WIND INDUCED INTERFERENCE EFFECTS ON NATURAL DRAUGHT COOLING TOWER

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***Abstract*—** The wind load is always the dominant load in the design of the cooling tower due to its large size, complex geometry and thin wall. In a series of wind tunnel tests, the wind-induced stresses in cooling towers situated in an arrangement of typical power plant buildings, are investigated and compared to the stresses in an isolated tower. Interference factors are developed to quantify the stress increase due to the group effect. The design wind pressure at various level of tower measured from gust factor method and peak wind method. The variation of the flow-induced forces produced on each tower by the other one is referred to as interference. Using the registered pressures, numerical linear and nonlinear analyses were performed to calculate the structural responses of the isolated and grouped towers. The net coefficient of pressure distribution was plotted for various angle of wind incidence. From the study, it was found that Meridional stress is 8.86% more and circumferential stress is about 9.43% more in present study compared to existing NDCT model. Also, the highest net pressure coefficient is obtained as 1.436, when the wind incidence angle is about 0°. The value approaches to a minimum value of about -0.934, when the wind incidence angle is about 330° and occurring at about 105° angle. The results of present study are in close agreement with the existing structure. Thus, the numerical model is validated.

***Index Terms*—** Wind interference, Aero-elastic wind tunnel tests, Stress responses, cooling tower.

I. INTRODUCTION

Natural Draught Cooling Towers are Hyperbolic Reinforced Concrete (RC) shell structures used in thermal and nuclear power plants as cooling devices. In the last decade, Natural Draught Cooling Towers became even more inevitable means for the economic generation of electricity under environmental aspects.

The hyperboloid of revolution can be generated by rotating a hyperbola about its directrix. Shells of this type are built throughout the world as cooling towers to lower the temperature of coolants (water) used in electricity generating plants and chemical plants. This type of shell has proven to be efficient for use in Reinforced Concrete Natural Draught Cooling Towers for the conservation and reuse of the coolant.

In the present study, the sizing of cooling tower is taken based on the thermal design report and capacity of cooling tower. In this study 500MW capacity of Natural Draught Cooling Tower for Thermal Power Plant is taken. The tower is analyzed using the commercially available Staad Pro v8i software.

The wind load is calculated as per IS 11504 and IS 875 for the analysis of isolated case of cooling tower. For Interference case of cooling tower based on the wind tunnel study report pressure co-efficient is considered and it is multiplied with the dynamic wind pressure and corresponding surface area. Modal analysis is done for dynamic seismic load as per IS 1893:2002. In this study the cooling tower is analyzed for both wind and seismic loads.

DESCRIPTION OF THE COOLING TOWER

General Arrangement

Cooling tower consists of RCC shell, which is hyperbolic, shaped except for the portion at bottom, which is conical. The shell is supported on 44 pairs of diagonal columns in RCC, which are raked tangential to the Meridional profile of the shell at its bottom; the open system of columns also provides the air inlet opening. The diagonal columns rest on RCC pedestals, which are in the same inclined plane. The RCC pedestals are an integral part of the pond wall in RCC, which retains the re-cooled water. Pond wall spanning between the pedestals will be considered. At bottom, a ring shaped horizontal RCC ring foundation below the pond wall and pedestal is provided. The soil bearing capacity for ring foundation is considered 50t/m2 at depth of 5.0m from FGL.

RCC platform 1.2m wide all around the tower at top shall be provided, which is accessed by two M.S. cage ladders. These ladders spring from the top of an RCC staircase. The ladders are on outside up to throat level and then on the inside up to the top, with inter connection through a landing platform and access door at the throat level. The RCC staircase leads from ground level up to the level of water distribution system. Internal walkways in RCC are provided on periphery of tower cantilevering from the shell at the hot water distribution level and on the hot water distribution duct inside the tower.

Functional Requirements of the Cooling Tower

Duty and Capacity

a. Quantity of circulating water per tower : 60000 cum/hr

b. Type of tower : Natural draught (hyperbolic)

c. Period of operation : 24 hrs continuous

d. Hot water inlet temperature : 43.0 degree C

e. Re-cooled water outlet temperature : 32.5 degree C

f. Design relative humidity : 50%

g. Design ambient wet bulb temperature : 27 degree C

h. Design wind speed : 39 m/sec

Important Dimensions

a) **Elevations (in meters)**

i) Pond sill +0.00
ii) Ground level -0.30
iii) Basin floor at periphery -2.30
iv) Working level of water -0.30
v) Top of the tower +160.00
vi) Throat of the tower +129.00
vii) Bottom of ring beam +8.00
viii) Top of fill +14.00
ix) Bottom of fill +8.00
x) Bottom of drift eliminators +15.55

Table 5.1 Elevation details of Natural Draught Cooling Tower

b) Internal Diameters of the Tower (in metres)

i) Diameter at sill level +122.00
ii) Diameter at throat level +67.10
iii) Diameter at top of tower +68.50

Accordingly, the profiles of the towers are as shown in fig. 1 all the details i.e. height of tower above ground level, height from throat to top of the tower, height of air vent, Diameter at sill level, Diameter at throat level, Diameter at top of tower indicated in the following fig.1, are in meters.

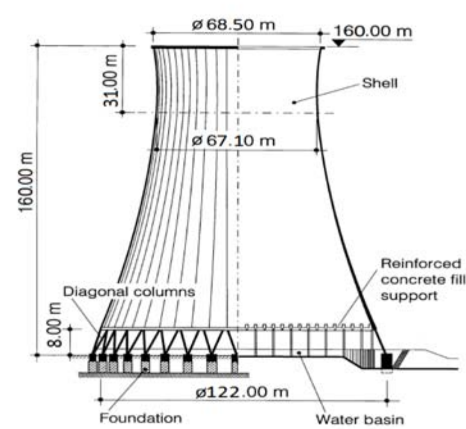


Fig: 1. Profile of the cooling tower

In this case, wind load is calculated by the following two methods and the results are tabulated in table 1.

a. Gust factor method

b. Peak wind method

Table 1 Design wind pressure at various levels of cooling tower

Level	Peak Wind Method K2 Table 2	Vz	PzN/m^2	Pz KN/m^2	Gust Factor Method K2 Table33	Vz	Pz =0.6Vz^2	Pz G*Coeff.
8.836	0.9300	52.452	2360.54	2.361	0.6700	37.7	2140.0	2.140
10	0.93	52.452	2360.54	2.361	0.67	37.7	2140.0	2.140
11.589	0.9427	53.168	2425.50	2.425	0.6859	38.6	2242.7	2.243
15	0.97	54.708	2567.96	2.568	0.72	40.6	2471.3	2.471
15.575	0.9734	54.902	2586.25	2.586	0.7234	40.8	2495.1	2.495
19.715	0.9983	56.303	2719.92	2.720	0.7483	42.2	2669.3	2.669
20	1	56.4	2729.26	2.729	0.75	42.3	2681.6	2.682
23.858	1.0154	57.270	2814.14	2.814	0.7654	43.1	2793.0	2.793
28.004	1.0320	58.2057	2906.82	2.907	0.7820	44.1	2915.4	2.915
30	1.04	58.656	2951.97	2.952	0.79	44.5	2975.2	2.975
32.154	1.0465	59.0204	2988.77	2.989	0.7965	44.9	3024.1	3.024
36.308	1.0589	59.7233	3060.37	3.060	0.8089	45.6	3119.5	3.120
40.4658	1.0714	60.4268	3132.90	3.133	0.8214	46.3	3216.4	3.216
44.6285	1.0839	61.1311	3206.36	3.206	0.8339	47.0	3315.0	3.315
48.7962	1.0964	61.8363	3280.76	3.281	0.8464	47.7	3415.1	3.415
50	1.1	62.04	3302.41	3.302	0.85	47.9	3444.3	3.444
52.9693	1.1042	62.2745	3327.42	3.327	0.8542	48.1	3478.1	3.478
57.1484	1.1100	62.6044	3362.77	3.363	0.8600	48.5	3525.9	3.526
61.3338	1.1159	62.9349	3398.37	3.398	0.8659	48.8	3574.1	3.574
65.5262	1.1217	63.2660	3434.21	3.434	0.8717	49.1	3622.8	3.623
69.7261	1.1276	63.5976	3470.31	3.470	0.8776	49.4	3671.8	3.672
73.9341	1.1335	63.9298	3506.67	3.507	0.8835	49.8	3721.3	3.721
78.1507	1.1394	64.2628	3543.29	3.543	0.8894	50.1	3771.2	3.771
82.3765	1.1453	64.5965	3580.18	3.580	0.8953	50.4	3821.5	3.822
86.6120	1.1513	64.9309	3617.35	3.617	0.9013	50.8	3872.3	3.872
90.8577	1.1572	65.2661	3654.79	3.655	0.9072	51.1	3923.5	3.924
95.1139	1.1632	65.6022	3692.53	3.693	0.9132	51.5	3975.2	3.975
99.3806	1.1691	65.9391	3730.55	3.731	0.9191	51.8	4027.4	4.027
100	1.17	65.988	3736.09	3.736	0.92	51.8	4035.0	4.035
103.658	1.1729	66.1530	3754.80	3.755	0.9229	52.0	4060.7	4.061
107.945	1.1764	66.3465	3776.79	3.777	0.9264	52.2	4091.0	4.091
112.241	1.1798	66.5403	3798.89	3.799	0.9298	52.4	4121.4	4.121
116.546	1.1832	66.7345	3821.10	3.821	0.9332	52.6	4152.0	4.152
120.856	1.1867	66.9290	3843.41	3.843	0.9367	52.8	4182.7	4.183
125.171	1.1901	67.1237	3865.80	3.866	0.9401	53.0	4213.6	4.214
129.269	1.1934	67.3086	3887.13	3.887	0.9434	53.2	4243.0	4.243
133.370	1.1967	67.4936	3908.53	3.909	0.9467	53.3	4272.6	4.273
137.690	1.2002	67.6886	3931.14	3.931	0.9502	53.5	4303.8	4.304
142.009	1.2036	67.8834	3953.80	3.954	0.9536	53.7	4335.2	4.335
146.328	1.2071	68.0783	3976.53	3.977	0.9571	53.9	4366.7	4.367
150	1.21	68.244	3995.91	3.996	0.96	54.1	4393.5	4.394
150.646	1.2104	68.2658	3998.48	3.998	0.9605	54.1	4398.2	4.398
154.965	1.2130	68.4120	4015.61	4.016	0.9639	54.3	4429.9	4.430
158.565	1.2151	68.5338	4029.93	4.030	0.9668	54.5	4456.5	4.457
160	1.24	69.936	4196.52	4.197	1	56.4	4767.3	4.767

Wind interference case:

a. Surrounding Structures

The plan view of the proposed Bellary thermal power station is shown in figure 3 and 4, the figure shows the two cooling tower, two chimneys, and other structures such as ESP, Boilers, and power house. For simulation of vicinity terrain around the proposed cooling towers, all the adjoining structures as mentioned above are to be included.

b. Site Location

The site of Bellary thermal power plant stage – II expansion is located at Bellary district in the State of Karnataka, India. The general terrain around the TPS location is in category 2 with open terrain with well scattered obstructions having heights generally between 1.5 to 10m

c. Wind Speed

The basic wind speed (Vb), from figure 1 of IS: 875 (Part 3) – 1987, is 39m/sec at Bellary. Basic wind speed is based on peak gust velocity averaged over a short time interval of about 3 seconds and corresponds to mean heights 10 m above ground level in an open terrain (Category 2) for a 50 year return period. The basic wind speed is modified to include the following effects to get design wind velocity at a height (Vz) for the structure:

Fig.2 Picture of instrumented NDCT along with other nearby plant structures for interference study in the wind tunnel (typical orientation).

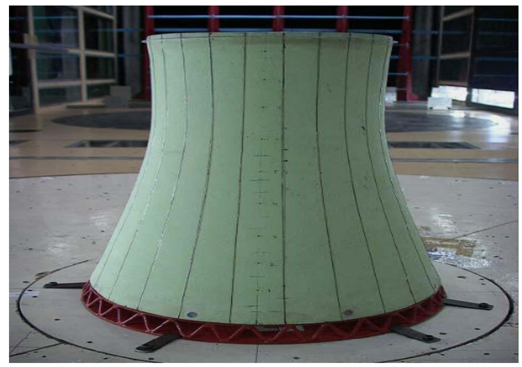


Fig 3 Isolated case of cooling tower

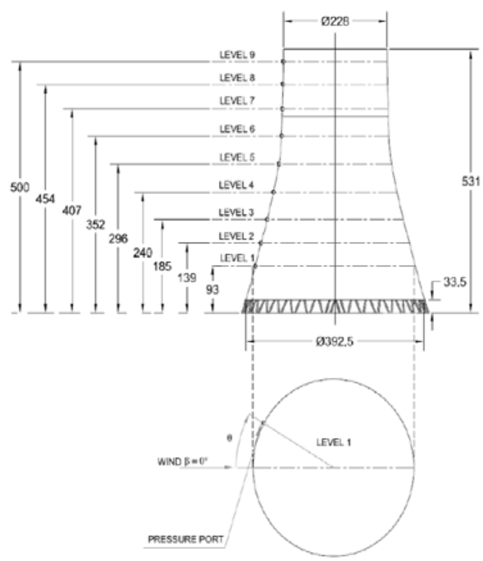
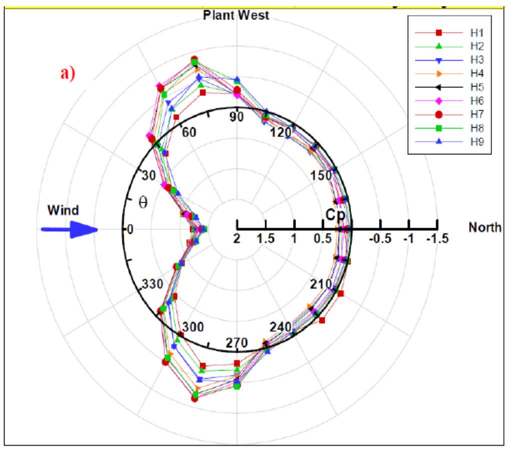


Fig.4 Sectional elevation of the pressure model of NDCT

A NDCT model of 1:300 scales was tested under simulated flow conditions for interference configurations. The mean pressure data has been obtained at nine different heights all around the periphery of the model in 15o interval.

The highest net pressure coefficient is obtained as 1.436, when the wind incidence angle is about 0°.

The minimum value of Cp is about -0.934, when the wind incidence angle is about 330° and occurring at about 105° angle in azimuth with respect to wind.



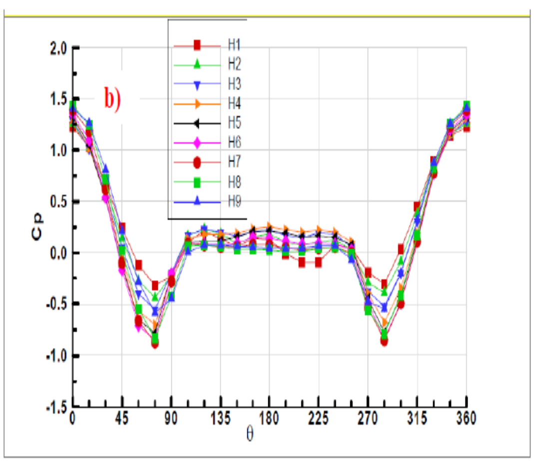
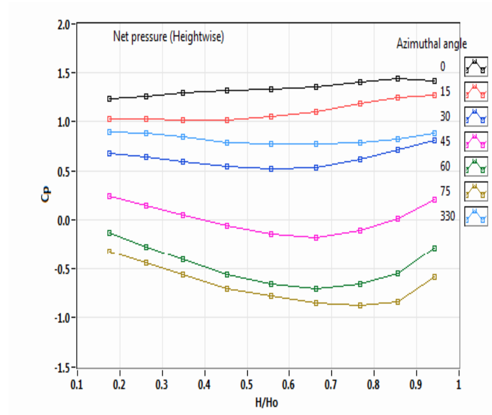


Fig.5 Interference case, wind incidence angle = 0 degree



a) Cp distribution along the periphery in polar plot

b) Cp distribution along the periphery in X-Y plot

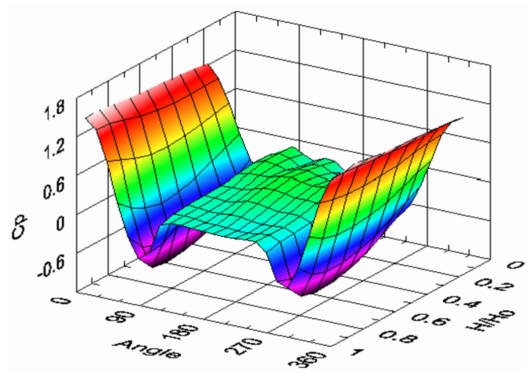
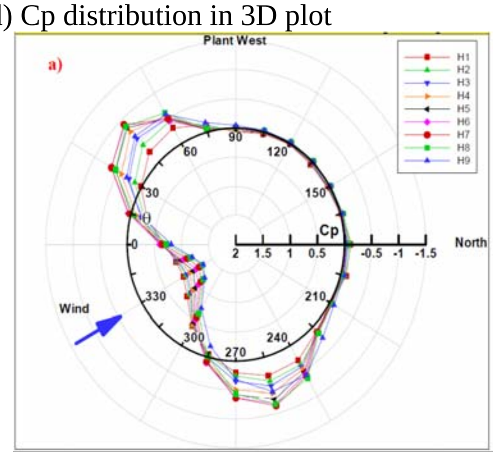


Fig.6Net pressure coefficient distribution on the NDCT for interference case, wind incidence angle = 0 degree

c) Cp distribution along the height

d) Cp distribution in 3D plot



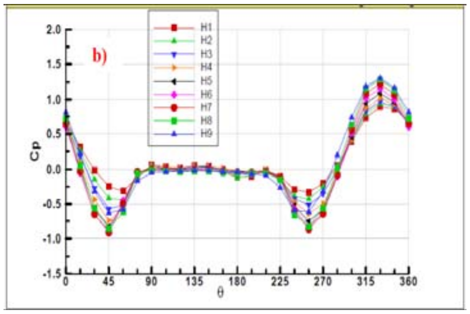
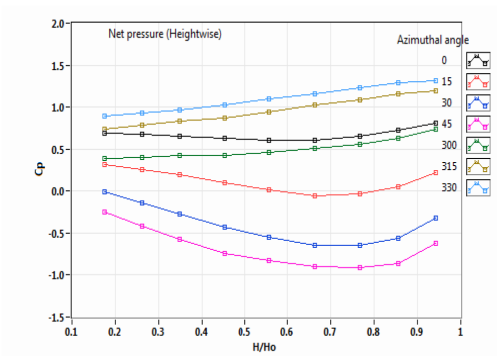


Fig.7 Interference case, wind incidence angle = 30 degree

a) Cp distribution along the periphery in polar plot

b) Cp distribution along the periphery in X-Y plot



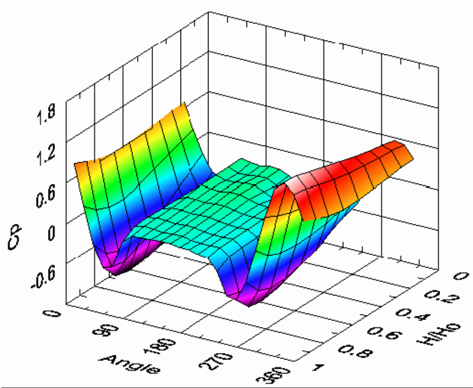
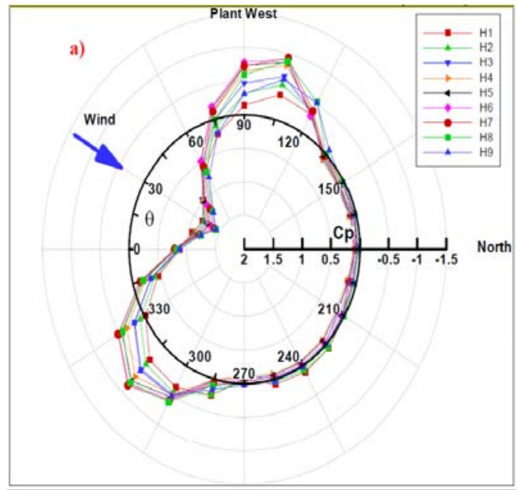


Fig.8 Net pressure coefficient distribution on the NDCT for interference case, wind incidence angle = 30 degree

c) Cp distribution along the height

d) Cp distribution in 3D plot



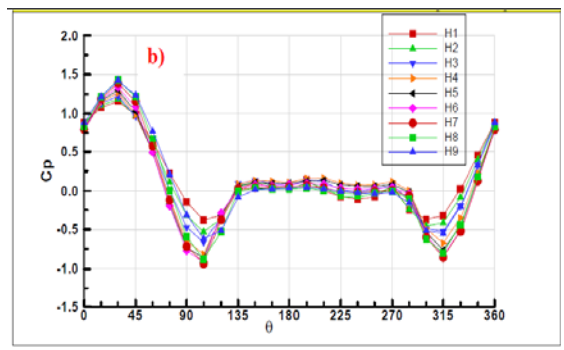
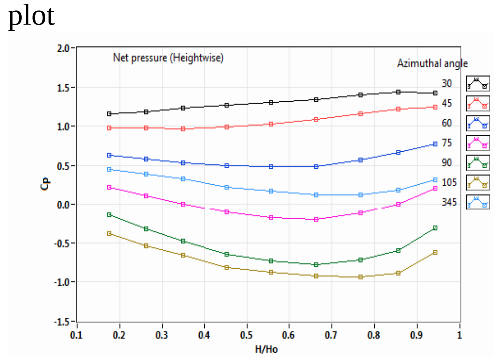


Fig.9 Interference case, wind incidence angle = 330 degree

a) Cp distribution along the periphery in polar plot

b) Cp distribution along the periphery in X-Y plot



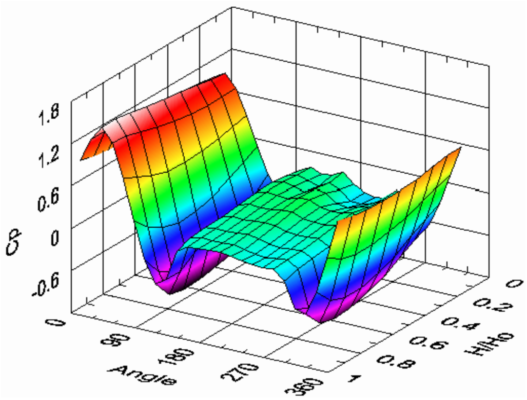


Fig. 10 Net pressure coefficient distribution on the NDCT for interference case, wind incidence angle = 330 degree

c) Cp distribution along the height

d) Cp distribution in 3D plot

Modeling and Meshing

The structure is modeled using beam and plate elements available in Staad Pro. v8i. The shells are meshed using quadratic 4 node plate element, raker column is modeled using 3D beam element and pedestal, pond wall is modeled by 4 node quadrilateral elements. The ring beam at the the base of the shell which is modeled by using 3 nodded triangular elements. The cooling tower shell is supported by diagonal columns called raker columns which are fixed at the base.

Finite element model of the problem generated using Staad Pro is shown in Fig. 11. Therefore the total number of the nodes and elements used in the entire model is 2948 and 2684 respectively. Node to node connection is used to join the elements and 88 numbers of 3D beam members are used to model the raker columns.

Fig. 11 Finite Element Model of cooling tower

Validation of the Model

Results of the numerical simulation are compared with that obtained by the existing cooling tower is given in Table 2. It can be seen that the deflection of the shell and Raker column predicted by present study is more by about 19.4% and 24% respectively.

The Meridional Stress distribution along the length and circumferential stress distribution at the ring beam level are shown in Fig. 12 & 13. It is observed that stresses obtained by the present study are more compared to the existing Natural Draught Cooling Tower. It can be observed that 8.86% more Meridional stress in present study compared to existing structure and in circumferential stress is about 9.43% more compared to existing structure.

It can be observed that the results of present study are in close agreement with the existing structure. Thus, the numerical model is validated.

Table 2 Validation Of The Numerical Model By Considering Displacement Due To Wind

Displacement in m due to wind load at extreme top level	Present study	Existing NDCT
shell	0.048	0.042
Raker column	0.0031	0.0025

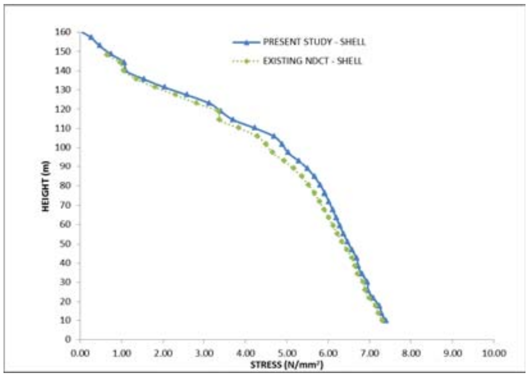


Fig.12 Meridional stress distribution

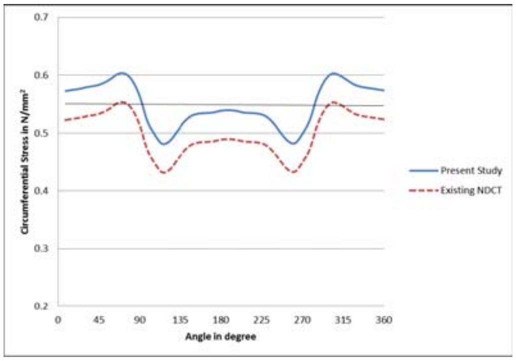


Fig.13 Circumferential stress distribution at ring beam level

Conclusions

Based on the present numerical investigation which includes circumferential pressure variation along the periphery as well as deflection control along the height of the tower for various wind incidence angle, the following conclusions are drawn:

The highest net pressure coefficient is obtained as 1.436, when the wind incidence angle is about 0°. The value approaches to a minimum value of about -0.934, when the wind incidence angle is about 330° and occurring at about 105° angle.

The deflection of the shell and Raker column predicted by present study is more by about 19.4% and 24% respectively compared to existing structure.

It can be observed that, Meridional stress is 8.86% more in present study compared to existing structure and circumferential stress is about 9.43% more compared to existing structure.

The results of present study are in close agreement with the existing NDCT. Thus, the numerical model is validated.

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