Investigation on Natural Draft Cooling Tower with Different Case Study of Slenderness Ratios

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Abstract- The prime focus of the present major project work is to study the behavior of chimney structure under the effect of wind loads. The location selected for the study is Raipur in Chhattisgarh (INDIA). This Research Study comprises of wind analysis with the design of Reinforced Concrete (RC) Natural draft-cooling tower. Such chimneys or cooling tower are designed with Indian Standard code of practice (IS 4998:1992). RCC Natural Draft Cooling Tower is been modeled in STAAD.Pro V8i. Self-weight of the tower along with steel supports and temperature load are considered for this study. Particularly as cooling tower as a huge RCC Structure is at risk to the wind pressures so it is essential for us to derive correct measure for the tower against the wind analysis or design wind speed. In other words, model with different H/D ratio i.e., 1,2,3,4,5 with common height and differ in base diameter are analyzed for wind speed 39m/s for the parameters such as Displacement, Stress & Drag force. After the analysis, the tower whomever are efficient and practically safe are suitable for the general construction. ***The main objectives of this study are as follows-***

- ✓ To model the tower with common height with different base diameter having slenderness ratio (H/D) varying from 1.0 to 5.0.
- ✓ To analyze & design concrete & wind analysis for each main cases.
- ✓ To analyze individual & comparison outputs of Cooling Tower cases for parameters such as Displacement, Plate Stress and Drag Force.
- ✓ To check the practical efficient behavior of RCC Cooling Tower with graphical representation of each cases.

Keywords: Cooling Tower, H/D, Displacement, Drag Force, RCC

1. INTRODUCTION

In 19th century, cooling towers originated through the development of condensers for use with the steam engine. Condensers use relatively cool water, via various means, to condense the steam coming out of the cylinders or turbines. This reduces the back pressure, which in turn reduces the steam consumption, and thus the fuel consumption, while at the same time increasing power and recycling boiler-water. However, the condensers require an ample supply of cooling water, without which they are impractical. A hyperboloid cooling tower was patented by the Dutch engineers Frederik van Iterson and Gerard Kuypers in 1918. The first hyperboloid cooling towers were built in 1918 near Heerlen. The first ones in the United Kingdom were built in 1924 at Lister Drive power station in Liverpool, England, to cool water used at a coal-fired electrical power station.

By the turn of the 20th Century, several evaporative methods of recycling cooling water were in use in areas lacking an established water supply, as well as in urban locations where municipal water mains may not be of sufficient supply; reliable in times of demand; or otherwise, adequate to meet cooling needs. In areas with available land, the systems took the form of cooling ponds; in areas with limited land, they took the form of cooling towers.

1.1 Various Classifications of Cooling Tower

- **Classification by Use -**
  1. Heating, Ventilation & Air Conditioning
  2. Industrial cooling towers
- **Classification by build -**
  1. Package type
  2. Field erected type
- **Classification With respect to the Heat Transfer Mechanism -**
  1. Wet Cooling Towers
  2. Closed Circuit Cooling Towers
  3. Dry Cooling Towers
  4. Hybrid Cooling Towers
- **Classification With Respect to Drawing Air through the Tower –**
  1. Natural Draft
  2. Mechanical Draft
  3. Fan Assisted Natural Draft

HVAC (Heating, Ventilating, And Air Conditioning) Cooling Tower is used to dispose of ("reject") unwanted heat from a chiller. Water-cooled chillers are normally more energy efficient than air-cooled chillers due to heat rejection to tower water at or near wet-bulb temperatures. Industrial cooling towers are much larger than HVAC towers. HVAC use of a cooling tower pairs the cooling tower with a water-cooled chiller condenser.

Fig. 1.1 HVAC Towers

Industrial Cooling Towers can be used to remove heat from various sources such as machinery or heated process material. The primary use of large, industrial cooling towers is to remove the heat absorbed in the circulating cooling water systems used in power plants, petroleum refineries, petrochemical plants, natural gas processing plants, food processing plants, semi-conductor plants, and for other industrial facilities.

Fig. 1.2 Industrial Cooling Towers

Natural Draft - Utilizes buoyancy via a tall chimney. Warm, moist air naturally rises due to the density differential compared to the dry, cooler outside air. Warm moist air is less dense than drier air at the same pressure. This moist air buoyancy produces an upwards current of air through the tower. Sometimes also called ***Hyperboloid*** (sometimes known as hyperbolic) cooling towers have become the design standard for all natural-draft cooling towers because of their structural strength and minimum usage of material. The hyperboloid shape also aids in accelerating the upward convective air flow, improving cooling efficiency. These designs are popularly associated with nuclear power plants. However, this association is misleading, as the same kind of cooling towers are often used at large coal-fired power plants.

Fig. 1.3Natural Draft

1.2 Terminology for Wind Analysis for Design Wind Speed

The wind load on buildings/ structures shall be in accordance with revised edition *IS: 875 (Part 3)-2015*. It can be mathematically expressed as follows:

$$V_z = V_b . K_1 . K_2 . K_3$$

Where V_z, = design wind speed at any height z in m/s;
K_1= probability factor (risk coefficient)
K_2 = terrain, height and structure size factor
K_3 = topography factor

2. Problem identification

- The cooling tower is been considered in the study. Since the height of tower is 50m standard throughout the study. So, at this particular height, exactly which case study of base diameter would be practically applied in the field is to be investigated.
- To understand this study better, we known concrete material is brittle in nature and steel is ductile so to balance this condition we have to analyze how much amount of plate stress takes place in cooling tower.
- Similarly, if load is applied laterally on a RCC Tower, forces develop along the height of the tower. If the tower is weak in lateral dimension, it will feel flexure in that direction and fails. Hence, this amount of displacement is to be found out whichever is safe enough as the considered cases.
- It is been observed that due to wind forces, the dimension having bigger diameter at the base is more vulnerable; it is due to more enlarge portion present in the base making the structure more susceptible by drag forces and lateral displacement only.
- It has been observed that the damage due to deformation of plates in tower makes the RCC structure very uneconomical as we know wind speed given as per code is of 50-year avg. speed which occur once in whole span of life time. So, if the vulnerable

conditions can be identified by the study then there is no worry at the time of high-speed tornado or cyclone or hurricane.

3. Methodology

3.1 Summary of the Study

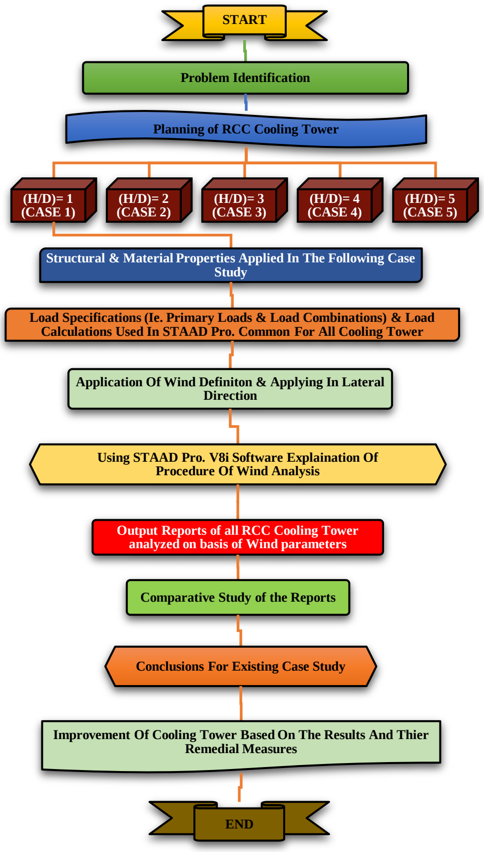


Fig. 3.1 Flow Chart of Summary of Methodology

3.2 Structural & Material Properties of Cooling Tower to be analyzed

The Top area i.e., top diameter considered here are taken equal for all different cases as well as the height of cooling tower is kept constant for all different cases i.e., Slenderness Ratio (H/D) = 1, Slenderness Ratio (H/D) =2, Slenderness Ratio (H/D) = 3, Slenderness Ratio (H/D) = 4, Slenderness Ratio (H/D) = 5, respectively analyzed under wind analysis as per IS 4998:1992. The top diameter of cooling tower is of 12 mm with an effective height of 50 meter excluding the support. The total height of cooling tower is taken as 50 meter plus the fixed support of 3 meter height equal to 53 meter for all the structures and also the section properties is also common for all case frame structures. The following below are the Case Study to be analyzed and designed in this research study-

Table 3.1 Case Distribution List of all Models for the Research Study

Main Cases	Ratios	Case Study Details
Case 1 Tower	*Slenderness Ratio (H/D=1)*	Tower Having H/D Ratio 1.0 with wind speed 39 m/sec
Case 2 Tower	*Slenderness Ratio (H/D=2)*	Tower Having H/D Ratio 2.0 with wind speed 39 m/sec
Case 3 Tower	*Slenderness Ratio (H/D=3)*	Tower Having H/D Ratio 3.0 with wind speed 39 m/sec
Case 4 Tower	*Slenderness Ratio (H/D=4)*	Tower Having H/D Ratio 4.0 with wind speed 39 m/sec
Case 5 Tower	*Slenderness Ratio (H/D=5)*	Tower Having H/D Ratio 5.0 with wind speed 39 m/sec

The various important structural configuration of Cooling Tower plays an important role in the design and analysis of the tower especially base diameter of tower. The parts are as follows – Height of tower, Top diameter of tower, Throat diameter of tower & distance of top from the throat. In this study, were "H" is height of cooling tower and "D" is Base diameter of tower. The ratio of H/D is said to be slenderness ratio as discussed above in the table. The cooling tower cases is divided into cases based on the different slenderness ratio *i.e. Tower Having H/D Ratio 1.0(Case 1 Tower), Tower Having H/D Ratio 2.0(Case 2 Tower), Tower Having H/D Ratio 3.0(Case 3 Tower), Tower Having H/D Ratio 4.0(Case 4 Tower), Tower Having H/D Ratio 5.0 (Case 5 Tower) with each case is analyzed for wind speed 39 m/sec as per IS code 875 Part -3 and also analyzed for the drag force parameter developed due to lateral force.* The structural data provided in this study and considered for design analysis of cooling tower are given below-

Table 3.2 Structural Properties for Design of RCC Cooling Tower

Slenderness Ratio (Height/ Lateral Dimension)	Top Diameter(m)	Base Diameter(m)	Throat Diameter(m)	Distance of Top from Throat (m)
H/D = 1.0	**12**	**49.58**	**9**	**7**
H/D = 2.0	**12**	**24.31**	**9**	**13**

H/D = 3.0	**12**	**16.73**	**9**	**18**
H/D = 4.0	**12**	**12.44**	**9**	**24**
H/D = 5.0	**12**	**10.02**	**10**	**45**

The following below table shows all the structural properties common for all the case study considered on this project and the case models have been designed for these properties –

Table 3.3 Structural Properties used for all buildings

Particulars	Structural Properties
Number of Sections (according to height)	0 m to 50 m
Total height including the supports	53 meter
Slab/Plate thickness	300 mm
Height of Fixed Supports	3 meter
Steel Section for supports	ISA 200 X 150 X 20 mm
Dead load	IS 875 Part-1
Live load	IS 875 Part-2
Wind Load & Analysis	IS 875 Part-3
Code for RCC Cooling Tower	IS 4998:1992

Table 3.4 Material Properties used in all Frames

Particular	Details
Grade of Concrete	M30
Grade of Main Steel	Fe415
Grade of Secondary Steel	Fe415
Density of Reinforced Concrete	25 KN/m^3
Ultimate Tensile Strength of Steel (Indian std.)	420 N/mm^2
Yield Strength of Steel (Indian std.)	250 N/mm^2

3.3 Loading Specification & Calculations Common for all cases

The loads which is to be studied in the project is discussed under following clauses below in which their calculation detail is also been discussed ***such as Primary load, Wind Load & their load combination etc.***

3.3.1 Primary Loads Applied for Analysis –

In STAAD.Pro Software, the loads are taken in the form of load cases i.e., primary load cases and the load combination of primary load cases also which are used same for all four Cooling Towers adding to "load case detail" section in the software. The total number of load cases, magnitude of loads and load combinations used is same for all the four model cases. Firstly, here are the primary load cases which have been used in STAAD.Pro software analysis are given below in table 3.5 with their load type & numbers.

Table 3.5 Primary Load Cases

Load Case No.	Abbreviation Used	Load Type
1	WX	Wind Load
2	WZ	Wind Load
3	D.L.	Dead Load
4	Temp.	Temperature Load

3.3.2 Load Calculations Applied for the Design

The calculated load acting on the structures of dead load, temperature Load which is external load due to heavy gas fumes temperature and wind intensity calculation under basic wind speed 39 m/sec for further action in the analysis are given below-

- **Dead Load (D.L) –**

The dead load of the RCC frame structure containing beam, column and created Surface/Plate elements for the swimming pool is applied in the structure by assigning self-weight load in Y-Direction with load factor -1.

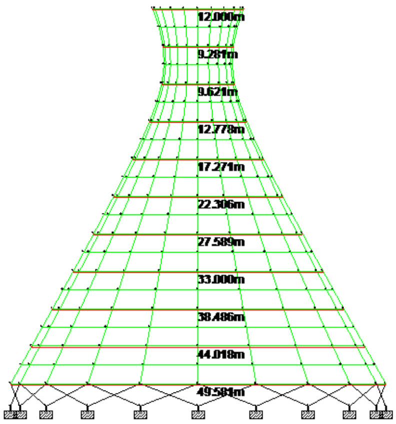
- **Temperature Load (Temp) –**

In this research, live load is in the form of temperature in the cooling tower which is considered here according to IS

4998:1992 i.e., *"Temperature Change for axial elongation"* here it is equal to 500, *"Temperature Differential from Top to Bottom"* consideration not greater than 100 and "*Temperature Differential from Side to Side"* equal to 1000. Temperature load is from inside of tower as a function. Temperature Load is designated or stands for Temp or "T" in STAAD.Pro while designing tower in this research work.

Wind Load (WX & WZ) –

Wind load calculation involves the calculation of wind pressure or wind intensity which is to be embedded in the software for the wind analysis which is done purely as per IS 875 Part-3. Here, Basic wind speeds presented in have been worked out for a 50 year return period. Basic wind speed $\mathbf{V_b}$ for some important cities/towns is also given in Appendix-A of IS 875 Part-3 as our location of cooling tower is in Raipur, Chhattisgarh having basic wind speed ***39 m/sec*** applied for wind analysis. Here, the Coefficient of Risk Factor **(K_1)** is 1.08, ***Terrain Category 2-*** Open terrain with well scattered obstructions having heights generally between 1.5 to 10 m along with ***Class C-*** Structures and/or their components such as cladding, glazing, roofing, etc. having maximum dimension (greatest horizontal or vertical dimension) lies greater than 50 m giving the value of **K_2** as per Table 2 (IS 875 Part-3). For Topography factor**(K_3),** in this cooling tower we are considering the condition of wind slope greater than 3^0 hence the value is 1.0 as per IS 875 Part-3 . ***For Calculation of Design Wind Speed (refer Article 1.2) i.e.,*** $V_z = V_b * K_1 * K_2 * K_3$ and all the calculation is done with the help of STAAD Software. WIND LOAD is designated as WX & WZ where "W" stands for Wind load whereas X & Z represents their respective direction in STAAD Pro.



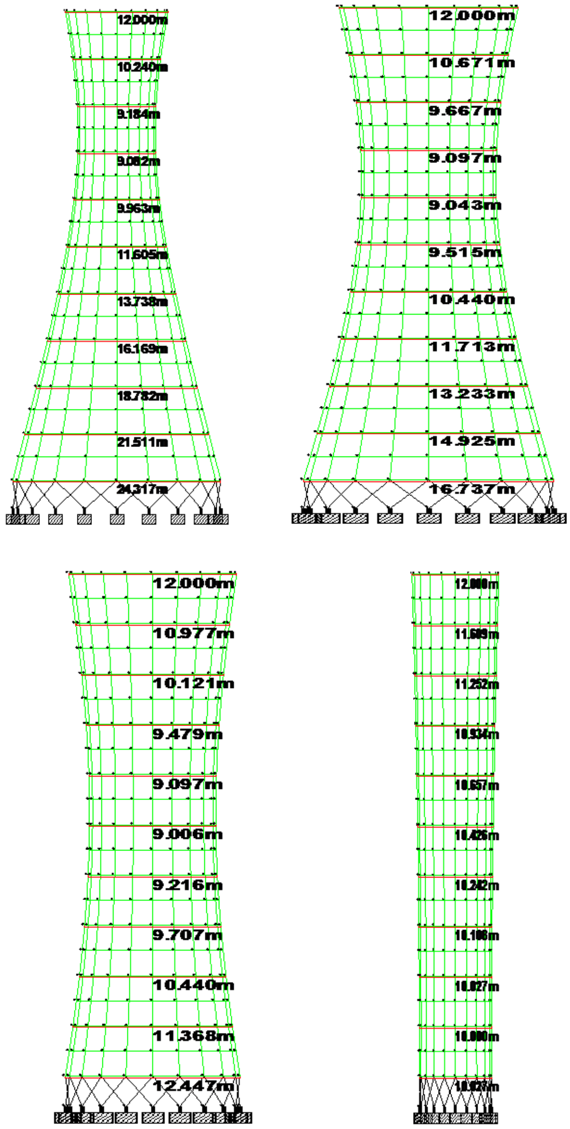


Fig. 4.1 Diameter of Tower from distance 5-50 m of all modal cases

4. Results & Discussions

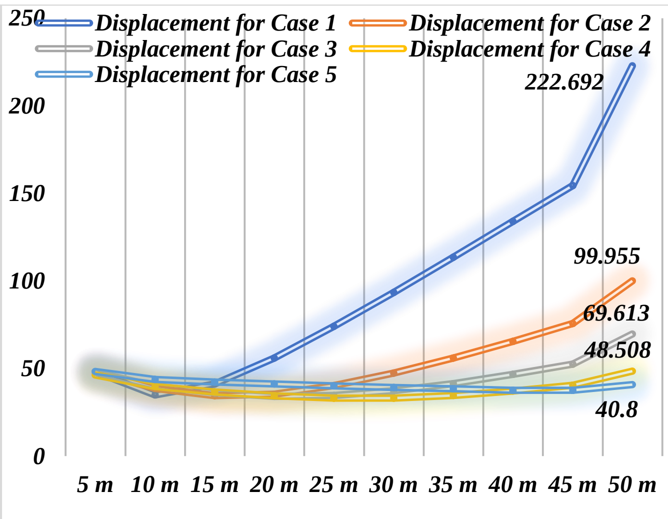
4.1 Comparison report of Displacement

The displacement of Cooling tower concludes that the efficient value of displacement for slenderness ratio (i.e. H/D =1.0) settled maximum value as compare to displacement for slenderness ratio (i.e. H/D =5.0) gives minimum value at 50 m height. Hence, it's concluded that the ***Diameter of RCC cooling tower plays a major factor in displacement.*** The table 5.16shows that report of maximum value of displacement for the cases are as follows- ***222.69 mm (Case 1 tower) > 99.95 mm (Case 2 tower) > 69.61 mm (Case 3 tower)> 48.5 mm (Case 4 tower)> 40.8 mm (Case 5 tower)*** respectively. We concluded that Greater the Slenderness ratio, Lesser the

Displacement in Cooling tower. Greater the Diameter of tower, greater the Displacement in Cooling towers. *When compared between the Case Towers at 5 m height due to common diameter of 12 m, the displacement shows not much difference but when compared at 50 m height, huge difference is analyzed making the respective Case 5 tower much practically safer.*

Table 4.1Comparison of Displacement Report

At Height (m)	Displacement for Case 1 (mm)	Displacement for Case 2 (mm)	Displacement for Case 3 (mm)	Displacement for Case 4 (mm)	Displacement for Case 5 (mm)
5 m	48.044	48.045	47.848	46.188	48.168
10 m	34.864	38.48	39.929	39.588	43.728
15 m	41.043	34.453	36.122	36.505	42.299
20 m	55.941	35.297	34.013	34.288	41.083
25 m	74.0	40.164	34.507	33.031	40.02
30 m	93.397	47.358	37.197	33.173	39.116
35 m	113.442	55.988	41.367	34.627	38.383
40 m	133.851	65.488	46.594	37.073	37.841
45 m	154.32	75.575	52.534	40.389	37.511
50 m	222.692	99.955	69.613	48.508	40.8



Graph 4.1 Comparison of Displacement Report

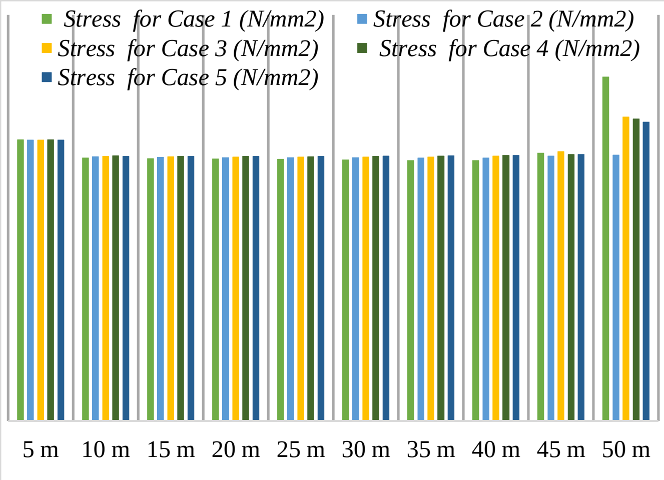
4.2 Comparison report of Plate Stress

The Plate stress in cooling tower concludes that the efficient value of stress for slenderness ratio (i.e. H/D =1.0) settled maximum value as compare to all other cases which shows much similar response in terms of stresses. ***Hence, concluded that Greater the Diameter of Cooling Tower, Greater the Plate stress in RCC towers.***

Table 4.2 Comparison of Plate Stress Report

At Height (m)	Plate Stress for Case 1 (N/mm²)	Plate Stress for Case 2 (N/mm²)	Plate Stress for Case 3 (N/mm²)	Plate Stress for Case 4 (N/mm²)	Plate Stress for Case 5 (N/mm²)
5 m	20.882	20.863	20.861	20.865	20.852
10 m	19.538	19.634	19.656	19.685	19.656
15 m	19.478	19.584	19.62	19.656	19.638
20 m	19.465	19.56	19.606	19.643	19.64
25 m	19.433	19.548	19.596	19.633	19.652
30 m	19.39	19.543	19.594	19.652	19.671
35 m	19.342	19.537	19.605	19.679	19.693
40 m	19.334	19.529	19.673	19.715	19.715
45 m	19.879	19.678	19.994	19.797	19.779
50 m	25.508	19.747	22.566	22.416	22.179

In the above table five comparative analysis is done for the RCC Towers, according to which value of stress is given by i.e. The table 5.2shows that report of maximum value of stresses for the cases are as follows- *25.5 N/mm² (Case 1 tower) > 22.566 N/mm² (Case 3 tower) > 22.41 N/mm²(Case 4 tower)> 22.17 N/mm² (Case 5 tower)> 19.74 N/mm² (Case 2 tower)* respectively. ***When compared between the Case Towers at 5 m height due to common diameter of 12 m, the stress shows not much difference but when compared at 50 m height, difference is analyzed making the respective Case 2 & 5 towers much practically safer.***



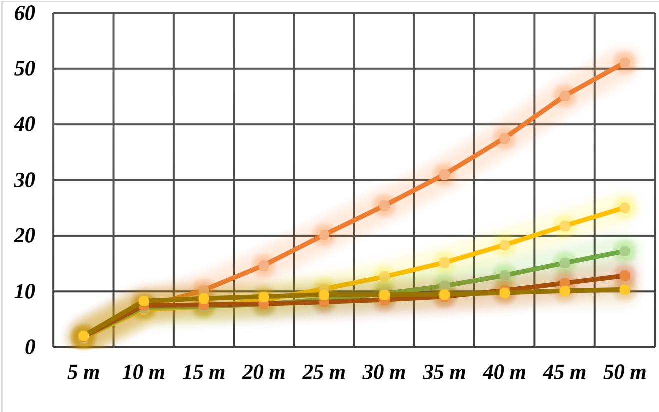
Graph 4.2 Comparison of Plate Stress Report

4.3 Comparison report of Drag Force

The Drag force or lateral force on Cooling tower concludes that the efficient value of drag force for slenderness ratio (i.e. H/D =1.0) settled maximum value as compare to drag force for slenderness ratio (i.e. H/D =5.0) gives minimum value at 50 m height. Hence, it's concluded that the ***Diameter of RCC cooling tower also plays a major factor in drag force parameter.*** The table shows that report of maximum value of drag force for the cases are as follows- *51.09 KN (Case 1 tower) > 25.06 KN(Case 2 tower) > 17.25 KN(Case 3 tower)> 12.83 KN (Case 4 tower)> 10.33 KN (Case 5 tower)* respectively. We concluded that Greater the Slenderness ratio, Lesser the Drag force in Cooling tower. Lesser the Diameter of tower, lesser the Drag force in Cooling towers. ***When compared between the Case Towers at 5 m height due to common diameter of 12 m, the displacement shows not much difference but when compared at 50 m height, huge difference is analyzed making the respective Case 5 tower much practically safer and economical.***

Table 4.3 Comparison of Drag Force Report

At Height (m)	Drag force for Case 1 (KN)	Drag force for Case 2 (KN)	Drag force for Case 3 (KN)	Drag force for Case 4 (KN)	Drag force for Case 5 (KN)
5 m	1.60	1.77	1.84	1.89	2.00
10 m	7.09	6.76	7.12	7.45	8.29
15 m	10.24	7.28	7.29	7.59	8.76
20 m	14.71	8.48	7.70	7.75	9.08
25 m	20.15	10.48	8.60	8.14	9.42
30 m	25.41	12.65	9.62	8.49	9.43
35 m	30.98	15.18	11.00	9.11	9.49
40 m	37.52	18.31	12.90	10.18	9.78
45 m	45.10	21.76	15.10	11.50	10.12
50 m	51.09	25.06	17.25	12.83	10.33



Graph 4.3 Comparison of Drag Force Report

5. Conclusions

The following conclusions have been clarified after the wind analysis on tower–

1) It has been observed that RCC cooling tower based on different slenderness ratio 1 to 5 respectively in which Case 1 tower having base diameter 49.58 m shows much higher displacement or deformation whereas Case 5 tower having least base diameter 10.02 m shows lesser deform in plates. It is been concluded that displacement for Case 1 towers is approximately ***0.5 times more*** than Case 2 Tower. Similarly, ***0.65 times more*** than more than Case 3 Tower, ***0.7 times more*** than more than Case 4 & 5 Tower. Making the conclusions that ***Greater the Slenderness ratio, lesser the Displacement in cooling tower. Greater the Size of Base dimension, Greater the Displacement in Cooling tower.***

2) The analysis demonstrates that due to lateral force i.e. wind force the drag force resisted by the ***cooling tower*** is such that the Case 1 tower shows maximum value i.e. 51 KN which is approximately ***is approximately 0.5 times more than*** Case 2 tower***, 0.66 times more than*** Case 3 tower, ***0.74 times more than*** Case 4 tower***, 0.8 times more than*** Case 5 tower. ***Hence, concluded that Greater the Slenderness ratio, lesser is Lateral or Drag force in cooling tower. Lesser the Size of CFST column, lesser is Lateral or Drag force in cooling tower.***

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