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APPLICATION OF TMD FOR VIBRATION CONTROL OF CHIMNEY

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ABSTRACT

Many tall and overhanging structures are susceptible to vibrations. Most of industrial chimneys and steel towers are structures particularly sensitive to the dynamic effect of wind and earthquake. This vibration of structure is control by various damping devices or dissipation methods. The tuned mass damper (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. The TMD is placed at the structure's location with the corresponding maximum of the vibration amplitude of the natural frequency. A TMD is connected to the structure at the location where a significant or the biggest vibration is occurring. The device is consisting of a moving mass, springs and a damping element

The aim of this paper is to get vibration control of chimney using Tuned Mass Damper. In this paper response spectral analysis of chimney is done and displacement is calculated, then TMD is attached at the top of chimney to control displacement at top of chimney.

KEYWORDS: Chimney, Tuned Mass Damper, TMD, Vibration control.

1. INTRODUCTION

Chimneys, as we know them today, are tall structure. Until the beginning of this century, the popular material for chimney construction was brick and steel. As chimney grew taller, a stage was reached when brick chimney become uneconomical and were replaced by steel chimney. Now day reinforced concrete chimneys are most popular and chimney heights go on increasing. As height of chimneys increases it becomes more slender. Chimneys are structures particularly sensitive to the dynamic effect of wind and earthquake. Mostly these are structures with low natural damping in combination with low natural frequency. Tuned Mass Damper(TMD) is one of the effective damping systems widely used to dissipate energy of vibration of structure. Various damping devices are used to damp the structural vibration. 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. The TMD is placed at the structure's location with the corresponding maximum of the vibration amplitude of the natural frequency. By attaching a secondary mass to the structure with approximately the same natural frequency, large relative displacements between the structure and the secondary mass will occur at resonance, and the mechanical energy of the system can then be dissipated by placing a properly tuned damper between the two. Application of TMD for vibration control of chimney was observed by Natthapong Areemit [2].

The optimal parameters for the tuned mass damper are obtained numerically and by an approximate analytical approach, in which the damping force is assumed to be equal to the force of a conventional tuned mass damper at resonance F. Rudinger[3].

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. To show the effectiveness of the proposed method, the response of several single and multi-degree-of-freedom structures, with and without TMDs, to different ground excitations are presented and compared to those from other methods. The method is also used to compute the tuning and damping ratios of substructures utilized as vibration absorbers in tall buildings.

2. MATERIALS AND METHODS

Equations of motion

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[1]

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

$M$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

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

$M_t x_t + C_t(x_t - x) + k_t(x_t - x) = 0$ (ii)

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

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

$M_t$is the mass of the TMD and $k_t$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) as shown in Figure 2. A 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 $\omega_t$to that of the structureω_o. Thus

$f = \frac{\omega_t}{\omega_o}$ (iv)

The mass ratio μ is

$\mu = \frac{M_t}{M}$ (v)

Where, M is the total mass of a SDOF structure or the generalized mass for a given mode of vibration of a MDOF structure computed for a unit modal participation factor. The damping ratio of the TMD is given by

$\xi = \frac{C}{2M_t\omega_t}$ (vi)

Sladek and Klingner use the Den Hartog method to select the parameters$f$ and ξ for a TMD placed on the top floor of a 25-store building. The basis for the Den Hartog method is to minimize the response to sinusoidal loading which for a undamped system results in the following TMD parameters [4]:

$f = \frac{1}{1+\mu}$ (vii)

And

$\xi = \sqrt{\frac{3\mu}{8(1+\mu)}}$ (viii)

Case study

Consider a 150-m tall RC cylindrical chimney-like structure of uniform cross-section D=12m, d=10.4m (Ac= 28.1486 m2, I= 443.62 m4) with a weight of 25 kN/cu.m and Ec= 3.2 x 1010 N/m2. The chimney is assumed clamped at the base, the mass and flexural rigidity are computed from the gross area of the concrete (neglecting the reinforcing steel) and damping is estimated as 5%.

Assume the shape function as $\varphi_{(x)} = 1 - \cos\left(\frac{\pi x}{2L}\right)$

Here determine the natural frequency, peak displacement and shear force for chimney due to ground motion characteristic by design spectrum fig.3 given below to a peak acceleration 0.25g.[1]

Determine the chimney properties

Length: L=150m.
Cross Section Area A=28.14m2
Mass/meter length:$\tilde{m} = m\int_0^L \left(1 - \cos\frac{\pi x}{2L}\right)^2 dx = 0.227mL, \tilde{m} = 71.71$ kgsec2/m2
Second moment of area $I = \frac{\pi}{4}(D^4 - d^4)$, I = 443.62 m4
Flexural rigidity: EI=1.419x1010 KNm2

Determine the Natural Period$\omega_n = \frac{3.66}{L^2}, \omega_n = \frac{3.66}{150^2}\sqrt{\frac{1.419x1010}{71.71}} = 2.288$ rad/sec

$T = \frac{2\pi}{\omega_n}$=2.746 sec.

Determine the peak value of Z_0

$$T = 2.746 \text{sec}. \xi = 0.05$$

The design spectra give A/g

$\frac{A}{g} = 0.25\left[\frac{\tilde{\omega}_n}{T}\right] = 0.25\left[\frac{1.8}{2.746}\right]$=0.163

$D = \frac{A}{{\omega_n}^2} = \frac{0.163\times 9.81}{2.288^2}$=0.3077

$Z_0 = \tilde{\Gamma}D = \frac{\tilde{L}}{\tilde{m}}D = 0.49m$

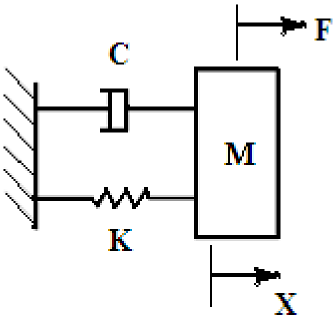
Determine the peak value of displacement (x)

$(x) = \varphi_{(x)}\, Z_0 = 1 - \cos\left(\frac{\pi x}{2L}\right) 0.49 = 0.49m$

Determine the shear force ν

$\nu = \tilde{L}\tilde{\Gamma}A, \nu = 0.363mL(1.6)163 \times 9.81$ =9989.74KN

Figure:



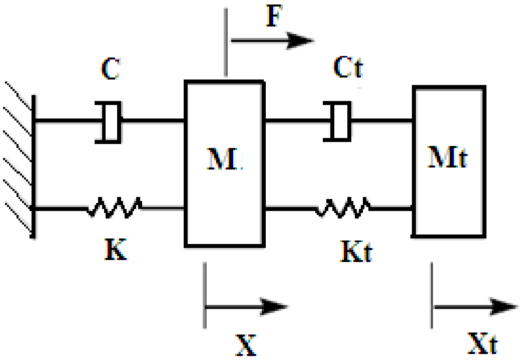


Fig. 1 Mathematical model of chimney Fig. 2 Mathematical model of chimney with TMD

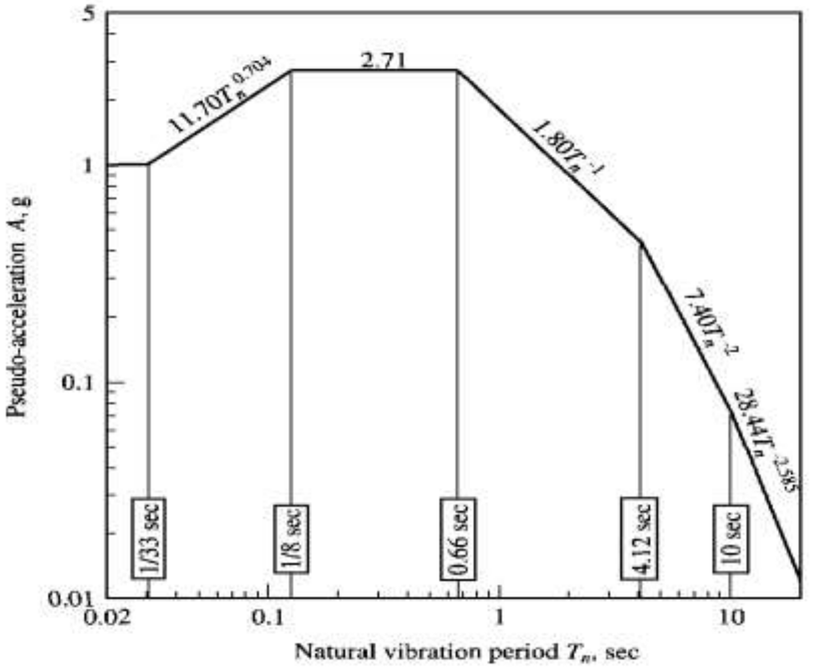


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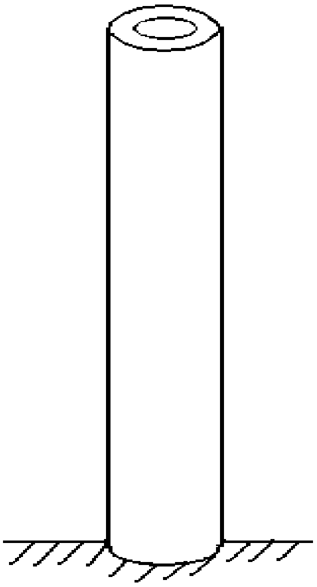
Fig.3 Response Spectrum for case study



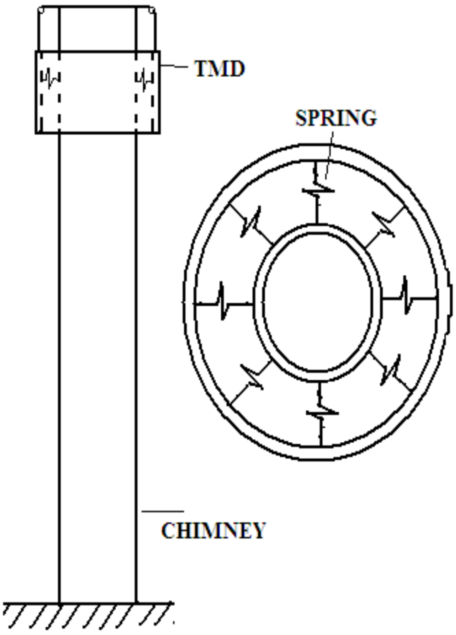


Fig.4 chimney Fig.5 chimney With TMD

3. RESULTS AND DISCUSSION

Above response spectra given in fig.3 is imported in SAP for analysis Schematic diagram of chimney and chimney with TMD is shown in fig.4 and fig.5 respectively.

To minimize the deflection of chimney TMD is lumped at top of chimney.TMD is modelled in SAP2000 after attachment of TMD results is obtained. The Comparison of hand calculation and SAP result are given in

table.1.Comparison of SAP Result of chimney without TMD and with TMD with percentage reduction are shown in table.2

Formulae:

$$M\ddot{x} + C\dot{x} + Kx = F \quad \text{(i)}$$

$$M_t x_t + C_t(x_t - x) + k_t(x_t - x) = 0 \quad \text{(ii)}$$

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

$$f = \frac{\omega_t}{\omega_o} \quad \text{(iv)}$$

$$\mu = \frac{M_t}{M} \quad \text{(v)}$$

$$\xi = \frac{C}{2M_t\omega_t} \quad \text{(vi)}$$

$$f = \frac{1}{1+\mu} \quad \text{(vii)}$$

$$\xi = \sqrt{\frac{3\mu}{8(1+\mu)}} \quad \text{(viii)}$$

Tables:

Table.1 Comparison of hand calculation and SAP result

	Hand calculation	SAP Result

Time Period	2.746sec.	2.9193sec.
Displacement	0.49m	0.4267m
Base Shear	9989.74 KN	10268.38KN

Table.2 Comparison SAP Result of chimney without TMD and with TMD

	without TMD	with TMD	% reduction due toTMD
Period	2.919sec	1.701sec	41.70
Dispt.	0.4267m	0.2125m	50.19
velocity	0.936m/s	0.796m/s	14.91

4. CONCLUSION

In this paper, the analysis of the effectiveness of a TMD in reducing vibration of chimney has been conducted. The chimney 150m tall and 12m in diameter was considered for case study. The results are summarized in Table 2 showing the use of TMD for effective vibration control of chimney.

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. In above case study TMD mass of 8240.615kN is used to control vibration control of chimney. The result indicates that using the proposed TMD reduces the displacement significantly up to 50.19%.

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