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RESEARCH ARTICLE

FREQUENCY ANALYSIS OF STEEL CHIMNEYS USING THE FINITE ELEMENT METHOD

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Abstract

Steel chimneys are utilized all over the world for quick work in industries and for discharging flue gases into nature. Where chimneys are utilized, the nearby region is not influenced by the chimney gases because the chimney height is set high.This paper focuses on frequency analysis of steel chimneys for 275m and 120 m heights. Two models of each chimney are considered, Model 1 tapered section with uniform thickness and Model 2 uniform diameter and thickness are considered. Finite element method (FEM) is used for extracting the first thirty frequencies in chimney. Finite element software ANSYS is used for frequency extraction. The effects of height to diameter of chimney, tapered and uniform cross-section on frequency of chimney are investigated.

Introduction:-

Chimneys are a very important part of industrial plants such that factories, coal mines power plants, etc. Steel industrial chimneys are a significant alternative to massively reinforced concrete chimneys due to the present-day strict environmental requirements, cutting-edge technical solutions regarding flue gas filtration, as well as economic concerns (Kuras et al. [8]). Steel chimneys are widely used because of their comparatively low weight, simplicity of manufacture, and quick construction. Steel chimneys have a number of drawbacks, including their susceptibility to corrosion, excessive wind-induced vibrations, and the impact of thermal interactions, especially in chimneys that vent hot gases (PisarekZdzislaw [11]).

The steel plates are used to create a self-supporting steel chimney or stack, which is supported by foundations.The chimney is referred to as self-supporting when the lateral forces (such as wind or seismic pressures) are transferred to the foundation via the cantilever action of the chimney. Under all working situations, the chimney and the foundation remain stable without any extra support. Industrial steel chimneys frequently have tall, circularin cross-section. The shape of a self-supporting steel chimney is essential for maintaining its structural integrity under lateral dynamic stresses. Steel chimneys are designed with the Indian standard codes (IS: 4998 and IS: 6533) and supplementary codes (IS: 456, andIS: 800).

Literature Review:-

Previous research on the steel chimney includes the following: Ciesielski et al. [1] studied two steel chimneys with similar characteristics. The results of the observations served as the base for analyses and also identified potential

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strategies for reducing chimney vibration. From the results it was decided to turbulizers and mechanical vibration dampers were utilized to reduce the sizeable chimney vibrations due to aerodynamic phenomena induced. Deng et al. [2] assessed a spiral guide plate-equipped steel chimney outer wall. Through computation of the modal, self-vibration, and wind vibration frequency, it was confirmed that the steel chimney can lessen the influence of the wind load on the chimney and flange connection. Thus, developed a technique for increasing the chimney's structural strength and effective in reducing the resonant frequency under wind load. Ellingsen et al. [3] carried out a full-scale field test on slender, low-damped light weight steel chimney.The initial vibration data was collected for consecutive 13 days period. Further, a statistical study was carried out and his amplitude and dominant frequency responses were shown as a function of wind speed and direction in terms of the probability distribution. From the results it was concluded that VIV occurrences of low (15% of diameter) to moderate amplitude (>30% of diameter) had been noted in a range of wind velocities 25% lower than predicted. Galemann and Ruscheweyh [4] examined the wind characteristics of full-scale experimental steel chimney at four levels with the help of a meteorological mast standing close to it. The pressure distribution's characteristic values with regard to drag and lift had been studied. The observed values of gust response factors were compared with the various literature data. Furthermore, it may be demonstrated that the Strouhal frequency's interaction with the chimney's natural frequency resulted into a new exciting frequency that was lower than the Strouhal frequency and thus, widens the resonance curve's bandwidth. Johns et al. [5] carried out experimental and analytical investigations for adding structural damping in steel chimneys in order to reduce the wind-excited swaying vibrations. From the results, it was observed that adding pads made of a particular damping material to the chimney's base structure significantly increased structural damping.

Kaweckiand Zuranski [6] investigated that bolt damage was doubled by cross-wind vibrations for steel chimney 100 m high. The chimney's measured damping capabilities allowed researchers to examine several methods for calculating the relative amplitude of vibration at low Scruton numbers and climatic circumstances during the vibrations were also reported. Koten H.V. [7] analysed the stresses and deflections of 12 existing steel chimneys in the wind direction and compared the design results with CICIND code. The number of load cycles to failure was calculated using an expectation of the critical wind speed and actual experience with failing chimneys was also compared. Kuras et al. [8] determined the dynamic properties such as vibration frequency and logarithmic decrease of damping of freely-supported steel chimneys fitted with vibration dampers. The basis of the results of tests that were conducted when adjusting the dampers on two steel chimneys with varied structural configurations and varying dynamic parameters were shown. The dynamic measurement data were collected using MEMS accelerometers, robotic total stations, and ground-based interferometric radar.

Mukhopadhyayet al. [9] carried out the failure analysis of a broken steel chimney in the lime plant due to a storm. The failing chimney plate and the welding between the plates were investigated by visual inspection, chemical analysis, characterization of macro and microstructures, hardness measurement, tensile property testing, and energy-dispersive spectroscopy (EDS). Additionally, the wind load at the site of the breaking was calculated. From the investigation, it was concluded that failure was caused due to slag entrapped inside the weld and also incorrect reconditioning approach as well as bad welding workmanship. Ogendo et al. [10] carried out a series of tests on 20 m chimney. A variety of damping layers with different levels of flexibility had been evaluated; the stiffer layers performed a little better than predicted, whilst the more flexible ones performed worse than expected. Corresponding full-scale studies demonstrated that theory and practice were well aligned and that the system damping level may be raised by up to three times. Pisarek [11] discussed the issues related to types of corrosion and rate of corrosion in the existing steel chimney. The causes of the accelerated corrosion at the chimney base were explained. The procedure for renovating and proper maintenance can reduce the corrosion breakdown in the chimney. Simonovic et al. [12] examined 60 m tall industrial steel chimney's root section using analytical and numerical methods. The steel structure's severe stress locations were numerically located using the finite element approach. The identified spots were close to where the fractures first appeared. The findings of the study enabled the statement of the advice for root redesign and additional maintenance measures for the chimney.

This paper focuses on the frequency analysis of steel chimneys for 275m and 120 m heights. Two models of each chimney are considered, Model 1 tapered section with uniform thickness, and Model 2 uniform diameter and thickness are considered. Finite element method (FEM) is used for extracting the first thirty frequencies in a chimney. Finite element software ANSYS is used for frequency extraction. The effects of height to diameter of a chimney, tapered and uniform cross-section on the frequency of chimney are investigated.

Numerical Study

In the present study, finite element method (FEM) is used to determine the modal frequencies of steel chimneys. Three-dimensional model of chimney is modeled using shell elements. The boundary condition of freely-supported chimney is fixed-base at bottom and free at top end is considered. The dimension of 275 m height chimney is: for Model 1 are bottom diameter 25 m and top diameter 12 m and thickness 0.795 m, Model 2 are bottom and top diameter 25 m and thickness 0.795 m. Similarly, for 120 m height chimney: for Model 1 are bottom diameter 5 m and top diameter 2.5 m and thickness 0.096 m , Model 2 are bottom and top diameter 5 m and thickness 0.318 m as shown in Figure 1. The material properties of steel considered are Modulus of elasticity 200 GPa, Poisson's ratio 0.3 and density 7850 kg/m^3.

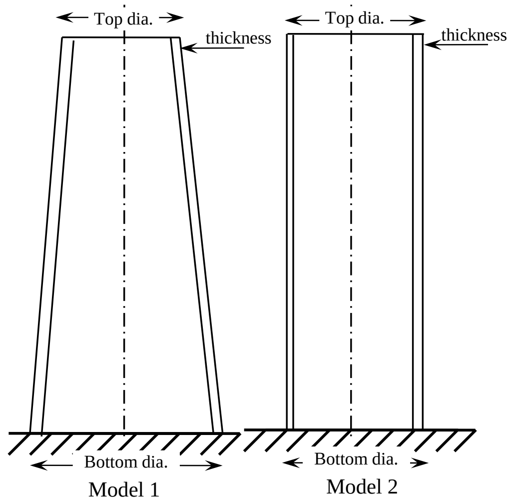


Figure 1:- Steel chimney models.

Results and Discussions:-

The modal frequency of the both chimneys for Model 1 and Model 2 are extracted using FEM using Ansys software. Table 1 shows the thirty modal frequency values. Due to symmetry the even mode no. frequencies are same. It can be observed that the fundamental model frequency of first mode for both the chimneys and also for Model 1 and Model 2 are same. From Table 1 and Figure 2 it can be seen that as the mode number increases the frequency values also increases for all the chimney models. It can also be seen that for 275 m height chimney Model 1 tapered section with uniform thickness the model frequeny values are higher as compared to Model 2 uniform diameter and thickness of chimney. For 120 m height chimney as the height to diameter ratio is more the model frequencies are higher than 275 m height chimney and also Model 2 frequencies are higher than Model 1.

Table 1:- Modal frequencies of the chimney models (in Hz).

Mode no.	275m		120m	
	Model1	Model2	Model1	Model2
1	0.35	0.30	0.38	0.32
3	1.56	1.78	1.75	1.98
5	3.76	2.84	4.42	5.44
7	4.26	3.53	8.27	6.51
9	6.10	3.61	9.61	10.35
11	6.70	3.97	13.18	16.49
13	7.70	4.58	19.04	19.52
15	9.17	4.83	21.04	23.67
17	9.22	6.26	25.83	31.64
19	10.17	8.11	32.18	32.53
21	10.70	8.15	33.07	37.48
23	12.24	8.51	33.54	37.63
25	13.71	9.94	35.43	37.78
27	13.99	9.99	39.61	38.08

29	14.65	10.09	40.39	38.59

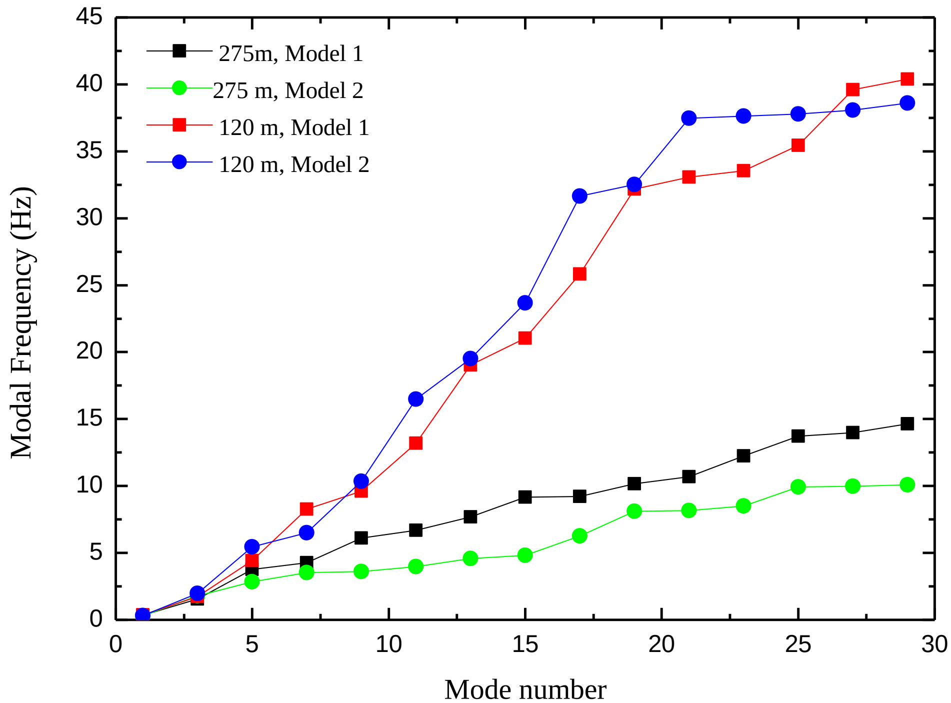
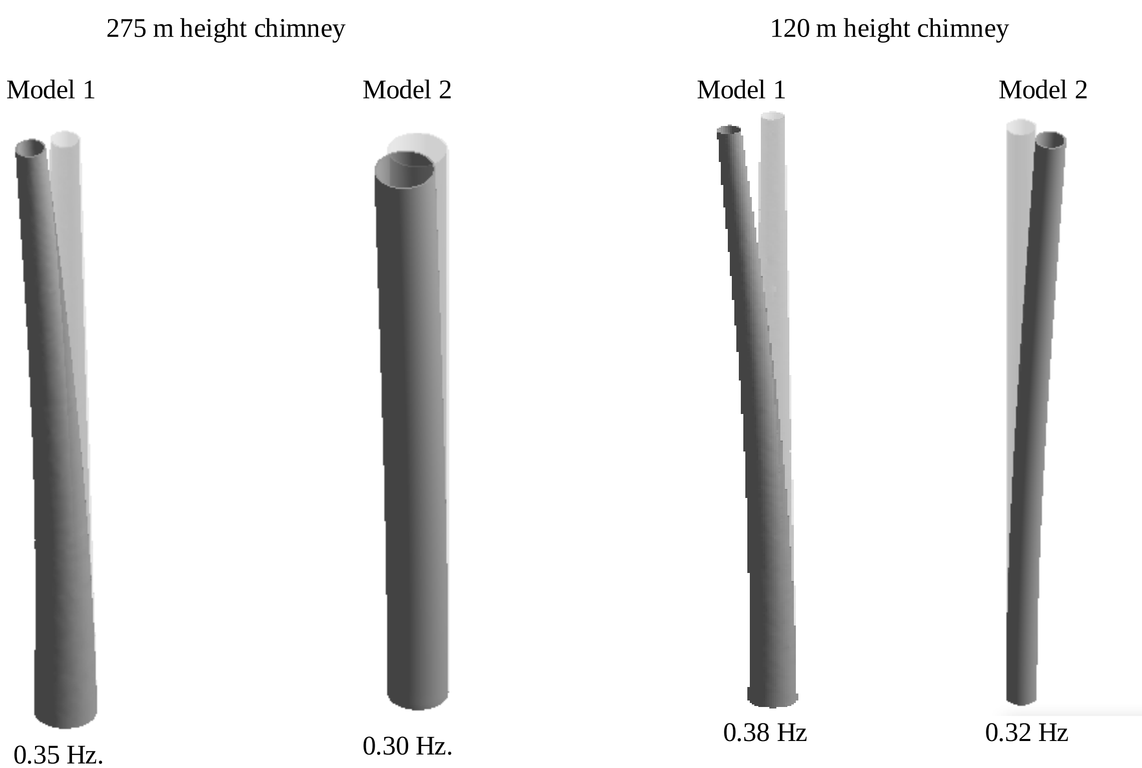


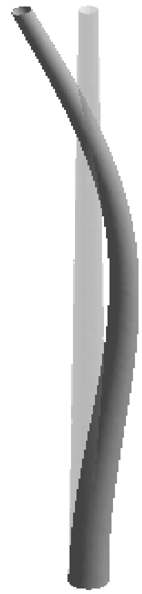
Figure 2:- Modalfrequency of Model 1 and Model 2 of chimneys.

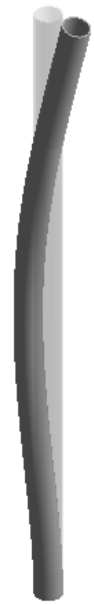
Figure 3 shows the mode shapes of both heights of the chimney for both Model 1 and Model 2. It can be observed that some of the initial mode shapes of chimneys are flexural mode along the height of the chimney. The fundamental frequencies of all the models of chimney are approximately same.



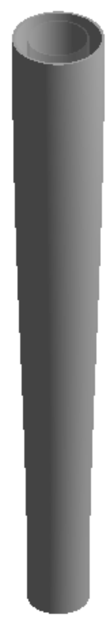

1.56 Hz.

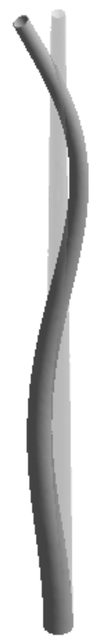

1.78 Hz.

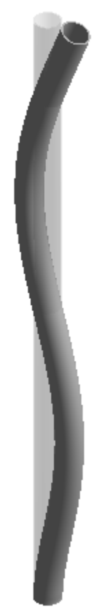

1.75 Hz.


1.98 Hz.


3.76 Hz.


2.84 Hz.


4.42 Hz.


5.44 Hz.

4.26 Hz. 3.53 Hz. 8.27 Hz. 6.51 Hz.

Figure 3:- Mode shapes of steel chimney models.

Conclusions:-

After analysis, the 275m and 120m heights of chimneys used finite element methods where two models are considered, Model 1 tapered section with uniform thickness and Model 2 uniform diameter and thickness. The following conclusions are obtained:

1. It can be observed that the fundamental model frequency of first mode for both the chimneys and also for Model 1 and Model 2 are same.

2. It can be seen that as the mode number increases the frequency values also increases for all the chimney models. It can also be seen that for 275 m height chimney Model 1 tapered section with uniform thickness the model frequeny values are higher as compared to Model 2 uniform diameter and thickness of chimney. For 120 m height chimney as the height to diameter ratio is more the model frequencies are higher than 275 m height chimney and also Model 2 frequencies are higher than Model 1.

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