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Analysis and Design of a Cooling Tower Considering Wind Pressure and Thermal Effect Using Staad.Pro

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ABSTRACT

Cooling tower is an integral part of every thermal power generation plant. Basically cooling tower are heat rejection devices used to transfer heat from hot water to the atmosphere air. Investigation involves experimental and two-dimensional computational fluid dynamics analysis of an actual industry operated cooling tower. Inlet water temperature and mass flow rate of water and air are having main influence on the performance of counter flow induced draft cooling tower. In cooling tower water is made to trickle down drop by drop, or form a thin layer over flat surface so that it comes into direct contact with air moving upwards in opposite direction. The heat transfer from the water to the air steam raises the air's temperature and its relative humidity to 100% and this air is discharged to the atmosphere. Likewise other parameters such as range, tower characteristic ratio can also be increased considerably, pressure at outer region, temperature variations.

In this study we will perform dynamic analysis of a tall tower considering thermal effect over the inner layer of the tower and wind pressure to determine its stability in terms of temperature, cracks, stability, resistivity, forces and displacement.

Keywords : Nonlinear Static Analysis, Deflection Cooling Tower, Analysis, Thermal, Displacement, Forces, Moment.

I. INTRODUCTION

Cooling towers are the essential components of many thermal and nuclear power stations. The towers vary in size that can be up to 200 meters tall and 100 meters in diameter having a complex hyperbolic geometry with thin walls. They may be subjected to a variety of loading conditions such as dead, wind, earthquake, temperature and construction loads. However, the wind load is considered to be the most critical load in the absence of earthquake.

Heat is discharged in power generation, refrigeration, petrochemical, steel, processing and many other industrial plants. In many cases, this heat is discharged into the atmosphere with the aid of a cooling tower. Figure 1.1 shows an example of the application of a cooling tower in a simple steam power plant. Heat is discharged into the atmosphere by the cooling tower via a secondary cycle with water as the process fluid.

The cooling tower (CT) is the most important piece of industrial equipment whose primary purpose is to remove the heat while minimizing water usage. They are often used in power generation plants to cool the condenser feed-water. In cooling tower water is made to trickle down drop by drop, or form a thin layer over flat surface so that it comes into direct contact with air moving upwards in opposite direction. The heat transfer from the water to the air steam raises the air's temperature and its relative humidity to 100% and this air is discharged to the atmosphere. As a result of this some water is evaporated and is taken away from the bulk of water, which is thus cooled. Thus evaporative cooling technique is used in the case of cooling towers.

In this study we will perform dynamic analysis of a tall tower considering thermal effect over the inner layer of the tower and wind pressure to determine its stability in terms of temperature, cracks, stability, resistivity, forces and displacement at different temperature.

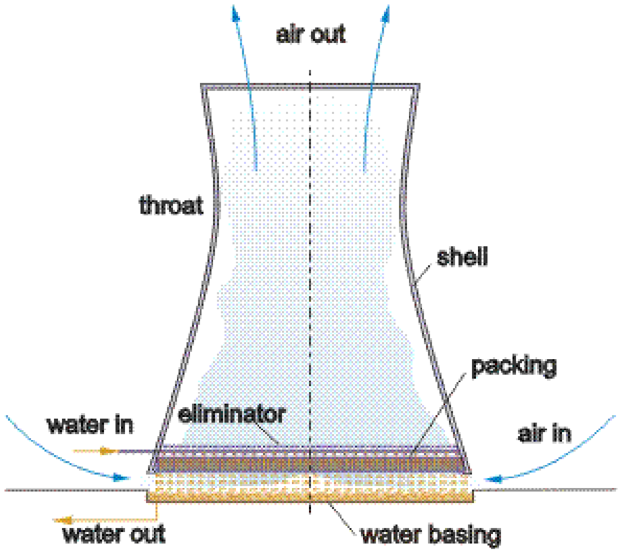


Fig 1: Cooling Tower

A cooling tower is a heat rejection device which extracts waste heat to the atmosphere through the cooling of a water stream to a lower temperature[1]. Cooling towers may either use the evaporation of water to remove process heat and cool the working fluid to near the wet-bulb air temperature or, in the case of closed circuit dry cooling towers, rely solely on air to cool the working fluid to near the dry-bulb air temperature.

Wind Load Analysis

Structures are subject to horizontal loads due to wind pressure acting on the buildings. Wind load is calculated as per IS 875(Part III)-1987. The horizontal wind pressures act on vertical external walls and exposed area of the buildings. Some of the pressure acting on exposed surfaces of structural walls and columns is directly resisted by bending of these members. The infill walls act as vertical plate supported at top and bottom by floor beams, thus transferring the loads at slab level. The parapet wall is at terrace transfers the wind loads to the surface slab by cantilever action. For simplicity, the wind loads acting on exposed surfaces of a given storey are idealized to be supported by upper and lower floors.

Thermal Analysis

Thermal analysis refers to any technique for the study of materials which involves thermal control. Measurements are usually made with increasing temperature, but isothermal measurements or measurements made with decreasing temperatures are also possible. Simultaneous use of multiple techniques increases the power of thermal analysis, and modern instrumentation has permitted extensive growth of application. The basic theories of thermal analysis (equilibrium thermodynamics, irreversible thermodynamics and kinetics) are well developed, but have to date not been applied to actual experiments to the fullest extent possible.

Objectives

The Primary objectives of the study are:

To determine thermal effect on structural members of the tower.

1. To Analyze the cooling tower structure considering wind pressure.
2. To Analyze the structure using Analysis tool STAAD.Pro.
3. To determine the cost of construction as per S.O.R. 2019.
4. To Determine suitable width of the tower to overcome heating effect.

II. LITERATURE REVIEW

Kumar and Mathews (2018) [17] the research paper presented that by increasing the mass flow rate of air the performance of cooling tower can be improved. All the performance parameters such as cooling water range, effectiveness, tower characteristic ratio has increased. The increase in the effectiveness of cooling tower was about 20%. When the (L/G) ratio was reduced from 3.25 to 2.60. The outlet temperature of cooled water is reduced to 2k. The effect of inlet water temperature on the performance of cooling tower was studied keeping other parameters such as mass flow rate, injection height, and fill area constant it was found that effectiveness is reduced by 8%. The effect of water mass flow rate was also studied and it was found that by optimizing the mass flow rate of both water and air the effectiveness can be increased. But reducing the mass flow rate of water reduces the output of the cooling tower and inlet water temperature depends on the plant operations.

Mondrety et. al. (2018) [7] the study of static structural, dynamic (model) and seismic behavior of hyperbolic cooling towers i.e. self weight, static loads and ground acceleration for seismic load condition. The boundary conditions considered are Top end free and Bottom end fixed. The material used for cooling tower is concrete. Three different cooling towers will modeled by using SOLIDWORKS 2016 software. Static structural analysis is performed by applying self weight of the cooling tower i.e.: due to gravity, stress, strain and deformation due to load is obtained for each cooling tower. MODAL analysis is performed on cooling tower by fixing it with ground, 6 different deformation modes shapes with respective frequencies are obtained as the result for each cooling tower. Response spectrum analysis is performed to study the seismic effect on cooling tower, for acceleration case 0.5g, 0.6g, and 0.7g. From the modal analysis table, it was conclude that as the height of the cooling tower increase the natural frequency will decrease.

Angalekar and Kulkarni (2018) [13] the research paper exhibited that the support of column to the tower could be supplanted by identical shell components with the goal that the product created could without much of a stretch be used. For such a show, a solitary instance of the pinnacle with elective 'I' and 'V' bolsters was considered displaying the conduct in regard of comparable plates which were indistinguishable from the conduct where the real segment underpins were considered. For this, the wind load over the structure was applied. The outcomes expressed that the proportionate shells gave indistinguishable diverted profiles to the use of the breeze loads, similar to those because of real backings. It was seen that the 'V' underpins give 73.6% more influence than 'I' bolsters on account of segment bolsters just as proportionate plate framework because of the utilization of wind load. The collapse load if there should arise an occurrence of 'I' supportive network was having a 40% higher incentive than on account of 'V' type supportive networks. The structure with the arrangement of reinforcement for example steel plate could support just about 35 to half more crumple load than that of plain concrete.

Outcome of the Study

The researchers have tried to find the variation in forces which occurs due to thermal effect following are the outcomes of literature review:

1 Determine that tall structures need to consider lateral load analysis
2 That structure considering thermal effect shows variation at different height.

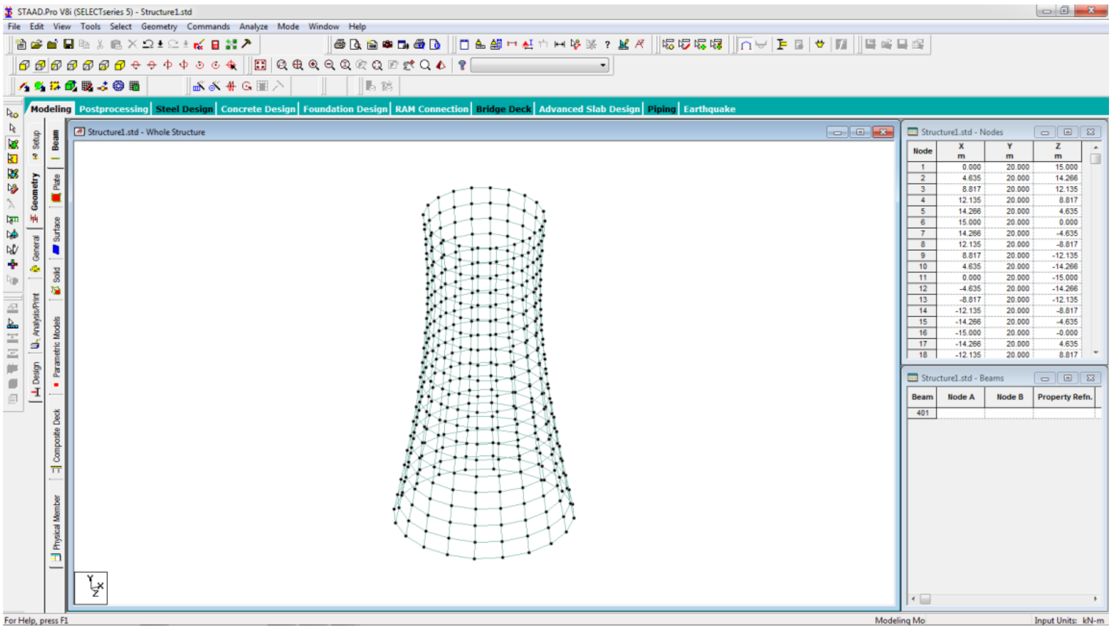
3 Wind pressure in tall structure shows higher displacement.

Following steps are followed as shown below:

Step-1: To prepare a literature survey related to our study.

Literature Survey was prepared for the past study undertaken till date and shortcomings were identified on which further research needs to be executed. This step further dealt with presenting the application of Cooling tower in various industries and its future prospects of general applications in various other industries.

Step-2:To Prepare geometrical structure of the study using analysis tool STAAD.



Structure1.std - Nodes

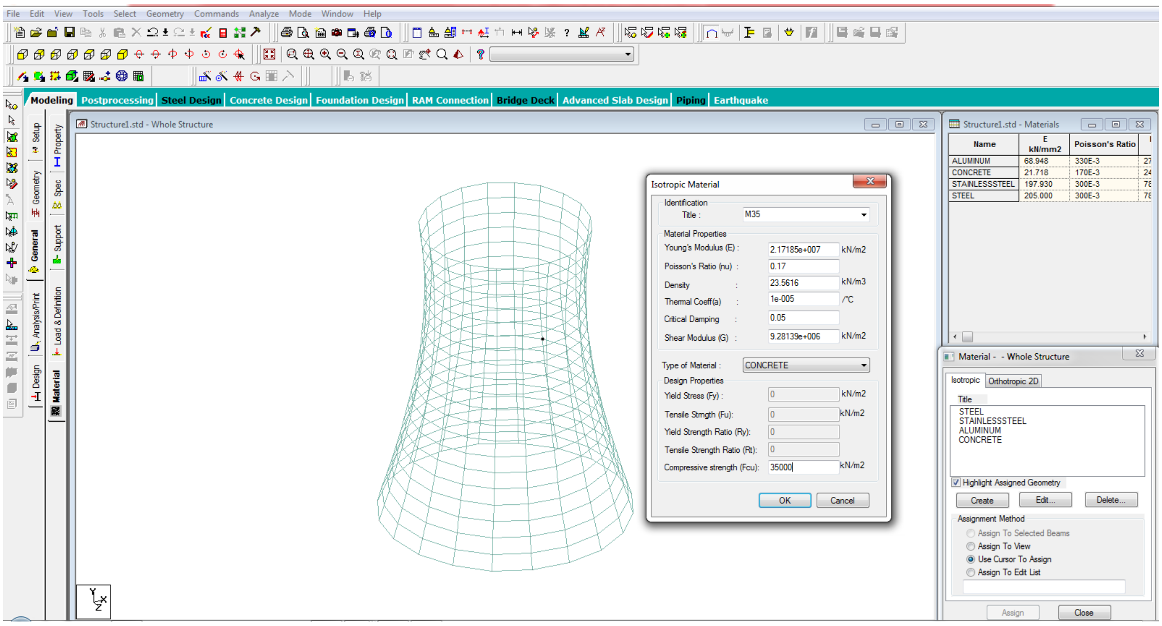
Node	X m	Y m	Z m
1	0.000	20.000	15.000
2	4.635	20.000	14.266
3	8.817	20.000	12.135
4	12.135	20.000	8.817
5	14.266	20.000	4.635
6	15.000	20.000	0.000
7	14.266	20.000	-4.635
8	12.135	20.000	-8.817
9	8.817	20.000	-12.135
10	4.635	20.000	-14.266
11	0.000	20.000	-15.000
12	-4.635	20.000	-14.266
13	-8.817	20.000	-12.135
14	-12.135	20.000	-8.817
15	-14.266	20.000	-4.635
16	-15.000	20.000	-0.000
17	-14.266	20.000	4.635
18	-12.135	20.000	8.817

Structure1.std - Beams

Beam	Node A	Node B	Property Refn.
401			

Fig 2 : Modelling of Cooling Tower using Staad.Pro.

Step-3: To Create material properties and assigning at structure.



Isotropic Material

Identification

Title : M35

Material Properties

Young's Modulus (E) : 2.17185e+007 kN/m2

Poisson's Ratio (nu) : 0.17

Density : 23.5616 kN/m3

Thermal Coeff(a) : 1e-005 /°C

Critical Damping : 0.05

Shear Modulus (G) : 9.28139e+006 kN/m2

Type of Material : CONCRETE

Design Properties

Yield Stress (Fy) : 0 kN/m2

Tensile Strngth (Fu): 0 kN/m2

Yield Strength Ratio (Ry): 0

Tensile Strength Ratio (Rt): 0

Compressive strength (Fcu): 35000 kN/m2

Structure1.std - Materials

Name	E kN/mm2	Poisson's Ratio
ALUMINUM	68.948	330E-3
CONCRETE	21.718	170E-3
STAINLESSSTEEL	197.930	300E-3
STEEL	205.000	300E-3

Material - - Whole Structure

Isotropic | Orthotropic 2D

Title

STEEL
STAINLESSSTEEL
ALUMINUM
CONCRETE

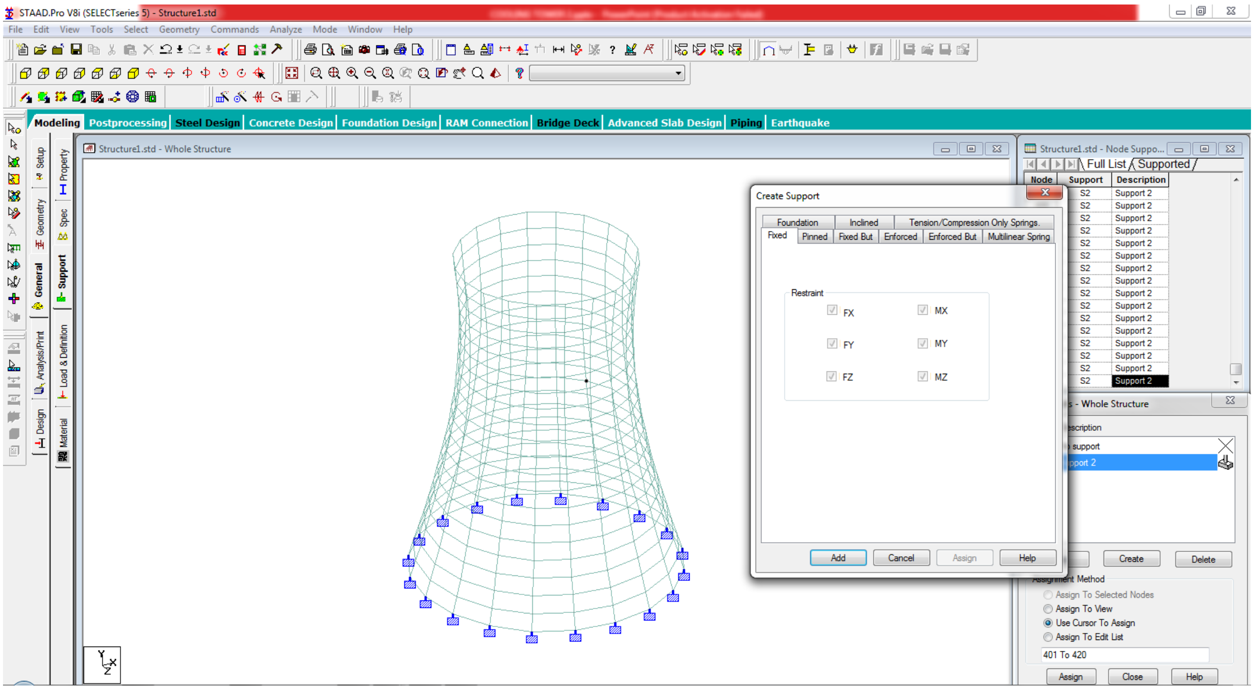
☑ Highlight Assigned Geometry

Assignment Method

○ Assign To Selected Beams
○ Assign To View
● Use Cursor To Assign
○ Assign To Edit List

Fig 3 : Assigning material and section properties

Step-3: Assigning fixed end condition at the bottom of the tower



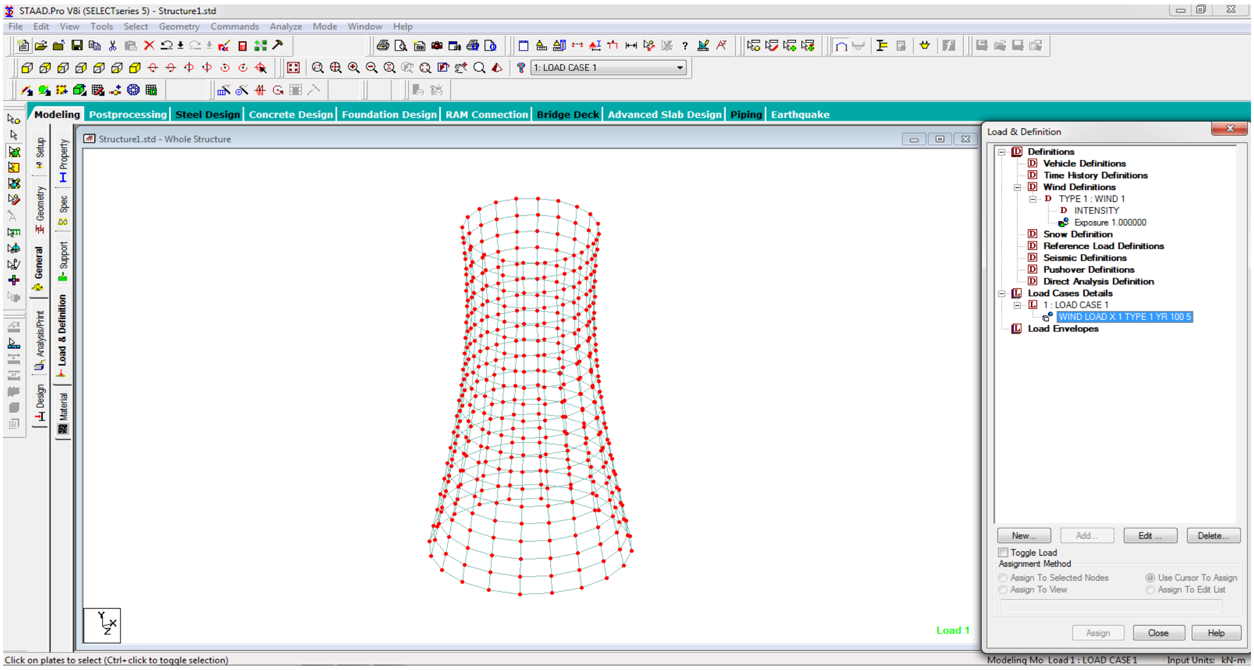
Restraint: ☑ FX ☑ MX ☑ FY ☑ MY ☑ FZ ☑ MZ

Node	Support	Description
	S2	Support 2
	S2	Support 2
	S2	Support 2
	S2	Support 2
	S2	Support 2
	S2	Support 2
	S2	Support 2
	S2	Support 2
	S2	Support 2
	S2	Support 2
	S2	Support 2
	S2	Support 2
	S2	Support 2
	S2	Support 2
	S2	Support 2
	S2	Support 2

Assignment Method
○ Assign To Selected Nodes
○ Assign To View
● Use Cursor To Assign
○ Assign To Edit List
401 To 420

Fig 4 : Assigning Support condition

Step-4: Assigning loading conditions:



- Definitions
  - Vehicle Definitions
  - Time History Definitions
  - Wind Definitions
    - TYPE 1 : WIND 1
      - INTENSITY
      - Exposure 1.000000
  - Snow Definition
  - Reference Load Definitions
  - Seismic Definitions
  - Pushover Definitions
  - Direct Analysis Definition
- Load Cases Details
  - 1 : LOAD CASE 1
    - WIND LOAD X 1 TYPE 1 YR 100 5
- Load Envelopes

☐ Toggle Load
Assignment Method
○ Assign To Selected Nodes ● Use Cursor To Assign
○ Assign To View ○ Assign To Edit List

Fig 5 : Loading conditions assigned

Step-6: Assigning Load combinations as per I.S. 875-III

Step-7: Analysis of cooling tower

Table 1: Geometrical Description of tower

SR .NO.	**PARAMETER**	**SIZES**
1	AREA	25 m^2
2	TOWER HEIGHT	60 m
3	LIVE LOAD	3 Kn / m^2
4	FLOOR FINISH	2 Kn / m^2
5	Structural wall	800 mm
6	Masonry	100 mm
7	Brick lining	100 mm
8	Top ring beam	400 x 400 mm
10	Wind pressure	39 m/s
11	Thermal effect	900 ^{O}C, 100 ^{o}C & 1100 ^{o}C.
12	SOIL PROPERTY	MEDIUM SOIL

Loading Conditions Adopted:

a) Dead Load (DL)

It is total dead load of structure bracings and dampers

b) **Live load:**

In this study we are considering thermal load of 800, 900, 1000 and 1100 ^{o}C. for analysis as live load for cooling tower.

a) Wind Load as per I.S. 875-III

Select basic wind speed as per (appendix-A) I.S. 875-III:2015.

Vb = 39 m/s

Basic wind speed shall be modified to include the following effects to get design wind speed, Vz at any height, Z for the chosen structure:

(a) Risk level.
(b) Terrain roughness and height of structure.
(c) Local topography.

Table 2 : Wind force parameters for proposed issue

S.No.	**Parameter**	**Value**	**Remarks**
1	Wind Speed	39 m/s	Appendix-A I.S. 875-III (2015)
2	Risk Coefficient K1	1	Table-1 (I.S. 875-III (2015))
3	Terrain Roughness and Height Factor	1.2	Category, Class & Table-2 (I.S. 875-III (2015))
4	Topography Factor	1	Table-3 (I.S. 875-III (2015))

III. Analysis Result

Axial Force

Table 3: Axial Force in KN

Storey	**Max. Axial Force in KN**			
	1100°	**1000°**	**900°**	**800°**
60	3025.9	3014.9	2919	2605.4
55	3025.5	3007.5	2917	2586.8
50	3025.1	3004.1	2916	2568.2
45	3024.8	3000.8	2913	2549.5
40	3024.3	2997.3	2911	2530.9
35	3023.9	2993.9	2909	2512.2
30	3023.5	2989.5	2909	2493.6
25	3023.2	2987.2	2907	2475
20	3022.9	2984.9	2906	2456.3
15	3022.6	2983.6	2905	2437.7
10	3022.3	2981.3	2904	2419
5	3022	2978	2902	2400.4
0	3021.7	2974.7	2901	2381.8

Table 4: Shear Force in KN

Storey	**Max. Shear Force in KN**			
	1100°	**1000°**	**900°**	**800°**
60	223.9	222.8	223	195.6
55	219.76	218.06	217	193.67
50	215.54	214.04	214	191.73
45	212.89	211.59	212	189.8
40	209.61	207.91	207	187.87
35	203.32	201.92	202	185.94
30	198.56	197.36	197	184
25	194.09	192.19	192	174.34
20	189.62	187.92	187	176.32
15	185.15	183.59	182	172.14
10	180.68	178.7	177	167.96
5	176.21	175	172	163.78
0	171.74	170.35	167	159.6

Table 5: Displacement in mm

Height of the Tower	Displacement in mm			
	800°	900°	1000°	1100°
60	50.32	91.56	106.2	112.65
55	47.21	86.07	102.1	108.54
50	44.1	80.58	97.99	104.43
45	40.99	75.09	93.91	100.32

40	37.88	69.6	89.83	96.21
35	34.77	64.11	85.75	92.1
30	31.66	58.62	81.67	87.99
25	28.55	53.13	77.59	83.88
20	25.44	47.64	73.51	79.77
15	22.33	42.15	69.43	75.66
10	19.22	36.66	65.35	71.55
5	16.11	31.17	61.27	67.44
0	0	0	0	0

Table 6 : Bending Moment in KN-m

Storey	**Max. Bending moment in KN-m**			
	1100°	**1000°**	**900°**	**800°**
60	389.21	378.21	367.4	290.3
55	375.99	357.99	359.6	289.32
50	367.89	346.89	351.7	276.92
45	359.43	335.43	339.7	264.52
40	351.24	324.24	328	252.12
35	336.72	306.72	312.3	239.72
30	329.87	295.87	302.7	227.32
25	318.65	282.65	287.8	214.92

20	307.43	269.43	272.9	202.52
15	296.21	257.21	258	190.12
10	284.99	243.99	243.1	177.72
5	273.77	229.77	228.2	165.32
0	262.55	215.55	213.3	152.92

Cost Analysis:

Table 7: Cost Analysis

S.No	**Case**	**Qty. of concrete**	**Qty. of reinforcement**	**Concrete rate/cu.m**	**Reinforcement rate/kg**	**Cost of concrete**	**Cost of reinforcement**
1	**Tower with 800 °C**	1290.76	3490.32	4500	48	58,08,420	167535.36
2	**Tower with 900 °C**	1386.45	3902.4	4500	48	62,39,025	187315.2
3	**Tower with 1000 °C**	1580.43	4521.34	4500	48	71,11,935	217024.32
4	**Tower with 1100 °C**	1654.98	4907.5	4500	48	74,47,410	235560

IV. Conclusion

Following Conclusions are made as per the results observed in above chapter are:

In terms of Bending moment it is observed that as we increases the temperature moment as at 800°C value is 290.3 kN-m whereas in 1100°C it increases to 378.21 kN-m

It is observed in the analysis that temperature effect plays a vital role in structural stability of the structure as there is observed a variation of more than 50% in displacement due to temperature variation, in 800°C displacement is 50.32 mm whereas in 1100°C value increases to 112.65 mm.

In terms of unbalance forces with increase in temperature sudden rise in stresses are observed as in 1100°C value is 223.9 KN whereas in 800°C it decreases to 195KN.

In terms of Axial Force variation of 35% is observed with the rise of temperature.

In terms of support reaction it is observed that with rise in temperature vertical pressure increases from 8703.67 KN in 800 °C to 9034.65 KN in 1100 °C.

In terms of cost analysis it is observed in above chapter that cost increases as we design the structure for higher thermal load. Since the requirement of Ast increases with rise in thermal load. Here it can be said that cost varies by 28.9% as we increases the temperature.

V. Future Scope

1. In this study we are considering wind pressure whereas in future we can select seismic force.
2. In this study we are performing static analysis whereas in future dynamic analysis can be consider.
3. In this study we are considering circular cooling tower whereas in future other shapes can be consider.

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