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Pendulum Dampers for Tall RC Chimney Subjected To Wind

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Abstract

Chimneys are a part of industrial growth in any country. Most current chimney design standards require analysis of dynamic analysis of chimney for earthquake and wind induced loads. Because of variation in dimensions of chimney along its height structural analysis such as wind oscillations have become more critical. If ductility is an important consideration in earthquake resistant design, control of deflection become critical in wind induced vibrations. Pendulum dampers are of the devices to control the deflection. In the present work pendulum dampers of different natural frequencies have been tried. The one which has the largest equivalent logarithmic decrement is found to reduce the response significantly. The response is compared with that of chimney with a tip mass. The paper discusses the dynamic analysis of 150m high RCC chimney subjected to wind. Analysis has been carried out for fixed base case.

Key Words: Pendulum, Logarithmic decrement, Wind Analysis, Time-History analysis, Sinusoidal Force

I. Introduction

Tall RC chimneys are commonly used to discharge pollutants at higher elevation. The enforcement of air-pollution control standards has led to the construction of increasingly tall RC chimneys worldwide. Further due to the availability of advanced construction materials chimney shell is being made thinner. As a result, chimneys have become more slender and sensitive to wind-induced vibrations. The cross-section of the chimney is generally hollow circular, from aerodynamic considerations, and tapered, from considerations of structural economy and aesthetics. The chimney is subject to gust buffeting in the along-wind direction due to drag forces, and also to possible vortex shedding in the across-wind direction. In the typical case of slender, tapered RC chimneys, it is the along-wind response which generally predominates and governs the design.

Tall reinforced concrete (RC) chimneys form an important component of major industries and power plants. Damage to chimney due to wind or earthquake load may lead to shutdown of power plants and important industries. However, if chimney is located in higher seismic zone and lower wind speed zone, then, earthquake forces may become comparable, if not more, than the wind loads. In fact, the chimney is designed for the combined effect of along-wind and across-wind loads. In the literature, various approaches to combine along-wind and across-wind loads are mentioned. In this paper a method given by IS 4998 (Part1): 1992 code is being used to obtain the combined design loads. Earlier many researchers have shown the results of earthquake analysis using the simplified procedures given in the codes. The objective of this paper is to analyze chimneys fitted with pendulum dampers for design wind loads.

II. Literature review

The earthquake design and analysis of chimneys subjected to earthquake excitation have typically been under taken using linear dynamic procedures such as the Response spectrum or Time history modal analysis techniques. Rumman (Ref. 10,12) published a number of papers describing the calculation of seismic forces for Reinforced Concrete Chimneys using the Response Spectrum technique some thirty years ago. Rumman also established a co-efficient for estimating the modal periods and associated mode shapes of Reinforced Concrete Chimneys that vary linearly in both mean diameter and thickness. Such methods which were very useful for estimating modal shear forces and bending moments have been superseded by finite element analysis software packages which can perform dynamic analyses relatively simply and cost effectively. The modal analysis method accurately predicts the response of tall Reinforced Concrete Chimneys in the elastic range as confirmed from a number of experimental studies carried out on real chimneys using ambient wind vibrations. Chimney tip deflections become quite critical under dynamic action of wind and they have to be controlled .Although there have been many methods suggested in literature to control the tip deflection, a detailed study on pendulum dampers to control the deflection is not much covered. Thus the following study is taken up.

III. Objective

An attempt is made to reduce the response of the chimney subjected to wind forces at critical speeds by attaching pendulum dampers whose equivalent logarithmic decrement value is maximum. Effect of attaching a tip mass equal to the mass of pendulum damper is also computed and compared.

IV. Salient features

The150m chimney is considered for the analysis. The 150 m chimney as shown in figure1 is of uniform taper whose outer diameter and shell thickness at the top and bottom are shown,

1. Height – 150m
2. Outer Diameter at Top – 8.18m
3. Outer Diameter at bottom – 13.64m
4. Thickness at top – 0.20m
5. Thickness at bottom – 0.40m
6. Grade of concrete – M30
7. Type of Soil = Hard soil
8. Basic wind speed = 33 m/sec

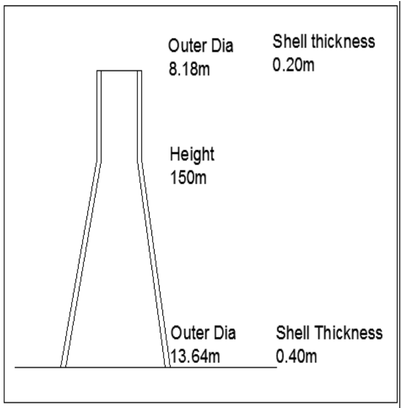


Fig-1: Geometry of Chimney

4.1 Modeling

The Chimney is modeled as vertical cantilever cylindrical shell having varying cross sections fixed at the base using shell element in STAAD PRO V8i. Chimney is divided into elements of 2.5 meter length along its height. The mass of each section is calculated by averaging the mass of above and below it. Chimney is idealized as a multi-degree freedom system with mass lumped at various levels. Natural frequencies and mode shapes are obtained from the finite element model of the chimney.

4.2 Material

The material used for chimney shell is M30 grade concrete whose weight density is 25 KN / m^3, Young's modulus (E) is 3.5 x 10^7 kN/m^2 and damping as a fraction of critical damping (ß) is considered as 0.016.

V. Results of Free Vibration Analysis

Free vibration characteristics such as natural frequencies and time periods are obtained from the free vibration analysis of chimney. The first 6 modes are shown in Table 1,2 and 3. The mode shapes are shown in fig 2

Table 1. Natural Frequencies and Time Periods of Chimney

Modes	Natural Frequency (Hz)	Natural Frequency (rad/sec)	Time Period (sec)
I	0.558	3.51	1.79
II	2.716	17.07	0.368
II	4.724	29.69	0.22
IV	5.211	32.74	0.192
V	5.458	34.29	0.183
VI	6.020	37.82	0.166

Table 2 Natural Frequencies and Time Periods of Chimney with Pendulum Damper

Damper Mass	1000kg			2000kg			3000kg		
Modes	Natural Frequency (Hz)	Natural Frequency (rad/sec)	Time Period (sec)	Natural Frequency (Hz)	Natural Frequency (rad/sec)	Time Period (sec)	Natural Frequency (Hz)	Natural Frequency (rad/sec)	Time Period (sec)
I	0.31793	1.998	3.14539	0.16390	1.030	6.13498	0.18770	1.1799	5.32757
II	0.45015	2.830	2.22147	0.31221	1.963	3.20295	0.35654	2.2412	2.80476
III	0.45980	2.890	2.17984	0.45853	2.882	2.18086	0.45863	2.883	2.18043
IV	0.63476	3.990	1.57541	0.46793	2.941	2.13708	0.47195	2.966	2.11888
V	1.91683	12.049	0.52169	1.91682	12.049	0.52170	1.91683	12.049	0.52170
VI	1.91787	12.0557	0.52141	1.9177	12.054	0.52144	1.91778	12.055	0.52144

Table 3 Natural Frequencies and Time Periods of Chimney with tip mass

Modes	Natural Frequency (Hz)	Natural frequency (rad/sec)	Time Period (Sec)
I	0.45286	2.8454	2.20820
II	1.90104	11.9445	0.52603
III	4.59585	28.8765	0.21759
IV	5.18719	32.5921	0.19278
V	5.34264	33.5688	0.18717
VI	6.37210	40.0371	0.15693

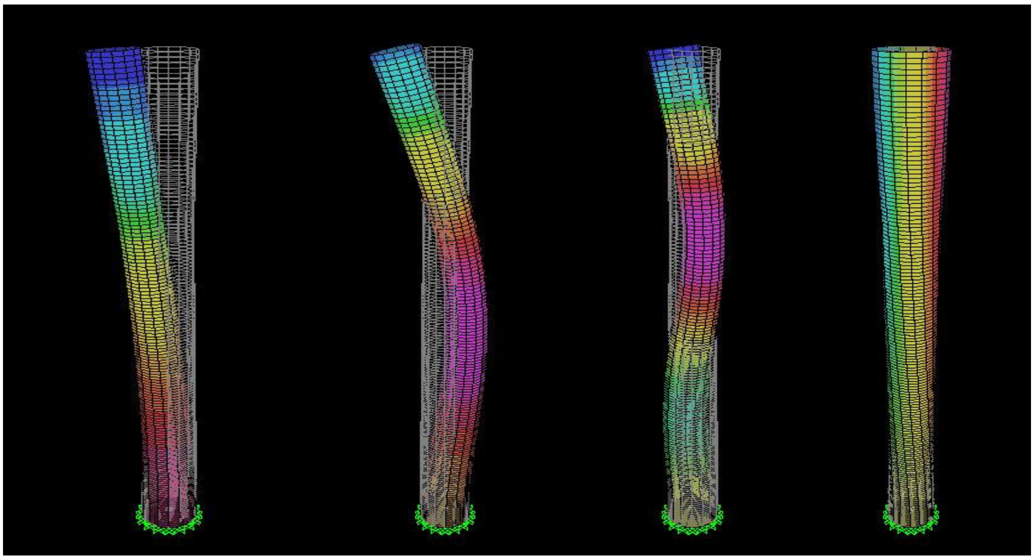


Fig 2 Mode Shapes of Chimney.

Figure 2 shows the different mode shapes of the chimney.
Critical wind speed and design wind speed are calculated as per IS 4998- 1992 and presented in Table 4.

Table 4 Critical Wind Velocity and Design wind Speed

Chimney Height (m)	Diameter (m)	Critical Wind Velocity, $V_{cr}= f_1d/S_n$ (m/s)			Design wind Speed $V_z=V_b*k_1*k_2*k_3$ (m/s)
		1st Mode	2nd Mode	3rd Mode	
150	8.18	22.82	111.08	193.21	45.045

VI. Results and Discussions

6.1 Dynamic Analysis of Chimney for wind loading.

The wind force proportional to square of the velocity is obtained from the velocity profile over the height of chimney. The resultant wind force over 2.5m segments of the chimney acting at the center of the segment is considered to act as a sinusoidal time varying force with frequencies ω_1, ω_2, .. ….. ω_n taken one at a time. The frequencies ω_1, ω_2 are also the natural frequencies of chimney in the 1st, 2nd and other modes respectively. The forcing frequencies are equal to ω_1,….. ω_n to create a resonant condition. Figure 3 show the sinusoidal force. The response is obtained using STAAD PRO and SAP 2000. Figure 5 show the response histories in terms of Maximum deflection, acceleration, velocity and principle stress due to a forces $F\sin\omega_1 t$ and $F\sin\omega_2 t$.

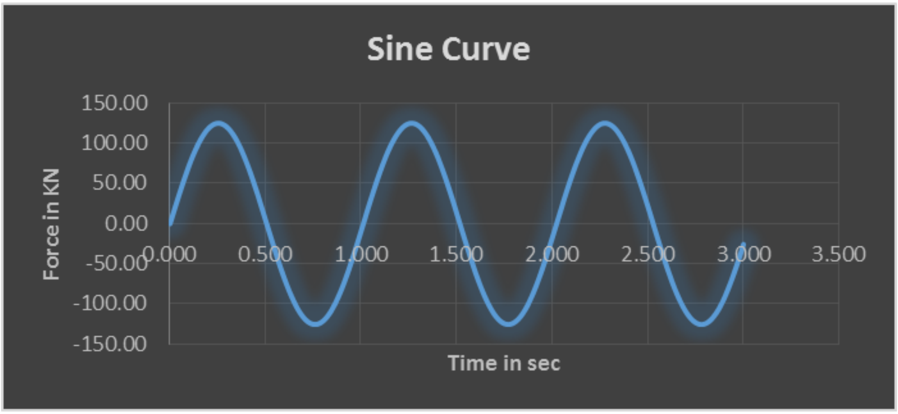


Fig 3 Vortex induced sinusoidal force

Table 5 Maximum Principal Stress

Chimney without Pendulum Damper (N/mm^2)	Chimney with Pendulum Damper(N/mm^2)
14.4	22.2

Table 6 show the principle stress of chimney. The maximum principle stress occurs at the base of chimney and is equal to 14.4N/mm^2, when the damper of 1000kg mass is added the principle stress at the location where the mass touches the wall of the chimney increases to 22.2N/mm^2. In fact it is required also compute the stress in the wall due to impact of the damper which is however out of scope of the paper.

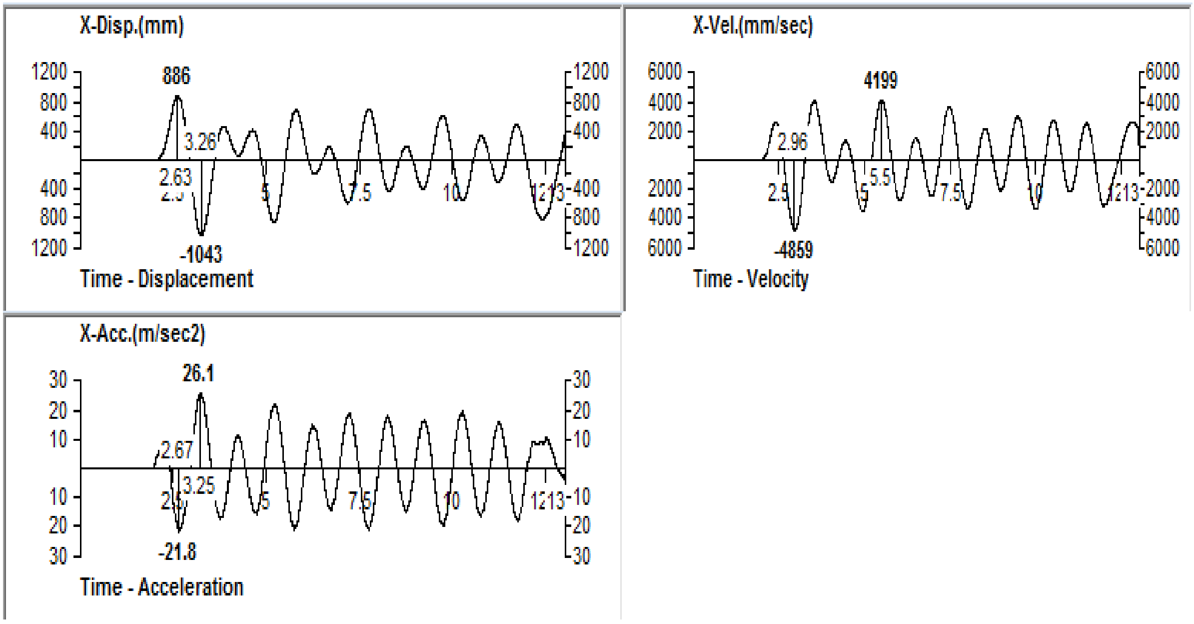


Fig 4 (a) Due to Fsinω_1t

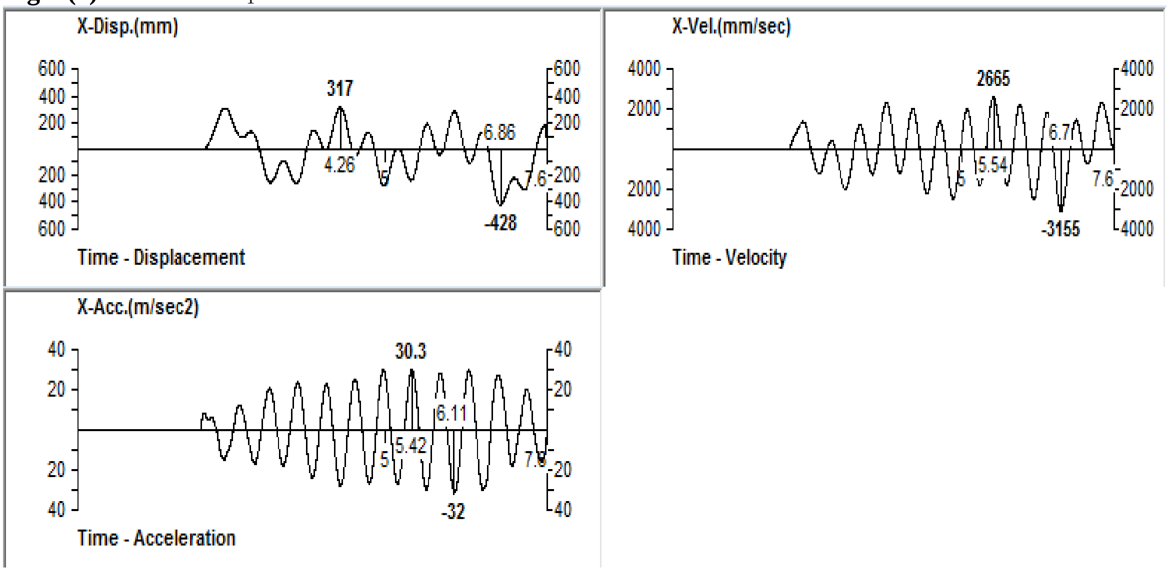


Fig 4 (b) Due to Fsinω_2t

Fig 4 Response histories for Fsinω_1t and Fsinω_2t

Figure 4a and b show the time histories of the response as the top of the chimney due to force Fsinω_1t and Fsinω_2t. When ω_1 and ω_2 on at frequencies of the chimney in the 1st and 2nd mode respectively. The values are tabulated in table 6. It may be seen that values of displacement and velocity are more due to Fsinω_1t while that of acceleration is less due to Fsinω_1t. Infact as the velocity of the wind increases with height, even the vortex shadding frequencies should increases with the height, which means that forces applied over the height should of varing forcing frequencies. However, the forcing frequencies has been kept same for convinience.

The maximum values picked from the time histories and tabulated separately in table 6

Table 6 Maximum Values without damper

Force	Fsinω_1t	Fsinω_2t
Displacement in mm	1043	428
Velocity in mm/sec	4859	2665
Acceleration in mm/sec^2	26100	32000

Pendulum damper

As mentioned earlier pendulum dampers with different masses are chosen to dampen the response. To obtain natural frequencies and equivalent logarithmic decrement each of the chosen damper it is subjected to an initial force which is suddenly applied and removed thus allowing the damper to vibrate freely. The damper is schematically shown in figure 5. The equivalent logarithmic decrement is obtained from the time histories, shown in figure 6,7 and 8. Equations for the best fit are obtained for all the equivalent logarithmic decrement curves and are along with R^2 values given in table 7. The best fits for the equivalent logarithmic curve are shown in figure 9. The dampers with the largest logarithmic decrement is attached to the chimney. The same set of forces as applied earlier are applied again and the response histories are obtained. They are shown in the figure 11. The maximum values are picked from the time histories and tabulated in table 8.

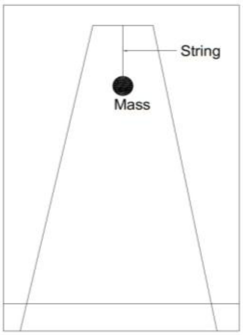


Fig 5 Chimney with damper

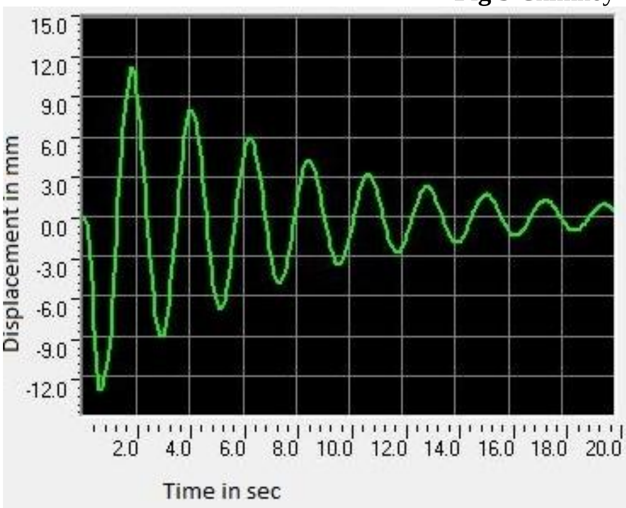


Fig 6 Response histories for 100KN initial force on 1000kg pendulum damper

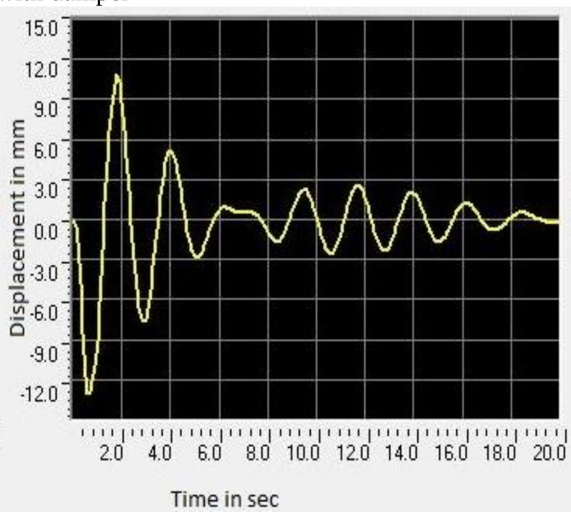


Fig 7 Response histories for 100KN initial force on 2000kg pendulum damper

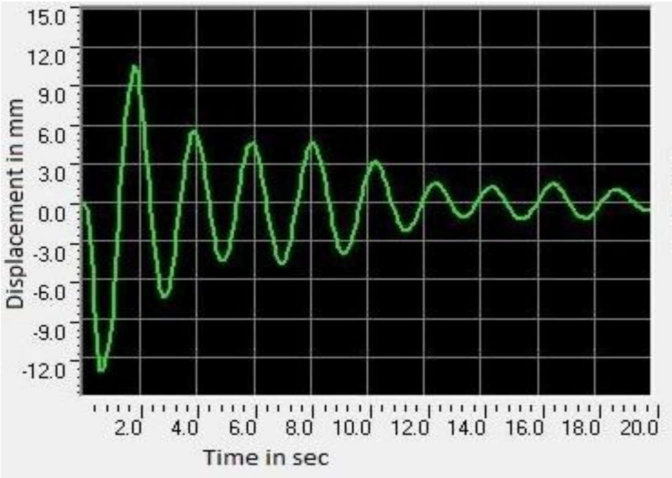
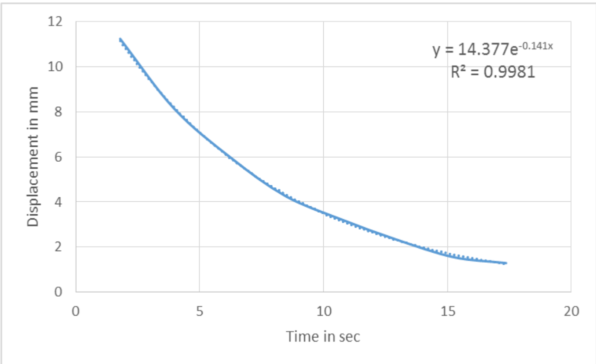
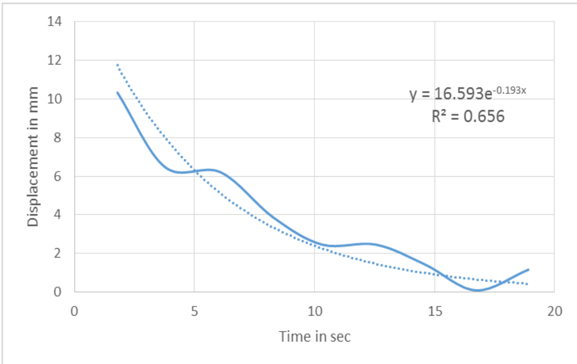


Fig 8 Response histories for 100KN initial force on 3000kg pendulum damper

For Response histories of 100KN initial force on pendulum damper





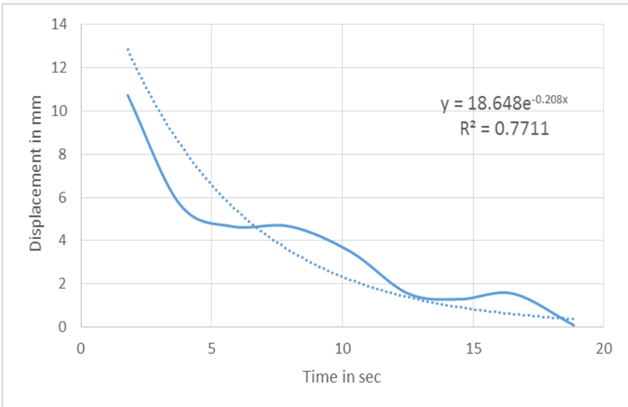


Fig 9 Typical equivalent Logarithmic decrement curve (For 100KN initial force)

Table 7 Equivalent logarithmic decrement and the corresponding R^2 values

Pendulum Damper Weight	Equations	R^2
1000kg	$14.377e^{-0.143}$	0.9981
2000kg	$16.59e^{-0.206}$	0.656
3000kg	$18.648e^{-0.193}$	0.7711

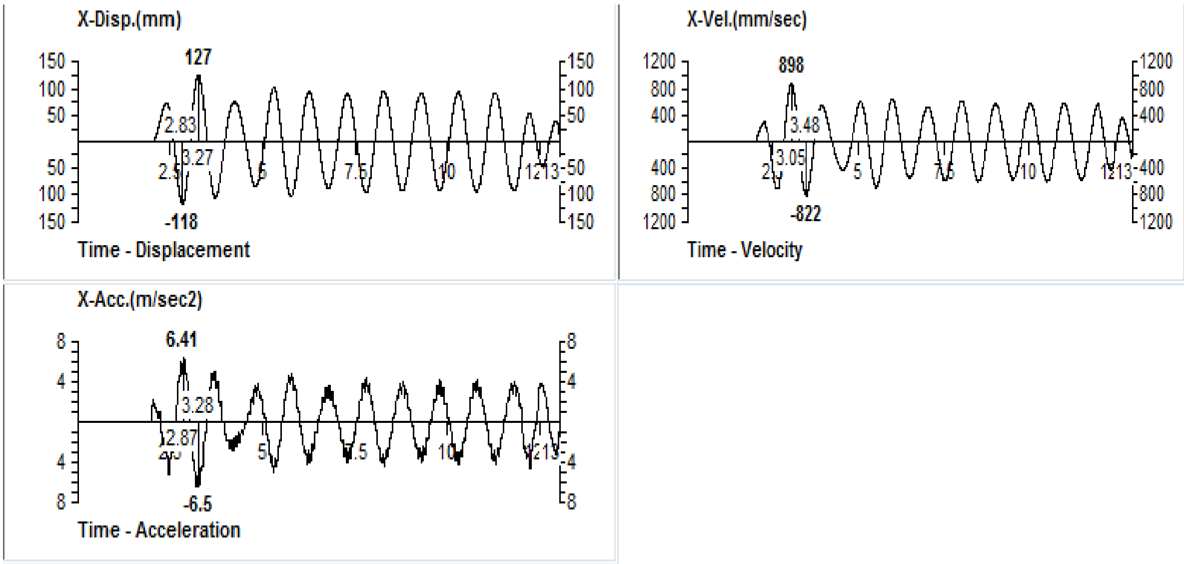


Fig 10 Response for wind loading with pendulum damper

Table 8 Maximum values picked from the above figures

	Without Pendulum damper		With Pendulum damper 1000kg		With Pendulum damper 2000kg		With Pendulum damper 3000kg	
	Mode 1	Mode 2	Mode 1	Mode 2	Mode 1	Mode 2	Mode 1	Mode 2
Displacement in mm	1043	428	127	54.4	127	54.1	112	54.3
Velocity in mm/sec	4859	2665	898	560	898	559	829	559
Acceleration mm/sec^2	26100	32000	6500	7130	6500	7100	6380	7130

The table 8 shows the comparison of displacement, velocity and acceleration of chimney without and with pendulum damper at the top of chimney. It is clear that the values of the displacement, velocity and acceleration decrease to the chimney with the pendulum damper.

6.3 Mass at chimney top

In this paper tip mass is provided by increasing the chimney thickness of 0.5m and depth is 0.2m which is equal to the pendulum damper weight. The same set of forces as applied earlier are applied again and the response histories are obtained. They are shown in the figure 11. The maximum values are picked from the time histories and tabulated in table **9.**

Table 9 Maximum values

	Mode 1		Mode 2	
	Normal	With tip mass	Normal	With tip mass
Displacement in mm	1047	823	428	313
Velocity in mm/sec	4850	2661	2660	2360
Acceleration in mm/sec^2	26100	19100	32000	21500

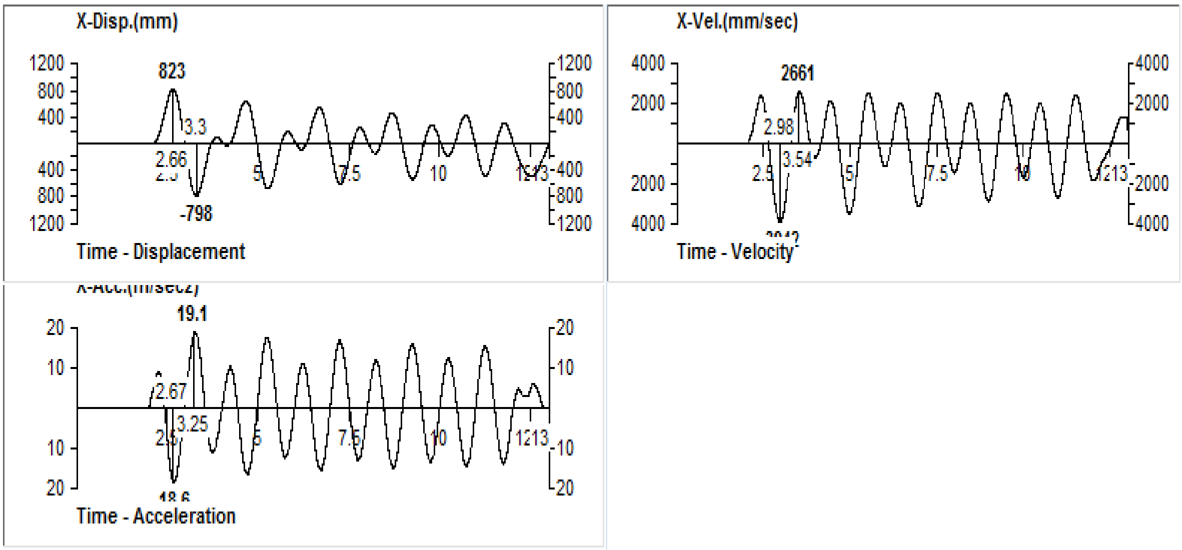


Fig 11 Response of chimney with tip mass

Above table shows the comparison of without mass and with mass at the tip of chimney. The displacement, velocity and acceleration decrease considerably for different modes, when a tip mass is added.

Conclusion

1. The natural frequency of the chimney decrease due to pendulum damper and mass at the chimney top.
2. The values of displacement and velocity are more due to $F\sin\omega_1 t$ while that of acceleration is less due to $F\sin\omega_2 t$
3. The best fitted equivalent logarithmic decrement curve damper is chosen for analysis.
4. The displacement, velocity and acceleration decrease to the chimney with the pendulum damper.
5. The displacement, velocity and acceleration decrease considerably for different modes, when tip mass is added.

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