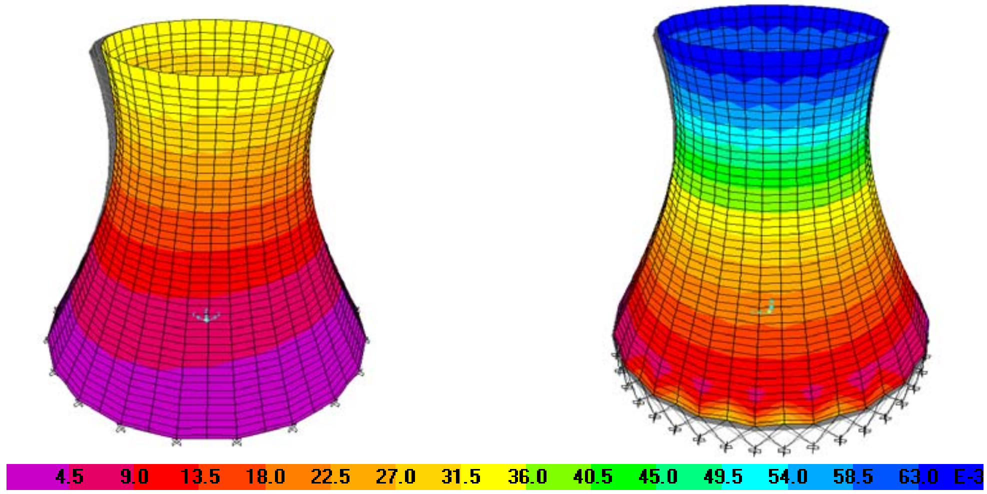



**Figure 6.** 3D Modeling of Radial displacements along the height of the tower for FBA, CSA

The distributions of principal stresses along the height of the cooling tower are drawn. These results are plotted corresponding to all the two models in Fig.4.7. It is clear from these plots, that as it was expected the ring beam in FBA model reduced the values of the principal stresses at the bottom of the cooling tower. This release lead to a significant reduction in values of principal stresses compare with Column Supported Analysis. A marginal tension stress was predicted at the bottom ring beam level. This will be taken care by the amount reinforcement provided. The Fixed Base model plays a significant role in the distribution of the stresses in tower and foundation. The distributions of principal stresses along the surface height of the cooling tower for FBA model are occurred locally, whereas in CSA are occurred globally, these amounts in CSA model are more than FBA model.

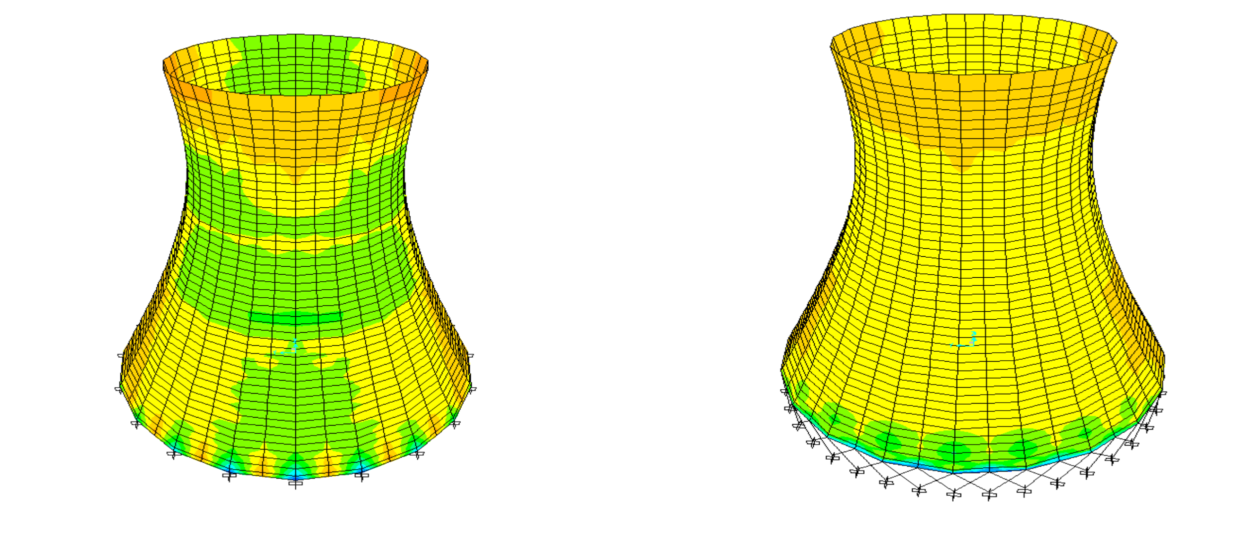



**Figure 7.** Variation of principal stresses along the height

## 5. CONCLUSIONS

Seismic behaviors of cooling towers have been analytically investigated. In the numerical study, iso-parametric solid element has been used for the finite element modeling, and time-integration dynamic analyses have been performed. A new model, in which the columns are replaced with a ring beam at the base, is also analyzed. The responses of the column-supported tower are obtained and compared with those of a tower is fixed at the base with the ring beam. Based on the investigation carried out in the present study, the analysis highlights the fact that in the column-supported cooling, potential of the buckling occurrence in the columns increases due to the compressive stresses effects, while, in the ring beam supported cooling towers, stresses at the base level considerably decrease. Moreover, radial displacements and moment occur in the tower shell and supporting columns, and there is also a significant release in values of principal stress when the effect of the bottom ring beam taken into consideration as compared to the column supported results. On this basis, the ring beam system is proposed as an alternative structural system for the cooling towers in the high risk zones.

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