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ANALYSIS OF SELF SUPPORTED REINFORCED CONCRETE CHIMNEY WITH GEOMETRY VARIATION

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Abstract - *Any structure needs to be withstand for two issues, strength and stability. Structure requires a support system that has sufficient strength to bear loads and stability to transmit it safely to the ground. The report shows an analysis of self-supported reinforced concrete chimney subjected to lateral loads like earthquake and wind loads by considering the variation in geometry. The previous investigations concluded that, height to diameter ratio and thickness of concrete shell are able to resist maximum part of lateral load on reinforced concrete chimney. The scope of present work is to analyse self-supported reinforced concrete chimney with different height to base diameter ratio and top to base diameter ratio. The equivalent static analysis has been carried out by using STAD-PRO Software and maximum moment and stress calculated as per procedure given in IS 4998 (part -1)-1992. The models where examined for parameters like shear force, bending moment, bending stress, deflection and modal oscillation. The behavior of reinforced concrete chimney will examine in this work by analyzing it. In this case we are going to assume the different base and top diameter and thickness of concrete shell maintaining the same height of self-supported reinforced concrete chimney. Based on the analysis, the best self-supported reinforced concrete chimney is suggested for such consideration.*

Key Words*: *Reinforced concrete, chimney, self-supported, wind load, Stad-pro V8i.

1. INTRODUCTION

In modern constructions, the reinforced concrete structures are mostly designed. These are an indivisible structure which behaves separately as the design variables are changes. The design of such structure becomes visible and more complex. However, in most cases these are the assembly of several basic structural components likewise, shell, slab, beams, columns, walls and foundations. In the initial design stage, working with the structure in all its complexity have to be resolved and prove to be well ordered. At this instant, the superstructure response must be studied and designed for risk-free case. For succeeding to that, design load to be used for the model to capture the essentials of the structural behavior which indicate the way the structure channels the applied loads into the foundations. Thus, models and numerical results established from computerized initially design are most useful in evaluate the response of structures. These obtained values will additionally apply to design the foundation work of particular models.

1.1 Background

Each structure is to be designed for strength, limiting deflection, and durability. The function and aesthetics of structures should keep in consideration during achieving this strength, deformation and durability. It may possible when the structural engineer had quite knowledge about architectural requirements. In case of high-rise structure, certain failures may occur due to lateral loads. The lateral loads are almost wind and earthquake, whose main horizontal force component acting on the dissimilar members of configuration. The horizontal force effects due to wind and earthquake loads are usually analyzed as an equivalent static load in most type of high-rise structure. These structures are designed in such a way that its every component must resist two types of loads like vertical Load due to gravity and lateral load due to earthquake and wind. The reinforced concrete chimney shell, which transfer vertical load and lateral load to the foundation. The present study is on the analysis of cantilever reinforced concrete chimney with variation in geometry and different orientation, when they are subjected to the lateral loads.

This report shows the certain design values for different configurations of chimney structures which may take consideration for foundation designing work. The effects of lateral force due to wind and earthquake loads are analyzed by an equivalent static load method and dynamic analysis by response spectrum method. The present study is carried for the region Nashik, district of Maharashtra state in India. According to which wind load and earthquake load parameters were considered as per IS code such as IS 4998(part-1):1992, IS 1893 (part-4):2005 and IS 875(part-3). The present study is carried only to study the merits and demerits of these types of chimney configuration based on the analysis, for such terrain conditions.

1.2 Classification of chimneys

A] Based on number of flues
- i) Single flue (each boiler will have an independent chimney)
- ii) Multi flue (Single chimney serves more than one boiler; more flues are housed inside a common concrete windshield)

B] Based on material of construction
- i) Concrete (Chimney); Reinforced/Pre-stressed
- ii) Steel (stack)
- iii) Masonry

C] Based on structural support
- i) Guyed stacks (used in steel stacks for deflection control)
- ii) Self-supporting (cantilever structures)

D] Based on lining
- i) With Lining: Lined chimneys/stacks
  Without lining: Unlined chimneys/stacks.

2. METHODOLOGY

Self-supported concrete chimneys experience various loads in vertical and lateral directions. Important loads that a concrete chimney often experiences are wind loads, earthquake loads, and temperature loads apart from self-weight, loads from the supplements, enforced loads on the examination podiums. Wind effects on chimney plays an important role on its safety as concrete chimneys are generally very tall structures. The circular cross section of the chimney subjects to aerodynamic boost beneath wind load. Yet again earthquake capacity is a most important consideration for chimney as it is considered as natural load. This load is generally vibrant in nature. Affording to code providing quasi-static methods are used for evaluation of this load and mention intensification of the regularized reaction of the chimney with a factor that depending on the soil and strength of earthquake. In popular of the cases vent fumes with precise great temperature released inside a chimney. Due to this a temperature grade with deference to ambient heat outside is developed and hence caused for stresses in the shell. Therefore, temperature effects are also important factor to be considered in the concrete design of chimney. This section defines the wind load and earthquake effects on self-supported concrete chimney.

2.1 OUTLAY OF WORK

A] Review of present literatures by various researchers Choice of types of structures.
B] Modeling of cantilever reinforced concrete chimney using STAAD.PRO
C] Development of load cases
D] Development of load combination
E] Static as well as dynamic analysis of reinforced concrete chimney for wind load and earthquake load.
F] Identify critical load combination for model of chimney
G] Determining parameters like bending moments, shear forces, displacement, time period and axial forces are compared for all type of structural systems.
H] Performing analysis on selected chimney models and comparison of the analysis results.
I] Discussion on detailing of analysis and graphs
J] Regression analysis for maximum axial forces coming on the chimney model
K] Results and discussions on analysis of cantilever reinforced concrete chimney
L] Conclusion on obtained results for the cantilever reinforced concrete chimney.

2.2 MODELLING

A single flue reinforced concrete self-supported chimney is deliberated for the analysis located in seismic sector III. The vent gas emission point will be 250 m above the finished floor level. The chimney height and top diameter are directed by leaving velocity of gas and dispersion of effluent to a greater area contained by specified limits of earth level concentration. It is known by test that downwash can be dodged if efflux velocity is superior to 1.5 times the wind speed for this reason, the chimney flue at top is based on least leaving velocity among 15 to 25 m/sec, and Indian code IS: 4998 stretches a firsthand formula to calculate the chimney elevation. The exterior outline of the chimney shell is derived from the structural consideration of the great structure and the base. The top portion to the extent possible is reserved cylindrical monitored by linear slopes. The diameter of the chimney shell at the top is set aside least possible allowing for accommodation of the flue, staircase and elevator. The bottommost diameter of chimney is ordinarily governed by structural requirements, for single flue chimney an outside batter in the range of 1 in 40 to 1 in 80, a ratio of height to base diameter in the range of 10 to 12 and a ratio of top to base diameter in the range of 0.2 to 0.8 is provided. Single flue of structural steel is provided to discharge the flue gases from the top of the chimney. The shell rests on R.C.C. mat foundation of circular shape.

Details of the R.C.C. chimney are as follows

1. Height of chimney	-	250 m
2. Outer diameter at bottom	-	25 m
3. Outer diameter at top	-	18.72 m
4. Thickness of shell at bottom	-	0.5 m
5. Thickness of shell at top	-	0.5 m
6. Grade of concrete	-	M35
7. Exit velocity of gas at top	-	25.0 m/sec

8. Maximum flue gas temperature - 135 °C
9. Seismic Zone - III
10. Basic wind Speed - 39 m/sec
11. Foundation Type - RCC circular mat
12. Structure Category - 1
13. Soil Type - Hard Soil
14. Elasticity of concrete - $3.5x10^{10}$ KN/m^2
15. Poisson's ratio - 0.17
16. Density of concrete - 25 KN/ m^3
17. Alpha - $11x10^{-6}$ / °C
18. Damping - 5 %

Model No.	Tapering angle (θ)	Tapering	slenderness ratio(height /base diameter)	Height (h) (m)	Base diameter (m)	Top diameter (m)	constant Thickness s= base/30
M-1	1.43	1 in 40	10	250	25	12.52	0.83
M-2	1.15	1 in 50	10	250	25	14.96	0.83
M-3	0.95	1 in 60	10	250	25	16.71	0.83
M-4	0.82	1 in 70	10	250	25	17.84	0.83
M-5	0.72	1 in 80	10	250	25	18.72	0.83
M-6	1.43	1 in 40	11	250	22.73	10.25	0.76
M-7	1.15	1 in 50	11	250	22.73	12.69	0.76
M-8	0.95	1 in 60	11	250	22.73	14.44	0.76
M-9	0.82	1 in 70	11	250	22.73	15.57	0.76
M-10	0.72	1 in 80	11	250	22.73	16.44	0.76
M-11	1.43	1 in 40	12	250	20.83	8.35	0.69
M-12	1.15	1 in 50	12	250	20.83	10.8	0.69
M-13	0.95	1 in 60	12	250	20.83	12.54	0.69
M-14	0.82	1 in 70	12	250	20.83	13.68	0.69
M-15	0.72	1 in 80	12	250	20.83	14.55	0.69

Fig -1: Geometry chart of models

2.3 ESTIMATION OF WIND LOADS

Two approaches of assessing of wind loads are given in IS 4998 (Part 1): 1992. The first is a simplified method and is possible to yield somewhat conservative results as far as across wind loads are concerned. The reason for this, as explained earlier, is the scarcity of basic fluid-elastic interaction information, sufficiently acceptable data on impressive turbulence in several parts of our nation and absence of any systematic full scale investigation on high structures in our country. Another method is based on random response method.

The wind loads shall be estimated by together the methods and the loading which produces greater moments shall be considered for design of chimneys.

2.3.1 SIMPLIFIED METHOD

A) Along-Wind Load or Drag Force:

The along-wind load or drag force per unit tallness of the chimney at any level shall be intended from the equation:

$F_z = p_z.C_D.d_z$ .... (1)

The design wind pressure (p_z), for the along- wind response, shall be obtained in accordance with IS 875 (Part 3); 1987, taking the appropriate factor depending upon the class of the structure as defined in that standard.

The chimney shall be divided into ten or more sections along its height and the load at any section shall be calculated by suitably averaging the loads above and below it. The moments are calculated from the sectional forces treating the chimney as a free standing structure.

B) Across-Wind Loads

The amplitude of vortex excited oscillation perpendicular to direction of wind for any mode of oscillation shall be calculated by the formula:

$$\eta_{oi} = \left\{ \frac{\int_0^H d_z \phi_{zi} \, d_z}{\int_0^H \phi^2_{zi} \, d_z} \right\} \times \frac{C_L}{4\pi S_n^2 K_{si}} \quad \text{.................................. (2)}$$

The recommended value of the peak oscillatory lift coefficient accounts for the Reynolds number, partial correlation of vortex shedding over the height of the chimney, effect of amplitude of oscillation and typical value of surface roughness. Calculations based on this value are acceptable for oscillatory amplitudes of up to 4 percent of the effective diameter. If the so computed value of the amplitude of oscillation η_{oi} exceeds 4 percent of the effective diameter, the amplitude of oscillation shall be increased as follows:

Amplitude of oscillation η_{oi} (for computed value of $\eta_{oi} > 0.04$ d) = (computed value of $\eta_{oi})^3$ / $(0.4d)^2$.

The sectional shear force (F_{zoi}) and bending moment (M_{zoi}) at any height z_o, for the i^{th} mode of vibration, shall be calculated from the following equations:

$$F_{zoi} = 4\pi^2 f_i^2 \eta_{oi} \int_{z_0}^H m_z \Phi_{zi} d_z \quad \text{........................ (3)}$$

$$M_{zoi} 4\pi^2 f_i^2 \eta_{oi} \int_{z_0}^H m_z \Phi_{zi(Z-Z_0)} d_z \quad \text{........................ (4)}$$

C) Calculation of Mass Damping Parameter (KSi)

Periodic reaction of the chimney in the i^{th} mode of vibration is very strongly dependent on a dimensionless mass damping parameter KS1 calculated by the equation:

$$K_{Si} = \frac{2m_{ei}.\delta_s}{\sigma.d^2} \quad \text{.. (5)}$$

D) Calculation of Equivalent Mass per Unit Length (mei)

The equivalent mass per unit length of vibration (m_{ei}) shall be calculated by the equation:

$$m_{ei} = \frac{\int_0^H m_z \cdot \phi^2_{zi} \cdot d_z}{\int_0^H \phi^2_{zi} \cdot d_z} \quad \text{.. (6)}$$

When the mass per unit length devises to be used in a numerical method of integration, it is recommended that the mass of the segment above the segment reflected be added to the mass of the segment below the section and the total mass so obtained divided by the total length of the two segments. [30]

E) Calculation of Critical Wind Speed

The critical wind speed (V_{cri}) for vortex shedding for the i^{th} mode of vibration shall be calculated from the equation:

$$V_{cri} = \frac{f_1 \cdot d}{S_n} \qquad (7)$$

The critical wind speeds for exciting the fundamental and higher modes of vibration of the chimney shall be calculated by substituting the relevant modal frequencies. All the modes which can be excited up to wind speeds 10 percent above the extreme predictable at the height of the active diameter shall be considered for subsequent analysis. If the critical wind speed designed for any mode of oscillation surpasses the limits specified previously, it is permissible to undertake that problem of vortex agitated resonance will not be a design criterion for that and the higher modes. In such cases across-wind analysis is not required.

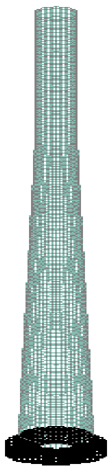

Fig -2: **Staad.pro designed model**

2.4 DESCRIPTION OF LOADING

A] Dead Load

Density of various materials considered for design

Concrete	:	25 KN/m³
Insulation	:	1 KN/m³
Soil	:	18 KN/m³
Structural steel	:	78.5 KN/m³

B] Live Load

5 KN/m² will be considered for the design of internal and external platforms.

C] Wind Load

The following wind parameters are followed in accessing the wind loads on the structure.

Basic wind speed	=	39 m/sec
Terrain category	=	2
Class of structure	=	C
Risk coefficient k1	=	1.06
Topography factor k3	=	1.00

K_2 factors shall be suitably taken along the height as given in Table – 2 and Table – 33 as per IS: 875 part-3.

2.5 STRUCTURAL ANALYSIS AND DESIGN

The following general steps are required to analyze and design a structure using STAAD-PRO.

1. Create or modify a model that numerically defines the geometry, properties, loading, and analysis factors for the configuration

2. Execute an analysis of the model

3. Review the results of the analysis

4. Check and optimize the design of the structure

This is done in three phases namely Pre-processing, Analysis and Post-processing. Model configuration, defining various material as well as section properties, assigning this properties, defining load cases, defining load combinations and defining analysis cases is done in pre-processing phase. In analysis phase model is analyzed as per set analysis option and analysis cases. And finally various results, outputs, deformed shapes, graphs, member forces and stresses are viewed in post-processing phase.

A] Phase I: Pre-Processing

In this phase first making of the frame model which is to be analyzed is done, and then properties of the material such as density of materials, modulus of elasticity is defined. Also various structural member's such as 4-noded plates of concrete shell, fixed supports at base are defined and assigned previously defined material properties to it. After following this initial steps basic model of RCC chimney structure is completed. Then various loads, load cases are defined and assigned. Finally setting analysis option is done as per requirements pre-processing is carried out and model is ready for analysis.

B] Phase II: Analysis

After carried out all the steps in pre-processing, the next phase is to analyse the model. There is option in Run analysis case and analysis should involve in pre-processing phase, structure is ready to analysis cases. As per our requirement we choose specific analysis is to be perform.

C] Phase III: Post-Processing

After analysis performed as per required analysis case, without any warning and errors, the software displays deformed results for maximum displacement, maximum base shear, axial force, story drift etc. Also animation and creation of videos of this animation are carried out in this phase.

3. RESULTS

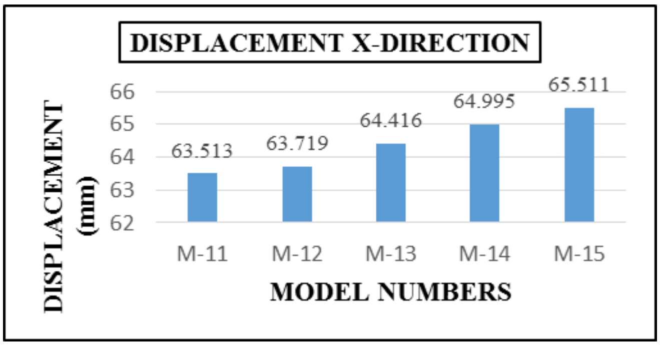

Chart -1: Displacement X-direction with H/D ratio 12

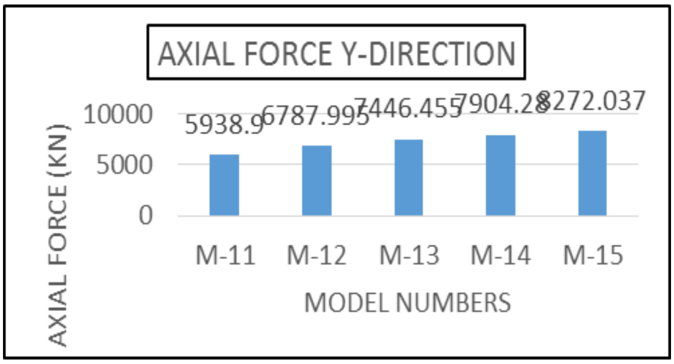

Chart -2: Axial force X-direction with H/D ratio 12

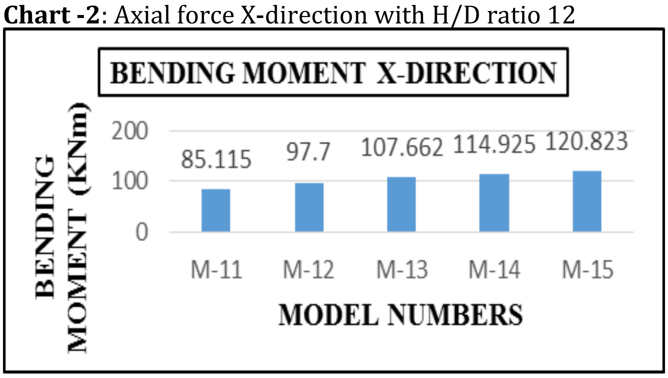

Chart -3: Bending moment X-direction with H/D ratio 12

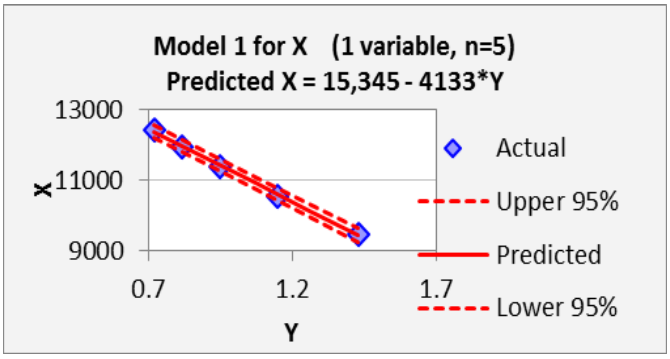

Chart -4: Regression results for axial force in y-direction for M-1 to M-5

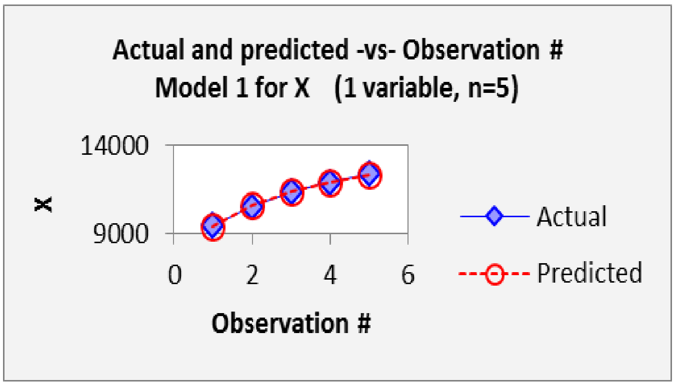

Chart -5: Regression results for axial force in y-direction for M-1 to M-5

4. CONCLUSIONS

1. All graphs show that, as the deflection of chimney decreases, the base shear force increases. Also for the same, time period gets increases.
2. The result shows that as the tapering ratio increases, the deflection of chimney get reduces as shown in graphs.
3. As compared to wind analysis, the seismic forces are observed more for R.C.C. chimney.
4. From all models, it has been observed that, the model with tapering ratio 1:40 and slenderness ratio 10 shows minimum deflection of 53.163 mm and the model with tapering ratio 1:80 and slenderness ratio 15 shows maximum displacement of 65.511 mm in X-direction.
5. From all models, it has been observed that, the model with tapering ratio 1:40 and slenderness ratio 12 shows minimum axial force of 5938.9 KN and the model with tapering ratio 1:80 and slenderness ratio 10 shows maximum axial force of 12414.184 KN in Y-direction.
6. From all models, it has been observed that, the model with tapering ratio 1:40 and slenderness ratio 12 shows minimum bending moment of 85.115 KNm and the model with tapering ratio 1:80 and slenderness ratio 10 shows maximum bending moment of 205.985 KNm in X-direction.
7. From all models, it has been observed that, the model with tapering ratio 1:40 and slenderness ratio 12 shows minimum base shear of 4622.8 KN and the model with tapering ratio 1:80 and slenderness ratio 10 shows maximum base shear of 8966.79 KN in X-direction.
8. From all models, it has been observed that, the model with tapering ratio 1:40 and slenderness ratio 10 shows minimum time period of 2.85 second and the model with tapering ratio 1:80 and slenderness ratio 12 shows maximum time period of 3.88 second in mode-1.
9. It is also observed that, the tapering ratio increases, the mass of chimney get reduces at top portion, hence the

center of mass of chimney shifted to downward which increases the stability of chimney.

10. As we decrease the tapering (i.e. from 1:40 to 1:80) with constant base diameter and height, the quantity of self-supported chimney is surges which rise the lateral forces, deflection, bending moment, time period on it, which becomes the structure uneconomical.

11. So this is concluded that the tapering should be increases up to 1:40 and slenderness ratio as 12 which gives efficient chimney structure for considering height of 250m.

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