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Dynamic Analysis of a Tall Chimney

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Abstract*: Any countries economic growth is dependent on the growth of the industries since they act as ladders for the invention and generation of new products. For the disposal of gaseous effluents the industries need chimneys. . Since they are highly slender even a little disturbance of the structure causes more deflections and enormous damage to the stability of the structure. Geometry of a chimney plays an important role in its structural behaviour like stability. This is because geometry is primarily responsible for the stiffness parameters of any structure. However, basic dimensions of a RCC chimney, such as height, diameter are generally derived from the associated environmental conditions. In the present investigation the main objective is to determine which loads are predominant on the structure and to find the slope which generates the least deflection for a chimney height of 310m. The cross section, bottom diameter and thickness of the chimney is maintained constant. The loads are calculated as per code IS 4998 (part-1):1992 and CED38 (7892): 2013 WC. The analysis is done using the STAAD-Pro. The deflections are observed and checked whether they are under the limiting value as mentioned in the code. A total of 8 models with different slopes are generated and analysed. The deflections and stresses at respective levels are observed and the best slope combination that gives least deflection is concluded.

***Keywords:* Geometry, Stability, Slope, Dynamic loads, Deflections.**

I. INTRODUCTION

A chimney is a means by which waste gases are discharged at a high elevation so that after dilution due to atmospheric turbulence, their concentration and that of their entrained solid particles is within the acceptable limits on reaching the ground. A chimney achieves simultaneous reduction in concentration of a number of pollutants such as sulphur dioxide, fly ash etc and being highly reliable it does not require a standby. A chimney also helps in decreasing the particulate matter such as fly ash and pond ash emitted from burning coal in the thermal power plants and helps in proper bifurcation of the particles when collected at a particular place. While these are the distinct merits, it is well to remember that a chimney is not the complete solution to the problem of pollution control. The main objectives of this paper are: To study various factors that influence the behaviour of the chimney, To study the impact of tapering on the behaviour of the chimney, To study the effect of wind loads and the seismic loads on the structure and to determine the loads that are more effective on the dynamic behaviour of the structure, To propose the best tapering which gives more stiffness and less deflections. The present paper discusses analysis of reinforced concrete tall chimney. The main focus is to compare the only wind analysis result with that due to both wind and seismic one. Dynamic wind analysis is done for along winds because no vortex shedding resonance condition is taken in generating the model. The analysis process is completely done by using software STAAD.

II. LITERATURE REVIEW

Kirtikanta Saho (2012), "Analysis of Self Supported Steel Chimney as per Indian Standard" the objective of this paper is to justify the code criteria with regard to basic dimension of industrial steel chimney. A total of 66 number self supporting steel flared unlined chimneys with different top-to-base diameter ratio and height-to-base diameter ratios were considered for this study. The thickness of the chimney was kept constant for all the cases. Maximum bending moment and stress for all the chimneys were calculated for the dynamic wind load as per the procedure given in IS 6533: 1989 (Part 2) using MathCAD software. Also the results were verified with finite element analysis using commercial software ANSYS. Basic wind speed of 210 km/hr which corresponds to costal Orissa area is considered for these calculations. Maximum base moments and associated steel stresses were plotted as a function of top-to-base diameter ratio and height-to-base diameter ratio. The results obtained from this analysis do not agree with the code criteria. Yoganatham .C et al (2013), "Modal Analysis of Rcc Chimney", the analysis and design of chimneys are normally governed by wind or earthquake load. In this paper modal analysis of a RCC chimney in a cement factory is carried out using the FEM software package ANSYS. The effects changes in the dimensions of the chimney on the modal parameters such as fundamental frequency, displacement etc are evaluated. The displacement of chimney is found to decrease with increase in all geometric parameter ratios. K.R.C. Reddy (2014), "Along Wind Analysis of Reinforced Concrete Chimneys", the analysis is done by random vibration approach and codal methods of India, America are presented in this paper. For the analysis based on random vibration approach the RC chimney is modelled as multi degree of freedom system subjected to static load due to mean component of wind velocity and dynamic load due to fluctuating component of velocity. The fluctuating component of wind velocity at a point is considered as temporal random process. Present codal methods of a long - wind analysis are found simplistic and are not equipped to estimate the deflection of chimneys. Different codes are giving different results though basic parameters are same. Dr. D. K. Raghuprasad et al (2014), "Pendulum Dampers for Tall RC Chimney Subjected to Wind", The paper discusses the dynamic analysis of 150m high RCC chimney subjected to wind. Analysis has been carried out for fixed base case. In the present work pendulum dampers of different natural frequencies have been tried the one which have largest equivalent logarithmic decrement is found to reduce the response significantly. The response is compared with that of chimney with a tip mass. The natural frequency of the chimney decreases due to pendulum damper and mass at the chimney top and also the displacement, velocity and acceleration decreases for the chimney with pendulum damper T Saran Kumar et al(2015), "Wind Analysis and Analytical Study on Vortex Shedding Effect on Steel Chimney Using Cfd"is the study of vortex shedding effect on steel chimney. Vortex shedding means at certain velocities air or fluid past a cylindrical body forms an oscillating flow, which depends on the size and shape of the body. Reynolds number used to predict fluid flow pattern fast a body is steady are turbulent. In this study, five models of chimneys with different heights and diameters at top and bottom, were designed as per IS 6533-1989(part 2) and wind load was calculated as per IS 875 (part 3)-1987.The study on the vortex shedding effect on different chimney models reveals that the wind induced vibration in the tall chimneys varies with respect to height. Anurag Jain et al (2016),"Non Linear Dynamic Analysis Of An Industrial Chimneys Pile Foundation System For Hurricane Loading", This paper presents the results of a nonlinear dynamic analysis to evaluate the structural performance pile and mat foundation system supporting a 350ft tall concrete chimney stack for hurricane force wind loads. The wind tunnel testing was conducted to develop wind load time histories along the height of the chimney. A geotechnical investigation was performed to determine the nonlinear characteristics of the pile behaviour under lateral and vertical loads. Analysis showed that for a 157mph wind sped pile axial forces remain below the threshold where permanent pile settlement is expected. Therefore, no settlement is expected at this level of loading and the pile foundation should remain fully functional.

III. METHODOLGY

A. Description of structure

In the present study a RCC chimney of 310m height subjected to the wind loads imposed due to the mean hourly wind speed of 55m/sec in the seismic zone III is considered for the analysis. Single flue of structural steel is provided to discharge the flue gases and is hung from the liner support platform near the chimney top. The shell rests on R.C.C. mat foundation of circular shape.

The following are the details of the chimney considered:

Self weight of the structure	–	25KN/ m^3
Height of chimney	–	310 m
Outer diameter at bottom	–	30 m
Outer diameter at top	–	3.0 m (minimum)
Thickness of shell at bottom	–	1.4 m
Thickness of shell at top	–	0.4 m
Grade of concrete	–	M30
Exit velocity of gas at top	–	25.0 m/sec
Flue gas volume from the flue	–	340 cum/sec
Maximum flue gas temperature	–	135^0C
Basic wind Speed	–	55 m/sec
Foundation Type	–	RCC circular mat

Single flue of structural steel is provided to discharge the flue gases and is hung from the liner support platform near the chimney top. The shell rests on R.C.C. mat foundation of circular shape. From the dynamic wind analysis the fluctuating load component on the structure is calculated and the analysis is made with the obtained loads. The calculation of moments and the loads is done using the expressions given in the code IS 4998 (part-1):1992 and CED38 (7892): 2013 WC. For finding the initial parameters like thickness at the bottom and top of the chimney the tapering of 1 in 50 is considered throughout. Taking these parameters constant for different tapering the change in stress and deflections in the chimney is studied. A total of 8 models are generated using different slopes in STAAD. The chimneys are modelled using tapering 1 in 30, 1 in 40, 1 in 50, 1 in 60, 1 in 70, 1 in 80, 1 in 90, 1 in 100.

The stresses and deflections at regular intervals is observed and a optimum slope for the design is concluded. The stresses and deflections at regular intervals is observed and a optimum slope for the design is concluded.

Fig. 1 Column model generated in STAAD

B. Load calculation

Generally wind does not blow at fixed rate. It blows at gusts. So this requires that the effects are taken in terms of equivalent loads. Here chimney is analysed as a bluff body having turbulent flow for the computation of along wind loads. Equivalent static procedure is used in codes known as gust factor method. Currently stipulated in all building codes and also in Draft Code CED 38(7892):2013 (third revision of IS 4998(part 1):1992). In this method wind pressure which is assumed to be acting on face of the chimney, due to this wind pressures are considered as static wind loads. This is then improved using the gust factor to make sure of the dynamic effects. The following codes used in estimation of along wing loads are: 1) IS875 (part 3):1987 - code practice for design loads for building and structures. 2)Draft Code CED 38(7892):2013 (third revision of IS 4998(part 1):1992). The following equations help us to calculate the fluctuating component of wind loads due to gust:

$$f_1 = 0.2 * \left(\frac{d_0}{H^2}\right) * \sqrt{\frac{E_{ck}}{\rho_{ck}}} * \left(\frac{t_0}{t_h}\right)^{0.3}$$

$$S = \left\{1 + 5.78 * \left(\frac{f_1}{\overline{V(10)}}\right)^{1.14} * H^{0.98}\right\}^{-0.88}$$

$$E = \frac{\left\{123 * \left(\frac{f_1}{\overline{V(10)}}\right) * H^{0.21}\right\}}{\left\{1.578 * \left(\frac{f_1}{\overline{V(10)}}\right)^{1.14} * H^{0.98}\right\}^{-0.88}}$$

$$B = \left\{1 + \left(\frac{H}{265}\right)^{0.63}\right\}^{-0.88}$$

$$r_t = (0.622 - 0.178 \log_{10} H)$$

$$\nu T = \frac{3600 f_1}{\left(1 + \frac{B\beta}{SE}\right)^{0.5}}$$

$$g_f = \left(\sqrt{2 * \ln(\nu T)} + \frac{0.577}{\sqrt{2 * \ln(\nu T)}}\right)$$

$$G = 1 + g_f * r_t \sqrt{B + \left(\frac{SE}{\beta}\right)}$$

$$F'_z = 3 * \frac{(G-1)}{H^2} * \left(\frac{Z}{H}\right) * \int_0^H \bar{F}_z * Z * dZ$$

Where

f_1 = natural frequency of unlined chimney in first mode of vibration (hz)
t_0 = thickness of the shell at the bottom (m)
t_h = thickness of the shell at the top (m)
d_0 = centre line diameter of the shell at the bottom (m)
E_{ck} = dynamic modulus of elasticity of the concrete (N/m^2)
ρ_{ck} = mass density of the concrete (Kg/m^3)
S = size reduction factor
$\overline{V(10)}$ =mean hourly wind speed at 10m height above the ground level (m/s)
H = total height of the chimney.
E = available energy in the wind at the natural frequency
B = background factor
r_t = twice the turbulence intensity at the top of the chimney
ν = the effective cycling rate
T = the sample period taken as 3600 sec

β = structural damping as a fraction of critical damping (0.016)
g_f =peak factor
G = gust response factor
The dead load and seismic load calculations are also calculated using the appropriate codes but not mentioned in this paper as the predominant forces is wind loads.

C. Model generation

A chimney is modelled in numerous ways changing the tapering of the shell keeping all the other parameters constant. Complete tapering is the tapering with which whole chimney is constructed. The various loads acting on the chimney are calculated and applied on the models generated in STAAD. The manually calculated values are being verified by the values originated when defined in STAAD.
The graphs which describe the values of loading in various models is given below:

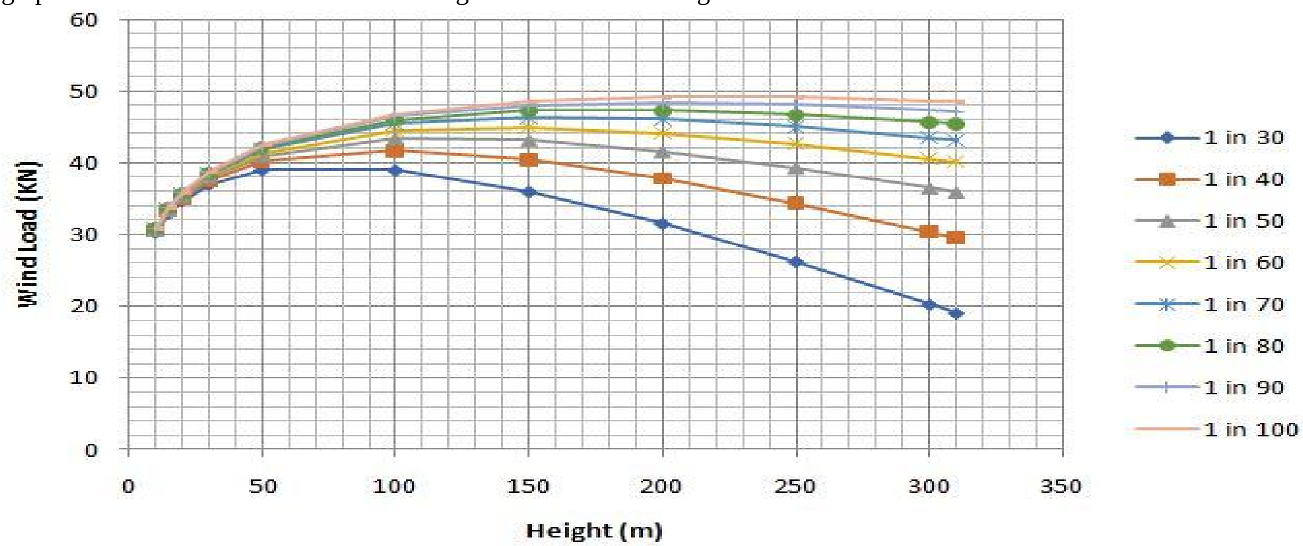

Fig 3 Wind loads on the models with uniform tapering and throughout

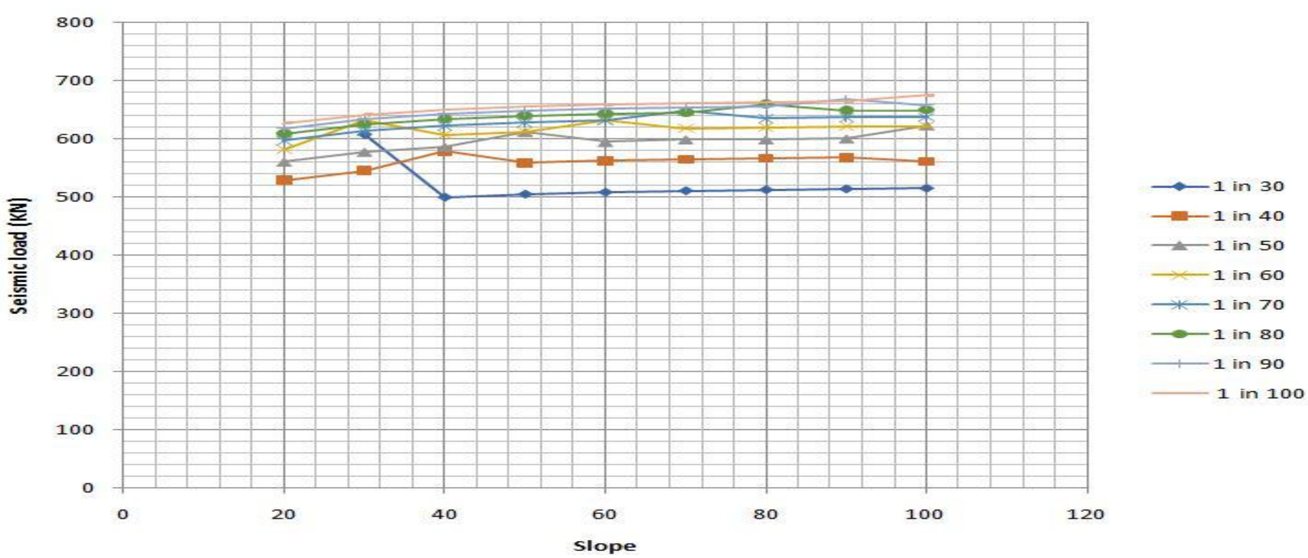

Fig 4 seismic loads on all models

Fig 3 describes the wind load on the structure at different heights for different slopes. Fig 4 describes the seismic loads on the structures for different slopes. After applying the loads analysis of the structure is done in STAAD. The pattern of loading is shown in the figure given below:

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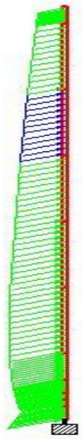

Fig 5 Wind load acting on the model

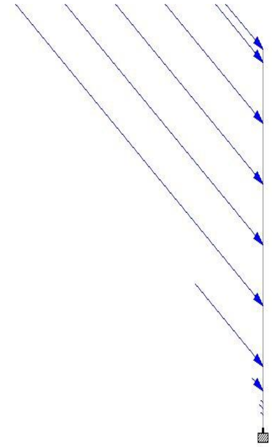

Fig 6 Seismic load on the model

IV. RESULTS AND DISCUSSIONS

After the analysis the deflections and stresses generated at different levels can be observed using the post processing mode. The stresses generated in a structure determine the reinforcement design on the structure. More the stresses more will be use of reinforcement at that joint. The graph given below shows the stress variation with respect to height for the models having constant slope throughout the height.

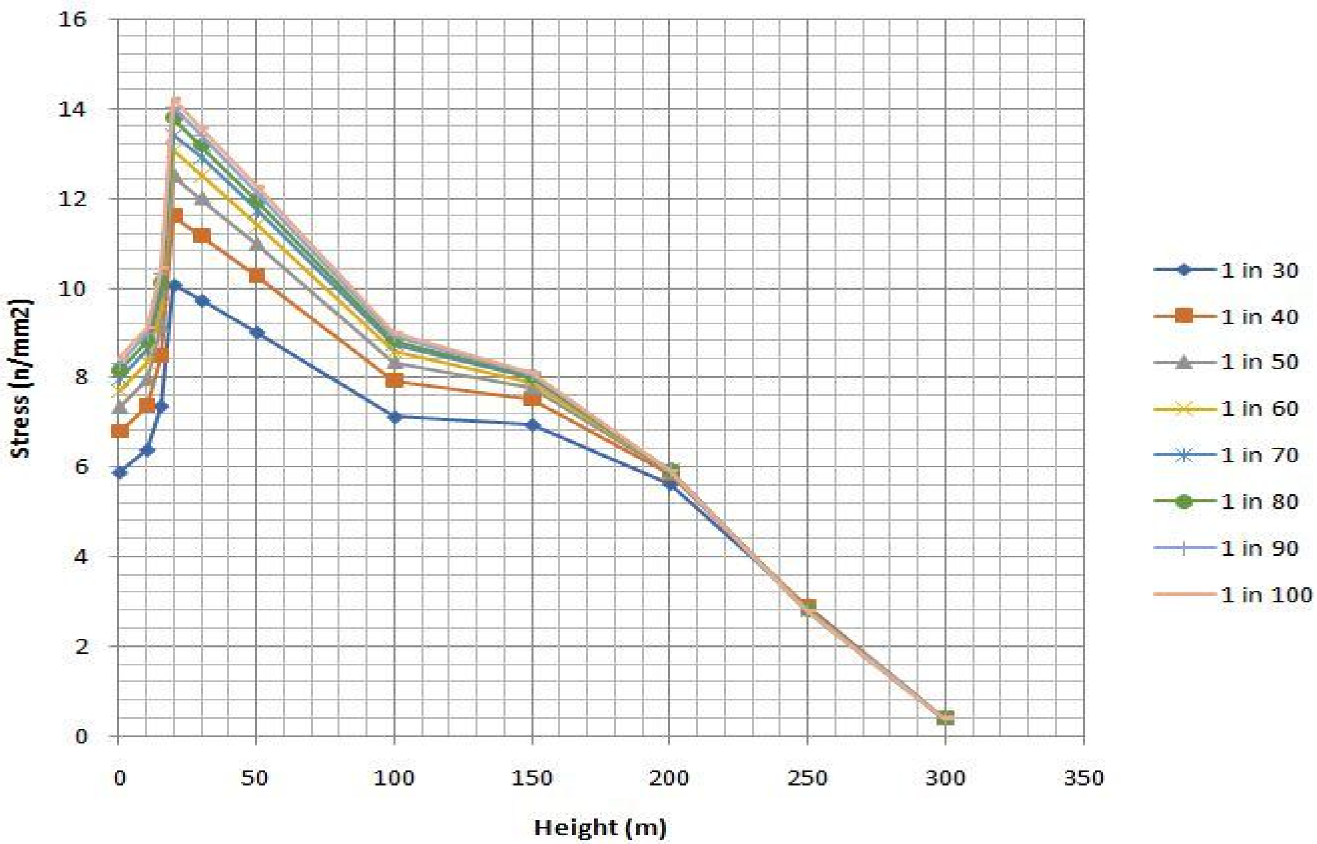

Fig 15 Stresses in the models having uniform slope through out

From the data given above it is seen that the stresses are more in the members having least tapering when compared with more tapering. It is also seen that higher stress are seen at the height of 20m from the bottom of the chimney in all the models. More reinforcement and the thickness of chimneys are necessary at the bottom till a height of 20m.

Table 1 Comparison of maximum stresses in all models

Slope	Max Stresses	Percentage of reduction
1 In 30	10.07	29.154355
1 In 40	11.602	18.376249
1 In 50	12.493	12.107781
1 In 60	13.075	8.0132264
1 In 70	13.388	5.8111721
1 In 80	13.791	2.9759392
1 In 90	14.027	1.3156043
1 In 100	14.214	0

From the models analysed it has been proved that there is definitely a reduction in stresses with the increase in the slope.

In the post processing mode of STAAD the deflections at respective nodes will be generated. More deflections affect the serviceability of the structure. Hence the deflections should be checked whether are under the limit as mentioned in the code. As per code IS 4998 (part-1):1992 the deflection should not exceed H/500 for an RCC Chimney of circular cros section. The graph below gives the deflection variation with respect to height in various models having the same tapering throughout the height. From the data given above it is seen that the deflections are more in the members having least tapering when compared with more tapering. It is seen from the percentage reduction table given below the deflections are definitely decreased when we use high slopes. The maximum deflection is observed at the top of chimney and is observed highest in the chimney tapered with 1 in 100 through out.

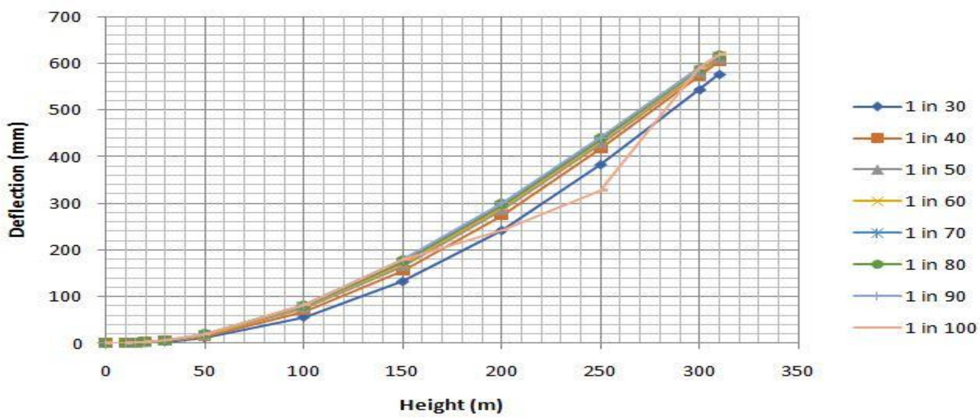

Fig 16 Graph showing deflection variation in various models

Table 2 Comparison of maximum deflections in all models

Slope	Maximum Deflection	Percentage Of Reductin
1 In 30	575.781	7.43529224
1 In 40	603.725	2.46254503
1 In 50	610.103	1.3914044
1 In 60	613.33	0.85793945
1 In 70	614.796	0.61744058
1 In 80	616.783	0.29329602
1 In 90	617.81	0.12657613
1 In 100	618.592	0

V. CONCLUSIONS

From the observations of Pre-analysis and Post-analysis the following conclusions are made:

A. As the tapering increases the volume of the chimney is decreased due to this the self weight of the structure is also decreased. In this way dead load on the structure is decreased
B. As the tapering increases the projected area decreases due to this the wind load acting on the structure is also decreased.
C. With increase in tapering the volume of the chimney is decreased due to this the weight of the chimney is decreased. As the weight of the body is decreased, the seismic excitation is also decreased.
D. From the observations made in the Post-analysis the stresses in the structure also decreases with the increase in tapering. The magnitude of deflections also decreases with the increase in tapering.
E. A stress reduction from 1.3% to 29.1% has been achieved from the models analysed.
F. The chimney in which high stress reduction is shown has low deflections when compared to others.
G. The chimneys constructed with more tapering have high resistance to the loading compared to the chimneys constructed with less tapering.
H. The most predominant loads in tall chimneys are the wind loads using just wind loads and its combinations on can design a chimney.

VI. SCOPE OF FUTURE WORK

A. A study can be done by generating various models by changing using combination slopes throughout the height.
B. Only along wind loads is considered for calculating the dynamic loads. In the future work across wind parameters can also be taken into consideration.
C. Soil -structure interaction effects are neglected in the present study. It will be interesting to study the response of the highly slender structures like chimneys considering the soil-structure interaction.
D. Damping coefficient is also neglected in the neglected in the present study. It is also an interesting factor in terms of dissipating the dynamic energy in such tall structures.

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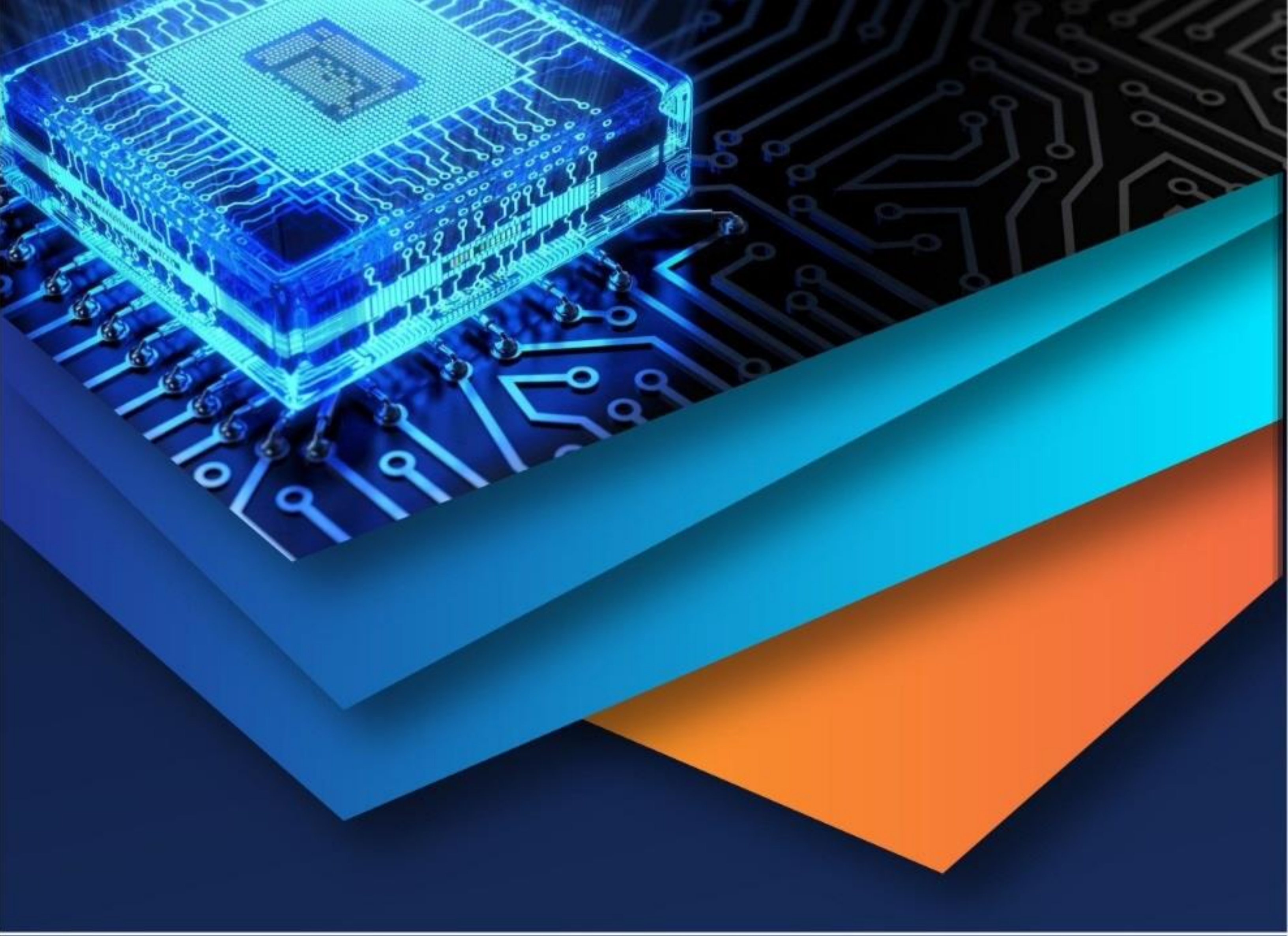

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