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# Comparative Study on NDCT with Different Shell Supporting Structures

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**Abstract—** Natural draft cooling towers are very essential in modern days in thermal and nuclear power stations. These are the hyperbolic shells of revolution in form and are supported on inclined columns. Several types of shell supporting structures such as A,V,X,Y are being used for construction of NDCT's. Wind loading on NDCT governs critical cases and requires attention. In this paper a comparative study on reinforcement details has been done on NDCT's with X and Y shell supporting structures. For this purpose 166m cooling tower with X and Y supporting structures being analyzed and design for wind (BS & IS code methods), seismic loads using SAP2000.

**Index terms—**Geometry, Raker Columns, SAP2000V17.0, Sandwich method, Soil Loads, Wind Pressure.

## 1. Introduction

A cooling tower is a structure which is designed for the evaporative cooling of water where hot water gets cooled by direct contact with air. Cooling towers are subjected to its self-weight and the dynamic load such as an earthquake motion and a wind effects. In the absence of earthquake loading, wind constitutes the main loading for the design of natural draught cooling towers. The shell structure is supported on inclined raker columns. There are several types of columns such as A,V,X,I,Y etc. The columns used for the cooling tower should withstand the self-weight of the structure and the loads acting on the structure. Therefore a comparative study on analysis and design has been done on cooling towers with X and Y supporting structures considering wind loads.

N.Prabakar [1] gave a brief description about the working principle and salient features of the cooling towers and the loads considered in cooling towers such as dead load, wind forces, soil pressure, earthquake loads and temperature loads. the shell reinforcement gives the clear idea about the stress distribution in circumferential and meridional surface. Dieter Busch[a], Reinhard Harte[b], Wilfried B. Kra¨tzig [c], Ulrich Montag[d] [2] has given a clear idea in design of 200m cooling tower here the stress distribution between the meridional and circumferential direction. In this paper it shows the description of geometry and followed by elucidation of the conceptual shape optimization. A.M. Nasir[a], D.P. Thambiratnam[a], D. Butler [b], P. Austin[b] [3] in this paper the hyperbolic tower is analyzed and the behavior of the tower is studied under earthquake loading. maximum meridional stress resultants and lateral deflection of the shell is found out. Tejas G. Gaikwad, N. G. Gore, V. G. Sayagavi, Kiran Madhavi, Sandeep Pattiwar[4] this paper gives an idea about the behavior of cooling tower in wind load conditions. Gust and peak winds methods are adopted in finding the wind pressure along the height and circumferential. Hoop stress is greatly affected by the changes in shell curvature. G. Murali, C. M. Vivek Vardhan and B. V.

Prasanth Kumar Reddy [5] in this paper three different cooling towers of varying height and parameters are being analyzed for wind loads and the optimization of the towers is done by comparing the meridional and circumferential stress resultants.

## 2. Salient Features of Tower

The shell structure consist of two hyperbolic shell of revolution both meeting at the throat of the cooling tower. The overall height of the cooling tower is 166m, it consist of varying thickness throughout the height of the structure. The top diameter of the tower is 79m, diameter of throat level is 78.5m, base diameter of the shell is 125.6m, height of throat from sill level is about 124.5m, and height of raker columns with respect to sill level is 9.81m. The geometry of hyperbola is derived from the equation of hyperbola with respect to the height of tower.

$$\frac{R^2}{a^2} - \frac{Z^2}{b^2} = 1$$

The tower shell is supported on inclined raker columns. There are several types of raker columns such as A,V,X,I and Y. In this paper X and Y raker columns are used for analysis and design. raker columns consists of inclined circular columns and pedestals. The diameter of circular column is 1.4m and 1.2m and size of pedestal is 3mx1.5m and 3.5mx1.8m for X and Y columns respectively. The tower foundation consists of annular raft foundation is about 3mx1.8m in depth.

### 2.1. Geometry of Hyperbolic Curve

The hyperbolic curve is derived from the hyperbolic equation. NDCT are mostly designed as thin shell structures supported along the circumference by a system of columns. Here the tower is designed for variation of thickness over the height of the tower.

TABLE1
Variation of Radius and Thickness Along the Height.

| Height m | Radius m | Thickness m |
|---|---|---|
| 166 | 39.5 | 0.4 |
| 165 | 39.44 | 0.396 |
| 159 | 39.12 | 0.3 |
| 126 | 38.25 | 0.3 |
| 96 | 40.2 | 0.311 |
| 60 | 47.41 | 0.318 |
| 45 | 51.53 | 0.322 |
| 30 | 56.10 | 0.331 |
| 9.81 | 62.8 | 1.37 |

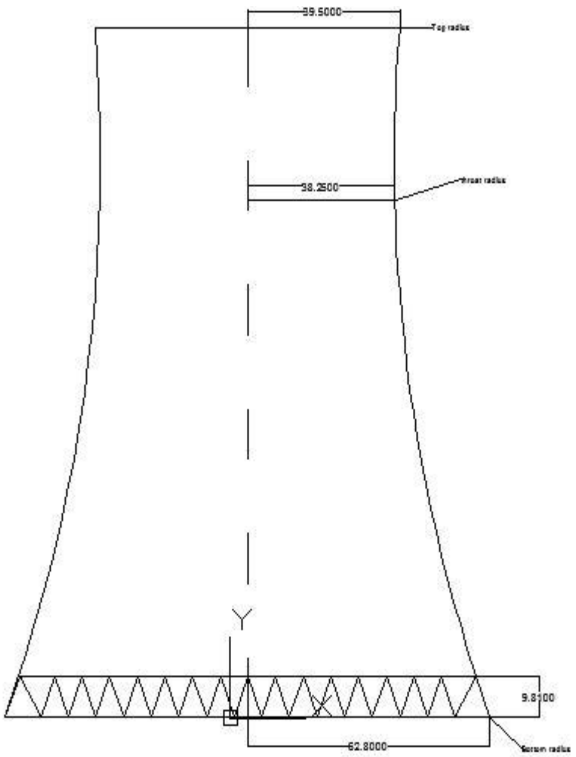


Fig1. Cooling tower specifications. Tower specifications with top, throat and bottom radius.

## 3. LOADS

Hyperbolic cooling towers may be subjected to various loading such as dead load, wind loads, earthquake loads, temperature loads and soil loads. For the proportioning of elements in cooling towers the effect of various loading conditions should be factored and combined as per codes and standards.

The loads considered for analysis and design of NDCT are dead loads, wind loads, and soil loads. The effects of these loads are factored and combined by using BS4485-4-1996 codes and IS875-3-1987.

### c.1. Wind Forces

Wind forces are the major externally applied force in design of cooling towers. In this paper the gust and mean wind forces applied on NDCT as per IS875-3-1987 and BS4485-4-1996.

### 3.1.1. IS 875-3-1987 Gust Wind Procedure

In this procedure actual design wind speed is calculated from the product of $k_1$, $k_2$ and $k_3$ with basic wind speed. The wind pressure is calculated along the height of the tower and along the circumference of the tower. The basic wind speed is chosen as per the location of the tower, the risk coefficient ($K_1$) is taken as per IS875, and the terrain category ($K_2$) is taken as per table 33 of IS875 and topography factor ($K_3$) is taken as 1 as per IS875. Pressure coefficient, $C_p$ is calculated as per IS11504-1985. Gust effectiveness factor and interference factor should be multiplied with design pressure to get actual design pressure.

actual design pressure, $P_Z = 0.6 \times (V_B.K_1.K_2.K_3)^2.C_P.GF.IF$

### 3.1.2. IS 875-3-1987 Mean Wind Procedure

In this procedure actual design wind speed is calculated from the product of $k_1$, $k_2$ and $k_3$ with basic wind speed. The wind pressure is calculated along the height of the tower and along the circumference of the tower. The basic wind speed is chosen as per the location of the tower, the risk coefficient ($K_1$) is taken as per IS875, and the terrain category ($K_2$) is taken as per table 2 of IS875 and topography factor ($K_3$) is taken as 1 as per IS875. Pressure coefficient, $C_p$ is calculated as per IS11504-1985. Interference factor should be multiplied with design pressure to get actual design pressure.

actual design pressure, $P_Z = 0.6 \times (V_B.K_1.K_2.K_3)^2.C_P.IF$

### 3.1.3. BS 4485-4-1996 Gust Wind Procedure

In this procedure site wind speed is calculated from the product of $k_1$, $k_2$ and $k_3$ with basic wind speed. The design mean wind speed is calculated by product of site wind speed($V_s$) and gust wind factor ($S_{gz}$). The wind pressure is calculated along the height of the tower and along the circumference of the tower. Pressure coefficient, $C_p$ is calculated as per BS4485-4-1996.

actual design pressure, $P_Z = 0.613 \times (V_{gz})^2.C_P$

### 3.1.4. BS 4485-4-1996 Mean Wind Procedure

In this procedure site wind speed is calculated from the product of $k_1$, $k_2$ and $k_3$ with basic wind speed. The design mean wind speed is calculated by product of site wind speed($V_s$) and mean wind factor ($S_{mz}$). The wind pressure is calculated along the height of the tower and along the circumference of the tower. Pressure coefficient, $C_p$ is calculated as per BS4485-4-1996.

actual design pressure, $P_Z = 0.613 \times (V_{mz})^2.C_P$

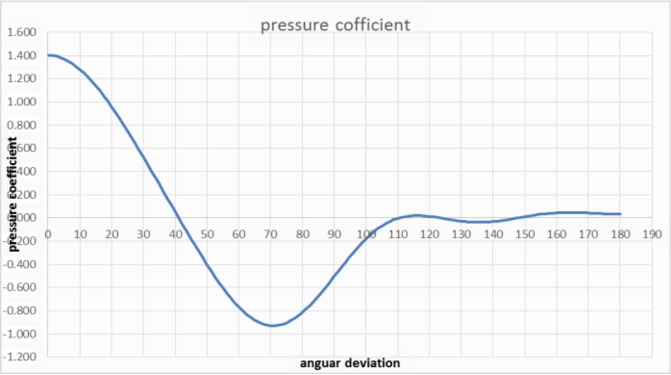


Fig2. Circumferential net wind pressure distribution.

The wind pressure outside the shell is assumed to be symmetrical about the centre line in the direction of wind. The wind pressure is calculated as per IS11504-1985 and BS4485-2-1996. The pressure distribution is calculated over the height of the tower.

$$P^1 = \Sigma F_n \cos n\Theta$$

### c.2. Soil Pressure

Raker columns are constructed usually below the ground level. The ground level lies on the top level of the pedestal. The total load from the shell transferred to foundation through raker columns. The soil load can be calculated as vertical and inclined portion that acts on the foundation and pedestals.

### c.3. Load Combination

The various design loads should be combined in accordance with the relevant design codes. Whichever combination provides maximum effect to the building or structure should be concerned for the design. In this paper the loads considered are dead load, wind loads and soil loads. The load combination is in accordance with IS456-2007and BS4485-4-1986.

Load combinations as per IS456-2007

a) 1.5 Dead load + 1.5 IS Gust wind + 1.5 soil vertical
b) 0.9 Dead load + 0.9 IS Gust wind + 0.9 soil vertical

Load combinations as per BS4485-4-1996

For design of tower shells:

c) Dead load + 1.5$\Phi_G$ BS Mean wind + soil vertical
d) 1.4 Dead load + 1.5$\Phi_G$ BS Mean wind + 1.4 soil vertical

For design of raker columns

e) Dead load + 1.5$\Phi_F$ BS Mean wind + soil vertical
f) 1.4 Dead load + 1.5$\Phi_F$ BS Mean wind + 1.4 soil vertical

$\Phi_G$, $\Phi_F$- wind amplification factors should be evaluated using meridional stress resultants from the windward side of the tower. $\Phi_G$ is for the tower shell, here the tower shell is divided into three parts as per BS4485-4-1996. $\Phi_F$ is for the shell supporting structures (i.e) raker columns which is evaluated at a height above the base of the shell equal to the distance between adjacent shell support nodes.

## 4. DESIGN ASPECTS

### 4.1. Analysis

The analysis of the towers are challenging task for a structural designer because of their shape combined with non-axisymmetric horizontal loads. In this paper the tower is modeled and analyzed using SAP2000 V17.0. The tower is divided into 105 slices of horizontal plates. Hence each horizontal slice is divided into 288 shell areas. The advantage of the finite element model of tower is that the structural modeling can include raker columns and tower foundations. Two sets of tower is being model one with X supporting structure and the other with Y supporting structure. The loads considered for the analysis of both the towers are dead loads, wind loads, soil loads. The behavior of the two towers has been studied by using the mode shapes and frequencies of the respective towers.

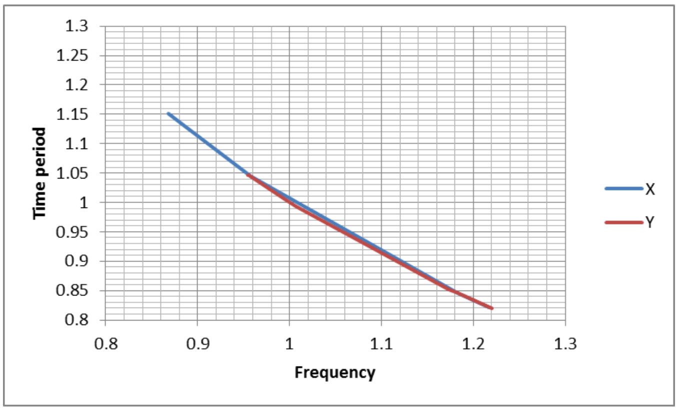


Fig 3. Frequency vs time period

Frequency of first mode of tower with X shaped raker columns is 0.86815 cyc/sec, similarly frequency of the first mode of tower with Y shaped raker column is 0.955 cyc/sec. as per IS875-3-1987 buildings and closed structures with a height to minimum lateral dimension ratio of more than about 5.0 and buildings and closed structures whose natural frequency in the first mode -is less than 1 Hz. Any building or structure which does not satisfy either of the above two criteria shall be examined for dynamic effects of wind. In this paper the tower with Y shaped raker column is much stiffened when compare to tower with X shaped raker columns.

### 4.2. Shell Design

The shell design is generally governed by the direct tension and moment acting on the section due to dead load, wind load and soil loads. In this paper the design of hyperbolic shells are done using eurocode EN1992-2-2005. Sandwich method is adopted to design the shells. In this method the shells are divided into three layers upper layer, shear layer and lower layers and a total of eight forces will act on the shell. In this method out of plane forces are also should be taken into account for design of shells. The outer layer carries the membrane action and the inner layers carry the shear forces.

### 4.3. Shell Reinforcement

Shell reinforcement will be in meridional and circumferential direction. The shell reinforcement is very sensitive to wind loads. In this paper the shell reinforcement is compared between the towers with X and Y raker columns. Usually the reinforcements in the meridional govern more when compare to circumferential. But circumferential reinforcements hold the meridional reinforcements and prevent from displacements.

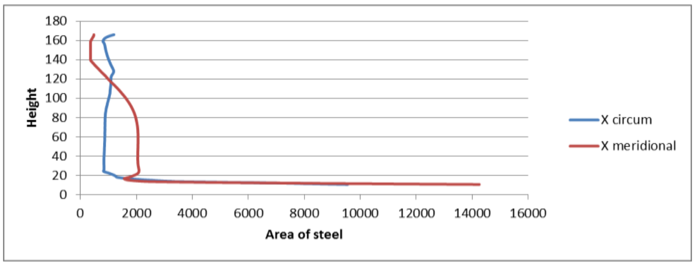


Fig4. Circumferential Vs Meridional top reinforcement

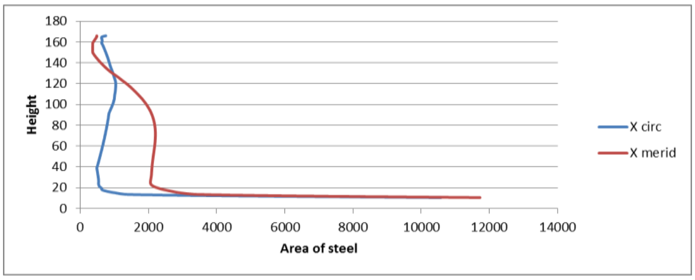


Fig5. Circumferential Vs Meridional bottom reinforcement

In the above figure it clearly shows that meridional reinforcements govern the circumferential reinforcements. But the circumferential reinforcements will be provided outside the meridional reinforcements in order to hold the total compression and tension forces in the meridional reinforcements.

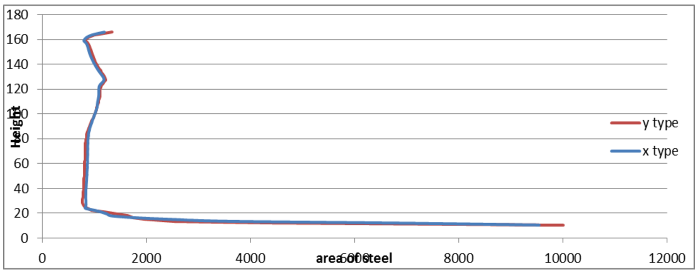


Fig 6. Circumferential top reinforcement

From the above graph it clearly shows that tower with Y raker columns governs more area of steel when compare to tower with X raker columns but over a small scale. From the height of 80m to 120m both the towers have minimum area of steel.

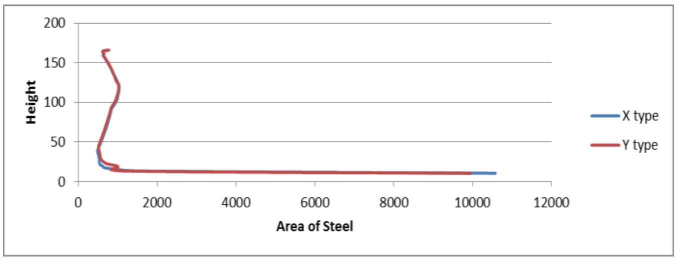


Fig7. Circumferential bottom reinforcement

From the above graph it clearly shows that tower with X raker columns governs more area of steel when compare to tower with Y raker columns.

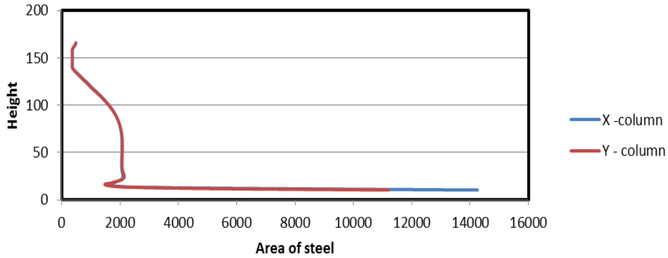


Fig8. Meridional top reinforcement

From the above graph it clearly shows that tower with X raker columns governs more area of steel when compare to tower with Y raker columns.

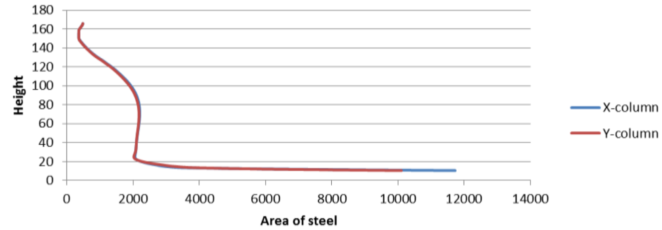


Fig9. Meridional bottom reinforcement

From the above graph it clearly shows that tower with X raker columns governs more area of steel when compare to tower with Y raker columns.

### 4.4. Column Design

The column design is generally governed by axial loads acting on the column due to load combinations. The loads that take place on the columns are dead load, wind loads and soil loads acts on the pedestals. There are two types of columns short and long columns. Columns are designed as short columns when the ratio of effective length to the breadth or depth is less than 12 similarly for long columns when the ratio between the effective length and breadth or depth of column is greater than 12. In this paper all the columns are designed as short columns as per SP16-1980.

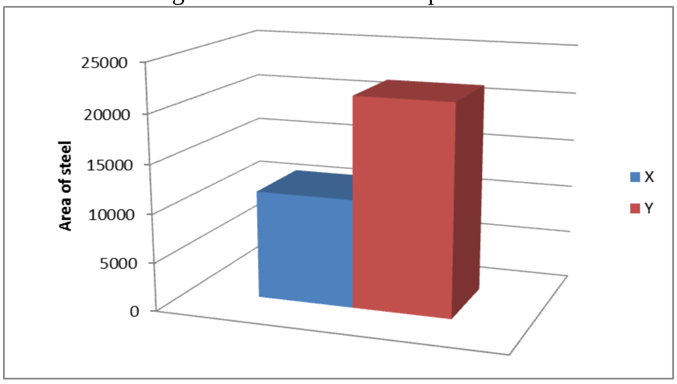


Fig10. Circular columns

here the Y type of columns governs more area of steel when compare to X type of columns due to its axial force and the percentage of reinforcement 0.8% for X type column and it 1.8% for Y type column.

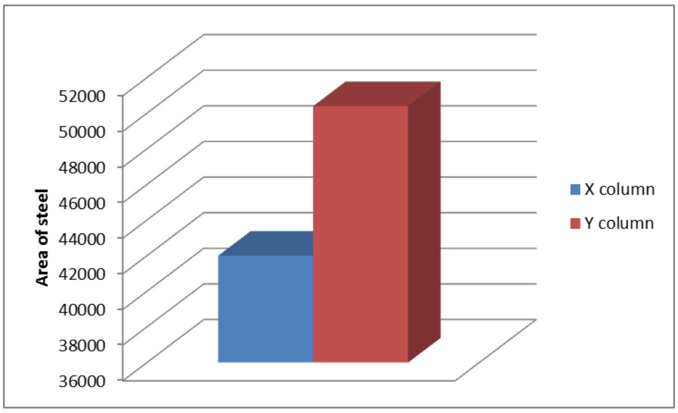


Fig11. Rectangular columns

Here the Y type of columns governs more area of steel when compare to X type of columns. The percentage of reinforcement is 0.8% and its same for both the X type columns and Y type columns. Due to geometric parameters there is increase in the area of steel.

### 4.5. Foundation Design

The load of the structure is being transferred to foundation through raker columns. The type of foundation adopted is anular raft foundation. It's a ring type foundation. The foundation is being designed for the maximum moments occur in the face of the column. And the area of steel is provided for the concerned moments. Minimum reinforcements are provided for both tower with X type columns and Y type columns.

## 5. CONCLUSION

Cooling towers are exceptional structures which require special expertise in design. Since its huge structure the quantity of the structure will also be high. Proper selection of parameters and elements will reduce the quantity of the structure. This paper shows the behavior of the towers with respect to wind forces, self-weight and soil loads and the design of hyperbolic shells using sandwich method. This paper emphasizes the idea of using the proper columns for the towers. The hyperbolic shell is rests on the raker columns which distributes the loads from the towers to the foundation. So a proper care should be taken in selection of raker columns. In this paper it shows that tower with X type of columns governs more steel when compare to tower with Y type of columns.

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