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Vibration Control of Uniformly Tapered Chimney by Using Tuned Mass Damper

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Abstract*— This paper presents an application of tuned mass damper to suppress vibration of chimney having 180m height. The application of tuned-mass dampers (TMD) is effective in improving the dynamic Performance of structures. A TMD consists of a relatively small mass which is attached elastically to the main structure. The use of tuned mass dampers (TMD) is widely used passive vibration damping treatment. These devices are viscously damped to 2nd order systems appended to a vibrating structure. Proper selection of the parameters of these appendages, tunes the TMD to one of the natural frequencies of the under damped flexible structure.Chimney of height 180m and bottom D=9.87,top D =4.75 with bottom thickness 0.60m and top thickness 0.17m has been considered for case study. This chimney was analyzed by defined response spectrum Analysis. For this response spectrum Analysis time period and frequency was calculated. Displacement obtain was control by using Tuned Mass Damper. The TMD is placed at top of chimney. To get optimal vibration control mass ratio characteristic was used. For this purpose 5 to 30 % weight of total weight of chimney has been considered as tune mass damper and spring stiffness (in kN/m^3). An optimal value was obtained from these results.

Keywords: **Chimney, Tuned Mass Damper, Vibration control.**

I. INTRODUCTION

Tall reinforced concrete (RC) chimneys are sensitive to wind vibrations under the influence of dynamic wind loads. They oscillate in along- and across wind directions. Along-wind vibrations occur due to gust in the direction of the incident wind and are associated with drag forces. Economy in chimney design can be achieved by controlling its wind response. A chimney should have an adequate factor of safety against collapse, either along wind, in response to fastest gust it is likely to experience, or across wind, in response to vortex shedding. In addition, violent movements of chimney are to be avoided, even if consequent chimney stresses are acceptable. Such large deflections not only pose a threat to the safety and integrity of the structure, but also affect sensitive equipment and human occupants. In this paper, some of the efforts towards controlling the vibrations in chimneys using various vibration dampers are presented. Fahim Sadek [4] in their paper briefly reviews studies on the use of TMDs for seismic applications and proposes a method for selecting the TMD parameters by providing equal and large damping ratios in the complex modes of vibration. The optimum parameters are formulated in terms of the mass ratio of the TMD, the damping ratio and mode shapes of the structure.

II. PRINCIPLE OF DAMPING SYSTEM

The movements of the chimneys in cross wind direction are caused by vortices. The forces due to these vortices can have the same frequency as the chimney and resonance can easily occur. The amplitude and stresses of the chimney can become large

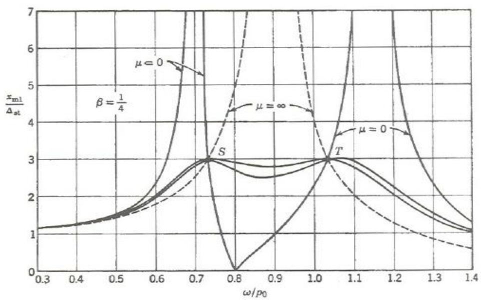

Fig. 1. Dynamic response of system with and without a damper

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The vertical axis shows the ratio between the dynamic Xml and the statics Δst movement of the chimney. On the horizontal axis is the frequency of loading divided by the resonance frequency of the chimney. The dotted curve in figure1 is the dynamic behavior of the chimney without a damper. The amplitude becomes very large if the frequency of the load (ω) becomes o equal to the frequency of the chimney (ρº). If the damping structure has been an optimal designed, then the amplitude is restricted to the curves with a horizontal tangent at the points S and T. The amplitude will not go above three time's static amplitude. This can be considered as an excellent reduction of movements and stresses or an increase of the damping.

III. EQUATIONS OF MOTIONS

A schematic model of the chimney and chimney with tuned mass damper is shown in Fig.1.and Fig.2. The equations of motion are given by

$$M\ddot{x} + C\dot{x} + Kx = F \qquad (1)$$

M is the effective mass of the structure, K is the effective stiffness of the structure. The structure is assumed to have a small linear viscous damping with damping coefficient C and F is ground acceleration. After the application of TMD equation of motion is given by

$$M\ddot{x} + C\dot{x} + C_t(x - x_t) + kx + k_t(x + x_t) = F$$
$$M_t x_t + C_t(x_t - x) + k_t(x_t - x) = 0 \qquad (2)$$

The equations can be rearranged in matrix form in terms of the absolute and relative displacements respectively as follows:

$$\begin{bmatrix} M & 0 \\ 0 & M_t \end{bmatrix}\begin{Bmatrix} \ddot{x} \\ \ddot{x}_t \end{Bmatrix} + \begin{bmatrix} C + C_t & -C_t \\ -C_t & C_t \end{bmatrix}\begin{Bmatrix} \dot{x} \\ \dot{x}_t \end{Bmatrix} + \begin{bmatrix} k + k_t & -k_t \\ -k_t & k_t \end{bmatrix}\begin{Bmatrix} x \\ x_t \end{Bmatrix} = \begin{bmatrix} F \\ 0 \end{bmatrix} \qquad (3)$$

M_t is the mass of the TMD and Kt is the Stiffness of the device connecting the TMD to the structure. Damping with damping coefficient C_t . A typical tuned mass damper consists of a mass m which moves relative to the structure and is attached to it by a spring (with stiffness k) and a viscous damper (with coefficient c). Tuned mass damper is characterized by its tuning, mass, and damping ratios. The tuning ratio *f* is defined as the ratio of the fundamental frequency of the TMD ω° to that of the structure.

IV. ANALYSIS FOR WIND LOAD

1. Determine properties of chimney
H = 180 m,
Ac = 9m2,
I = 103.35 m4
Ec = 3.2 x 1010 N/m2
Vb = 39m/s
K1 = 1.06,
K2 = 1.21,
K3 = 1.0
2. Determine Design speed
Vz = Vb.K1.K2.K3
Vz=39 x 1.06 x 1.21 x 1.0
Vz=50m/s
V180=50(180/10)0.28
.
3. Determine Design Pressure
Pz = 0.6Vz2
Pz = 0.6 x112.3172
Pz = 7569.065 N/m2
Pz = 7.569 KN/m2.
4. Determine drag force per unit height of the chimneyV180=112.317m/s

$$F_z = P_z C_D d$$

Fz = 59.76 N/m
5. Determine the Deflection at the tip of chimney

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$$\delta = \frac{F_z L^4}{8EI}$$

δ = 0.0023m

SAP 2000 result

TABLE: Joint Displacements							
Joint	**OutputCase**	**U1**	**U2**	**U3**	**R1**	**R2**	**R3**
Text	Text	m	m	m	Radians	Radians	Radians
8725	WL	0	0	0	0	0	0

V. Response-spectral Analysis for IS code spectra

H= 180 m,
Ac = 9 m2,
W=25x 9 x 180
W= 40500 KN
T = 0.075h0.75
=0.075× 1800.75
T =3.68 Sec.
For a period of 3.2146 s and with 5% damping
For seismic zone IV, Z=0.24, R=5 and I=2.

$$V_B = A_h W$$

$$A_h = \frac{Z}{2}\frac{I}{R}\frac{S_a}{g}$$

$$\frac{S_a}{g} = \frac{1.36}{T}$$ 0.55< T <4.0 for medium soil

$\frac{S_a}{g}$ =1.36/3.68
Ah = (0.24 x 2 x 1.36)/(2 x 5 x 3.68)
Ah = 0.0177
Base Shear,
VB = 0.0177 x 40500
V_B = 716.85 KN

SAP 2000 Result

TABLE: Base Reactions							
OutputCase	**StepType**	**GlobalFX**	**GlobalFY**	**GlobalFZ**	**GlobalMX**	**GlobalMY**	**GlobalMZ**
Text	Text	KN	KN	KN	KN-m	KN-m	KN-m
RESP SPECTRUM	Max	815.517	344.519	0.003595	18690.386	128855.7584	0.0036

Modeling in SAP2000

To work out the effect of TMD on chimney in this present study first chimney was modeled in SAP2000. chimney height used in this model was 180m, radius of chimney was 9.87m and thickness was0.6m. Base of chimney was fixed.

TABLE: Modal Periods And Frequencies							
Damper	**OutputCase**	**StepType**	**StepNum**	**Period**	**Frequency**	**CircFreq**	**Eigenvalue**
Text	Text	Text	Unitless	Sec	Cyc/sec	rad/sec	rad2/sec2
5%	MODAL	Mode	1	1.538028	0.65018	4.0852	16.689

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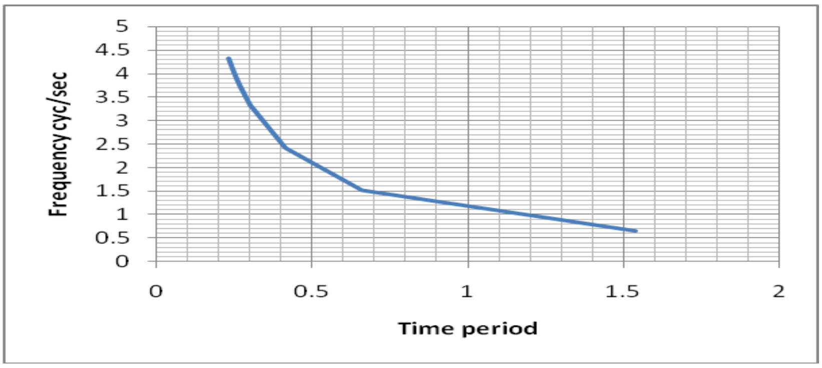
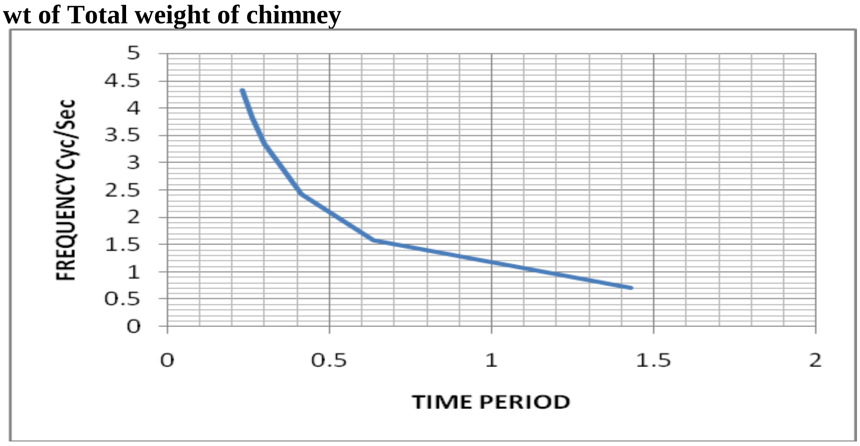
10%	MODAL	Mode	1	1.428347	0.70011	4.3989	19.351
15%	MODAL	Mode	1	1.3143	0.76086	4.7806	22.854

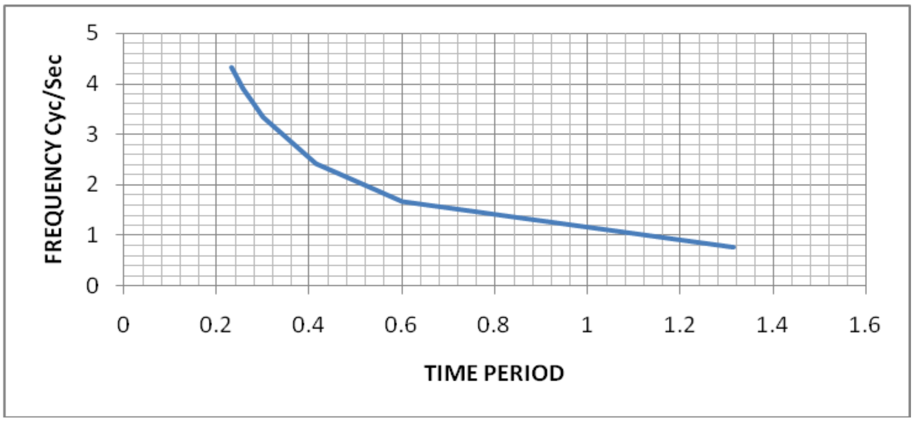
Graphs of time period vs Frequency for chimney with TMD



1) **Damper 5% wt of Total weight of chimney**



2) **Damper 10 % wt of Total weight of chimney**



3) **Damper 15 % wt of Total weight of chimney**

VI. CONCLUSION

The results of the study presented in this demonstrate that the use of TMD with a tuned frequency leads to a significant reduction in structural response. TMD mass of 5%, 10%, 15% Weight of total weight of chimney is used

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to control vibration control of chimney. The result indicates that using the proposed TMD reduces the displacement significantly 23%.

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