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RESPONSE OF COOLING TOWERS TO WIND LOADS

G. Murali, C. M. Vivek Vardhan and B. V. Prasanth Kumar Reddy
Vel Tech High Tech Dr.Rangarajan Dr.Sakunthala Engineering Colleges, Chennai, Tamil Nadu, India
E-mail: murali_220984@yahoo.co.in

ABSTRACT

This paper deals with the study of two cooling towers of 122m and 200m high above ground level. These cooling towers have been analyzed for wind loads using ANSYS software by assuming fixity at the shell base. The wind loads on these cooling towers have been calculated in the form of pressures by using the circumferentially distributed design wind pressure coefficients as given in IS: 11504-1985 code along with the design wind pressures at different levels as per IS:875 (Part 3)- 1987 code. The analysis has been carried out using 8-noded shell element (SHELL 93) with 5 degrees of freedom per node. The results of the analysis include membrane forces, viz., meridional force (N_ϕ) and hoop force (N_θ), and bending moments, viz., meridional moment (M_ϕ) and hoop moment (M_θ). The vertical distribution of membrane forces and bending moments along 0^o and 70^o meridians and the circumferential distributions at base, throat and top levels have been studied for both the cooling towers. For circumferential distribution, non-dimensional values have been obtained by normalizing the membrane forces and bending moments using the reference values at 0^o meridian. Similarly, the reference values at the base have been used for vertical distribution. These non-dimensional curves for both the cooling towers have been compared in the present study for the feasibility of any generalization.

Keywords: cooling tower, wind loads, membrane forces, bending moments.

1. INTRODUCTION

The natural draught cooling tower is a very important and essential component in the thermal and nuclear power stations. Due to their complexities in geometry and the spectacular failure of cooling tower at Ferry Bridge in England in 1965, and at Ardeer in Scotland in 1973, have attracted attention of many researchers throughout the world. In the absence of earthquake loading, wind constitutes the main loading for the design of natural draught cooling towers. A lot of research work was reported in the literature on the wind load on cooling tower [1 to 8].

Busch, *et al*., [1] demonstrated the optimization of a 200m high natural draught cooling tower by varying the height of throat and inclination of the meridian in reducing the stress due to wind load. The load bearing behaviour was observed to be best when the meridian curvature increases continuously from the bottom to the throat and by avoiding an abrupt change of curvature above the throat, as far as possible. Kratzig, *et al*., [2] described elasto-plastic simulation techniques for the detection of areas of possible crack-damaged due to wind and temperature effects in order to increase the durability by strengthening them. Boseman, *et al*., [3] discussed the merits of the stiffening approach for strengthening of cooling tower through finite element analysis applied to stiffened and unstiffened cooling towers. Lang, *et al*., [4] presented the extension of the linear static shell ring element to account for non-linear kinematic relation and non-linear material response in the shell of revolution. The displacement field in the circumferential direction was presented by means of Fourier serious, due to which no discretisation was necessary in the circumferential direction. Viladkar, *et al*., [5] studied the effect of soil-structure interaction on the design forces of shell, racker columns and raft foundation as compared to fixed base case. Niemann and Kopper [6] studied the influence of adjacent building and cooling towers on the wind induced peak response by evaluating interference factors. Orlando [7] studied the wind induced interference effect on two adjacent cooling tower through pressure measurements on cooling tower models in a boundary layer wind tunnel. Further numerical linear analyses were performed to calculate the structural responses of the isolated and grouped towers. Mungam and Wittek [8] studied the assessment of the design wind loads acting on RC cooling tower shell under the turbulent wind. Comparison between several methods was also performed using data measured by wind tunnel test on an isolated tower shell. The quasi - static response of an isolated RC cooling tower shell under the turbulent wind was compared with results obtained with the design wind load by means of GRF, LRC and optimized peak load distributions methods.

It can be observed that carrying out finite element analysis of cooling towers against wind loads requires thorough skills by the common designer. Formulation of design curves for membrane forces and bending moments in non-dimensional will help the designer in overcoming the required detailed finite element analysis of such towers. In the present study, two cooling tower of 122m (CT1) and 200m (CT2) high above the ground level have been considered with the geometrical details as given in the Table-1. Finite element analysis of the two cooling towers have been carried out to evaluate membrane forces, viz. meridional forces (N_ϕ) and hoop forces (N_θ), and bending moment viz. meridional moments (M_ϕ) and hoop moments (M_θ). In this paper, an attempt has been made to find the feasibility of generalizing the distribution of membrane forces and bending moments in non-dimensional form along the circumference at top, throat and near base levels, and along the vertical for 0 and 70° meridians. These non-dimensional values have been obtained by normalizing the actual values with reference values. For circumferential distribution, the reference values at 0° meridian have been considered. The reference values at the base have been considered for vertical distribution. Any commonality and differences in these normalized curves have been studied. Further, an additional cooling tower (CT3) of 200 m high which is same as for (CT2) tower but with the height ratio (= Height of throat/Total height) and diameter ratio (= Diameter at throat/Diameter at base) being same as those for CT1 tower has been analyzed in order to find any dependence of these normalized curves on these ratios.

Table-1. Geometrical details of 122m (CT1), 200m (CT2 and CT3) high hyperboloid cooling tower under wind load.

S. No.	Parameter description	Symbol	Parametric value		
			CT1 (Figure-1(a))	CT2 (Figure-1(b))	CT3
1	Total height	H	122 m	200 m	200 m
2	Height of throat	H_{thr}	98.26 m	142 m	161.1 m
3	Diameter at top	D_t	55.07 m	97.5m	90.2 m
4	Diameter at bottom	D_b	96.58 m	136 m	158.3 m
5	Diameter at throat level	D_{thr}	50.6 m	85.2m	83.1 m
6	(H_{thr}/H) ratio		0.805	0.69	0.805
7	(D_{thr}/D_b) ratio		0.524	0.626	0.524

2. WIND LOADS

Distribution of pressure of wind symmetrically alone has been investigated in the present study. Coefficient of pressure distribution with allowance for internal suction from Indian Standards, [9, 10] has been shown in Figure-1. The wind pressure distribution on the outside of the shell is assumed to be symmetrical about the centre line in the direction of wind. The circumferential pressure distribution can be represented by a Fourier cosine series of the form as given below:

$$P' = \sum_{n=0}^{7} F_n \cos n\theta$$

$$= F_0 + F_1 \cos\theta + F_2 \cos 2\theta + \cdots + F_7 \cos 7\theta \qquad (1)$$

where

P' = pressure coefficient
n = harmonic number
θ = horizontal angle measured from the windward meridian and
F_n = harmonic constants = [0.00071, 0.24611, 0.62296, 0.48833, 0.10756, -0.09579, -0.01142].

The same distribution has been used at all the levels along the height of the tower. The design wind pressure at any height above ground level has been obtained by using the following relationship between wind pressure, P_z (N/m²), and the design wind velocity, V_z (m/s):

$$P_z = 0.6V_z^2 \qquad (2)$$

The coefficient 0.6 in Eq. (2) is dependent on atmospheric pressure and ambient air temperature. The basic wind speed for the design of the cooling tower is obtained from the basic wind speed, Vb, and by including the following factors: (1) risk level, (2) terrain roughness, (3) height and size of structure and (4) local topography.

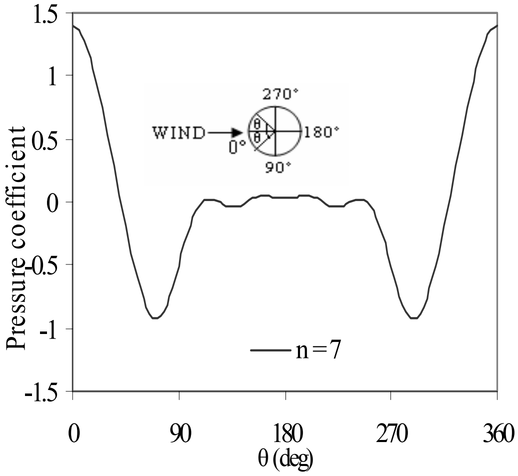

Figure-1. Circumferential pressure distribution as per IS code [1] on cooling towers.

It can be mathematically expressed as:

$$V_z = V_b k_1 k_2 k_3 \qquad \text{………… (3) [2]}$$

where

V_b = basic wind speed which is specified for different zones of the country
k_1 = probability factor (risk coefficient) based on the statistical concepts which take into account the degree of reliability required and the time period of wind exposure i.e., the life of the structure k_2 = the terrain height and

structure size parameter that gives the multiplying factor by which the basic wind speed shall be multiplied to obtain the wind speed at different heights in each terrain category for different sizes of buildings and structures

k_3 = the topography factor

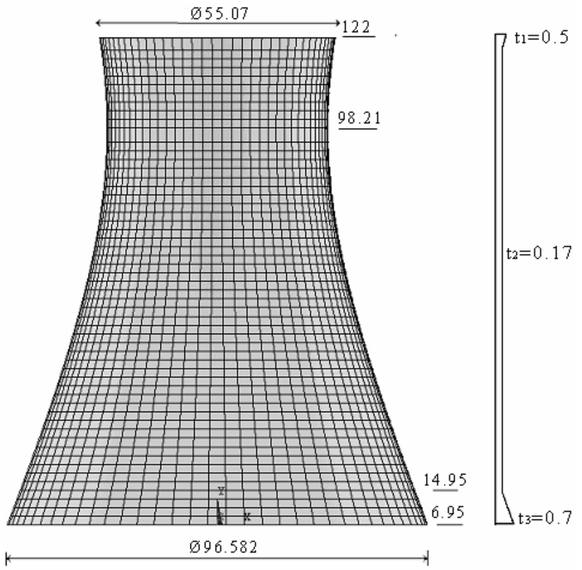

Figure-2(a). Geometry of 122m high cooling tower.

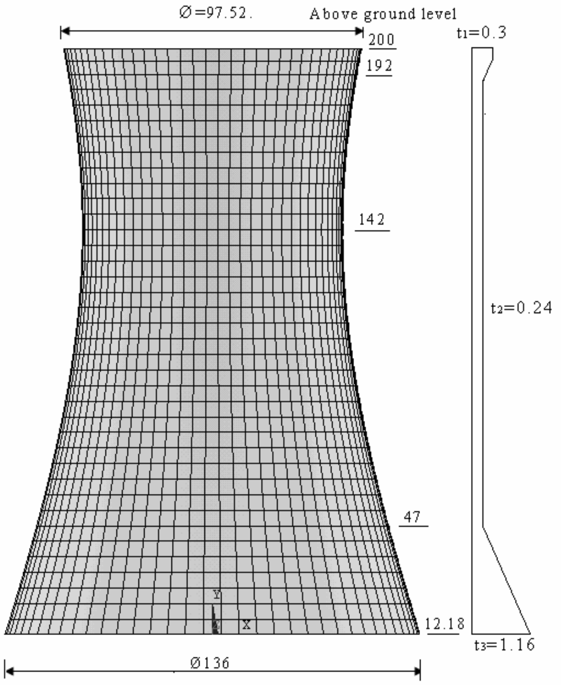

Figure-2(b). Geometry of 200 m high cooling tower.

Note: All dimensions and levels are in meters.
($E = 285\text{x}10^8$ N/m²; $\mu = 0.18$)

3. FINITE ELEMENT MODELING

The finite element analysis of the cooling towers has been carried out using ANSYS software. The shell element is the most efficient element for the solution of shells having the arbitrary geometry and it accounts for both membrane and bending actions. The analysis has been carried out using 8-noded shell element (SHELL 93) with 5 degrees of freedom per node. In the present study, only shell portion of the cooling towers has been modeled and fixity has been assumed at the base. Figure-2 shows the finite element model of CT1 and CT2 towers along with various geometrical and material details.

4. RESULTS AND DISCUSSIONS

The evaluated membrane forces (N_Φ and N_θ) and bending moments (M_Φ and M_θ) have been normalised with the reference values at 0° meridians for circumferential distribution at base, throat and top levels as shown in Figures 3, 4 and 5, respectively. It can be seen from Figure-3 that the normalizing curves for CT1 and CT2 towers at the base level compared well even though the ratios of ($H_{thr/}$ H) and ($D_{thr/}D_b$) were different for these towers. The small deviation as observed in Figure-3 between the curves for CT1 and CT2 towers were further minimized while comparing them between CT1 and CT3 towers. Figure-4 shows that the normalized curves for CT1 and CT2 towers at throat level compared well except for the normalized N_θ curve. Whereas, the normalized N_θ curves for CT1 and CT3 towers compared well which indicate that the normalized N_θ curve at throat level can be generalized with respect to the ratio of ($H_{thr/}$ H) and ($D_{thr/}D_b$)? Further, the small deviation in the normalized curves of M_ϕ and M_θ for CT1 and CT2 towers were observed to be minimized while comparing for CT1 and CT3 towers. The normalized N_Φ and N_θ curves at top levels were observed to be comparing well as shown in Figure-5 where as the curves of M_ϕ and M_θ for CT1 towers observed to be differing with the respective curves for CT2 and CT3 towers. It was observed that the M_ϕ and M_θ values at top were very small (i.e. close to zero) at 0°meridian.

The vertical distributions normalized curves at 0° and 70° meridians were obtained with the reference values at the base as shown in Figures 6 and 7, respectively. Here, the normalized heights were obtained by normalizing the different levels with the total height of respective tower. The normalized N_Φ curves for CT1 and CT2 towers along 0° meridian were observed to be comparing well for normalized heights above 0.6 (Figure-6). However, the normalized N_Φ curves for CT1 and CT3 towers observed to compare very well which indicates that the normalized N_Φ curve along the height is sensitive to the ratio of ($H_{thr/}$ H) and ($D_{thr/}D_b$). The normalized N_θ curves for all the towers along 0°meridian compare well for normalized height above 0.6 (Figure-6). However, the N_θ curves for CT2 and CT3 towers fall on either side of the curve for CT1 tower. The generalization of N_θ curve along the height requires further study. The normalized M_Φ curves for all the towers along 0° meridian compared well

(Figure-6). The normalized M_θ curves of CT2 and CT3 towers fall on either side of the curve for CT1 tower which also requires further study for generalization. The observations for the curves along height at 70° meridian (Figure-7) were same as that for 0° meridian case (Figure-6).

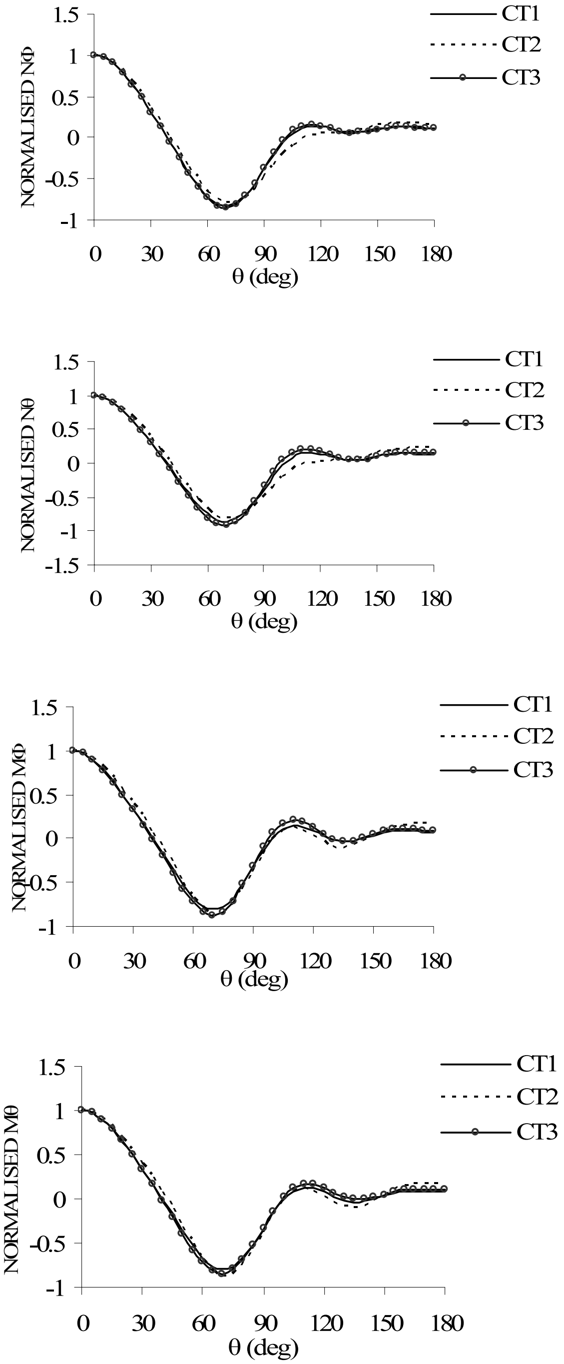

Figure-3. Circumferential distribution of normalized membrane forces and bending moments at base level.

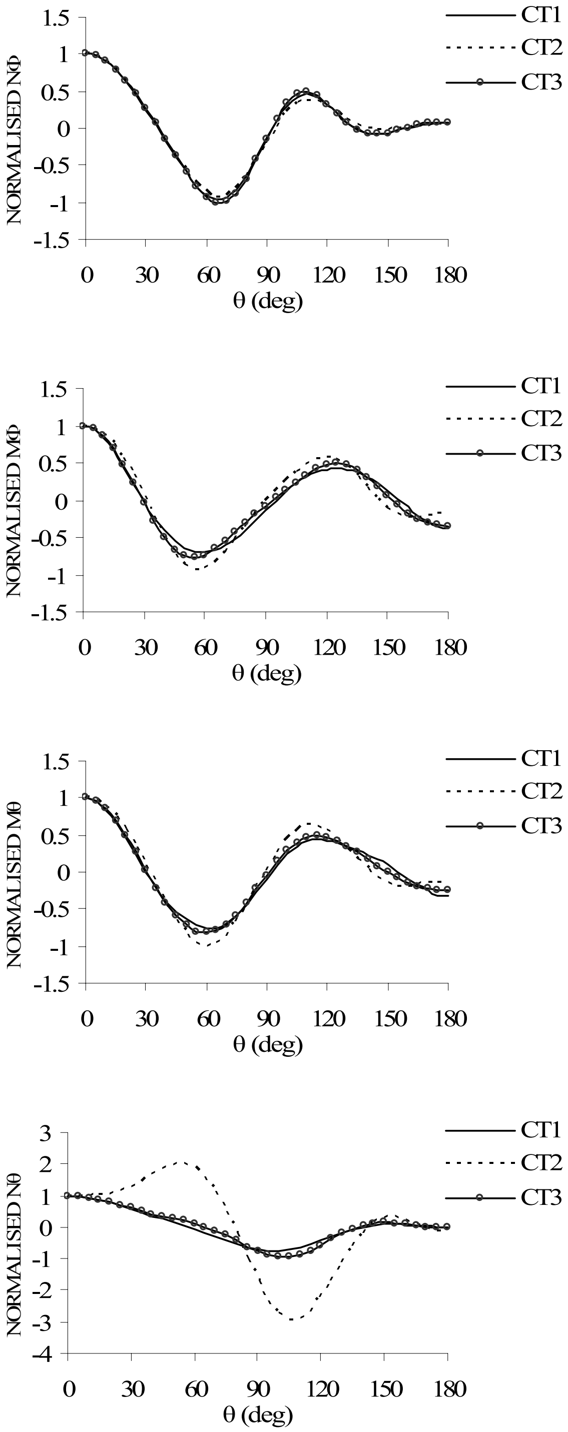

Figure-4. Circumferential distribution of normalized membrane forces and bending moments at throat level.

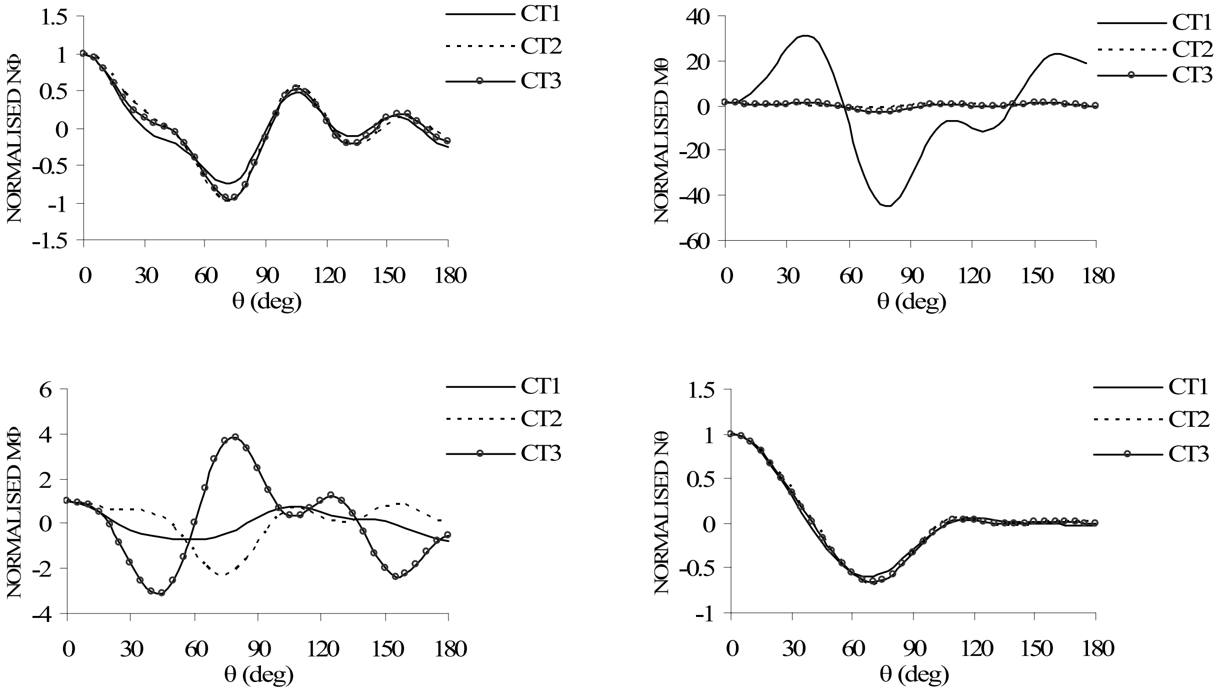

Figure-5. Circumferential distribution of normalized membrane forces and bending moments at top level.

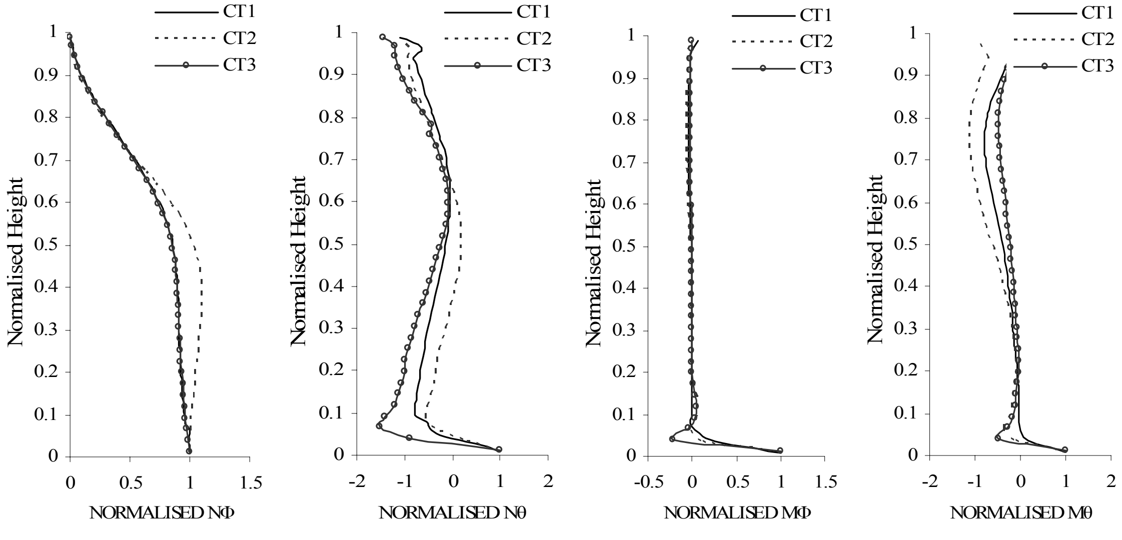

Figure-6. Vertical distribution of normalized membrane forces and bending moments at θ = 0° meridian.

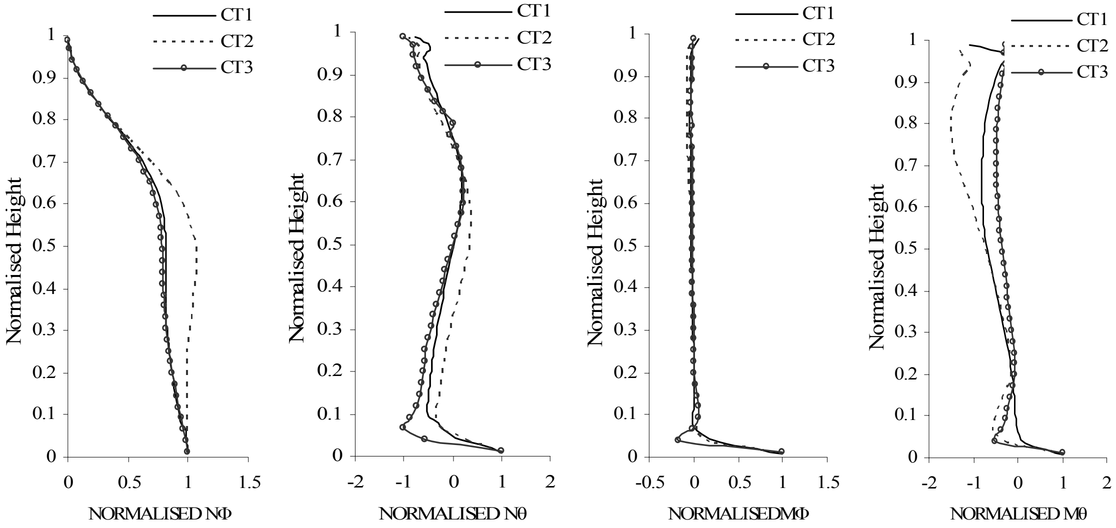

Figure-7. Vertical distribution of normalized membrane forces and bending moments at θ = 70° meridian.

5. SUMMARY AND CONCLUSIONS

In the present study, finite element analysis of three cooling towers, viz CT1, CT2 and CT3 (Table-1) has been carried to evaluate the membrane forces (N_Φ and N_θ) and bending moments (M_Φ and M_θ). The circumferential and vertical distributions of normalized curves for N_Φ, N_θ, M_Φ and M_θ have been compared for three towers. Based on this comparison the following conclusions were made.

a) In the case of circumferential distribution at base, throat and top levels:

- Most of the curves except for the N_θ curve at throat level, and M_Φ and M_θ curves at top level compared well with each other. This indicates that the well compared curves can be generalized independent of the ratios of ($H_{thr/}$ H) and ($D_{thr/}D_b$).
- The N_θ curve at throat level can be generalized with respect to the ratio of ($H_{thr/}$ H) and ($D_{thr/}D_b$).
- The M_Φ and M_θ curves at top indicate significant differences among all the three towers, this could be due to the actual values being very less at the top level.

b) In the case of vertical distribution at 0° and 70° meridians:

- The N_θ curves can be generalized with respect to the ratios of ($H_{thr/}$ H) and ($D_{thr/}D_b$).
- The generalization of N_θ and M_θ requires further study.
- The M_Φ curves can be generalized independent of the ratios of (H_{thr} / H) and ($D_{thr/}D_b$).

Such normalized curves can be used by the designer to evaluate the design membrane forces and bending moments without carrying out detailed finite element analysis of these hyperboloid cooling towers. Further study is warranted to obtain the relation between the wind pressure/ load distribution on the cooling tower and the reference values which are required for the usage of these normalized curves.

REFERENCES

[1] Busch D., Harte R. and Niemann H.J. 1998. Study of a proposed 200m high natural draught cooling tower at power plant Frimmersdorf/Germany. Engineering Structures. 20(10): 920-927.

[2] Kratzig W.B., Konke C., Mancevski D. and Gruber K.P. 1998. Design and durability of natural draught cooling tower by life-cycle simulations. Engineering Structures. 20(10): 899-908.

[3] Boseman P.B., Strickland I.G. and Prukl R.P. 1998. Strengthening of natural draught cooling tower shells with stiffening rings. Engineering Structures. 20(10): 909-914.

[4] Lang C., Meiswinkel R. and Filippou C. 2002. Non-linear analysis of shells of revolution with ring elements. Engineering Structures. 24: 163-177.

[5] Viladkar M.N., Karisiddappa Bhargava P. and Godbole P.N. 2006. Static soil-structure interaction response of hyperbolic cooling towers to symmetrical wind loads. Engineering Structures. 28: 1236-1251.

[6] Niemann H.J. and Kopper H.D. 1998. Influence of adjacent building on wind effect on cooling tower. Engineering Structures. 20(10): 874-880.

[7] Orlando M. 2001. Wind-induced interference effects on two adjacent cooling towers. Engineering Structures. 23: 979-992.

[8] Mungan and Wittek. 2004. Natural draught cooling towers. Taylor and Francis Group, London, U.K.

[9] 1985. IS: 11504, Criteria for structural design of reinforced concrete natural draught cooling tower, New Delhi, India: Bureau of Indian standards.

[10] 1987. IS: 875 (Part3), Code of practice for design loads (other than earthquake loads) for buildings and structures. New Delhi, India: Bureau of Indian Standards.