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Effectiveness of Multiple Tuned Mass Dampers

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Abstract*—*The seismic waves caused by an earthquake sway structures like E.S.R tanks, bridges, buildings in various ways depending on the frequency & direction of ground motion, and the height of the structure. In order to reduce the sway of structure, it is important to place large dampers into their design to interrupt the frequency. Various parameters like mass ratio, damping ratio and stiffness of structure are considered. The objective of research paper is to prove that, the use multiple tuned mass dampers(MTMD) rather than single tuned mass damper(STMD) can reduce the sway of structure within limit. For this a case study of R.C.C. ESR having capacity of 40m^3 is considered.

***Index Terms*—Tuned MassDamper,Dampin Ratio,Stiffness,Mass Ratio,Multiple Tuned Mass Damper, Single Tuned Mass Damper.**

I. INTRODUCTION

The seismic waves caused by an earthquake make structure to sway and oscillate in various ways depending on the frequency and direction of ground motion and height of structure. In order to enhance the structural seismic performance, a proper structure design is formulated engaging various seismic vibration control technologies. Tuned mass damper is a classical device consisting of an absorber mass, spring and viscous damper attached to main system. Today TMD's are extensively used in civil engineering structures to suppress vibrations due to wind and earthquake forces. A case study of ESR water tank having capacity 40 m^3 is considered for the comparative study of multiple tuned mass damper (MTMD) and single tuned mass damper (STMD).

II. TUNED MASS DAMPER (TMD)

A TMD consists of a mass mounted on a structure via a spring system and a viscous damper, preferably in a location where the structure's deflections are greatest. The spring and mass are 'tuned' so as to have a natural frequency close to that of the primary structure. When properly tuned, the TMD mass oscillates in the opposite direction from the primary structure. The motion of the mass relative to the main structure can be very large when the system is properly tuned and this provides an opportunity to dissipate a substantial amount of energy in the damper linking the mass to the main structure. The optimum configuration of the spring system will vary depending on the application. The TMD principle also applies to individual components prone to vibration such as slender columns, truss members and struts. The multiple tuned dampers mass have been proposed about a decade ago as a better option for single TMD. The basic configuration of MTMD structure system comprises a number of TMDs attached to the main structure as shown in the figure1 .

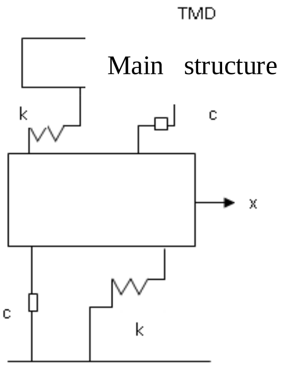


Fig 1 Idealized Structural model of TMD

III. THEROTICAL FORMULATION

(A) Structure with Single Tuned Mass Damper

For structure attached with STMD (Single tuned mass damper).Consider a structure attached with single tuned mass damper. Let, m_s, k_s, c_s, and Rs are the properties of main structure. Similarly, m_1, ω_1, R_1, c_1, are the properties of single tuned mass damper attached to the structure.

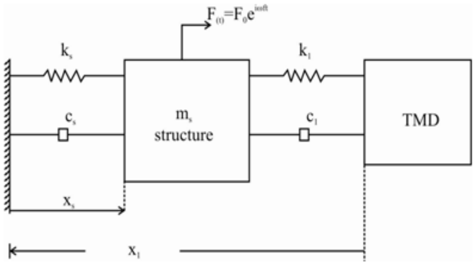


Fig 2 Idealized Structural model for STMD.

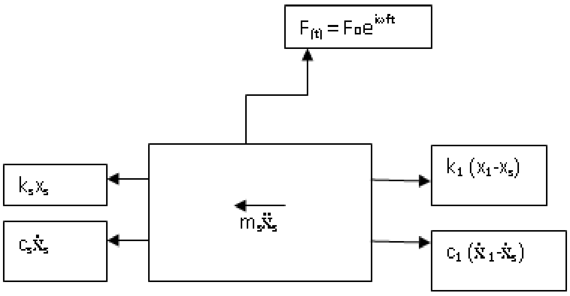


Fig 3 Mathematical model of structure with STMD

$$m_s\ddot{x}_s + c_s\dot{x}_s + k_sx_s - c_1(\dot{x}_1-\dot{x}_s) - k_1(x_1-x_s) = F_{(t)} \qquad -(1)$$

$$\therefore m_s\ddot{x}_s + \dot{x}_s(c_1+c_s) + (k_s+k_1)x_s - c_1\dot{x}_1 - k_1x_1 = F_{(t)} = Foe^{i\omega_f t}$$

$$x_s = x_s e^{i\omega_f t}$$

$$\dot{x}_s = x_s\, i\, \omega_f\ e^{i\omega_f t}$$

$$\ddot{x}_s = x_s i^2 \omega^2{}_f\ e^{i\omega_f t} = - x_s \omega^2{}_f\ e^{i\omega_f t}$$

$$\text{for}\quad x_1 = x_1\ e^{i\omega_f t}$$

$$\dot{x}_1 = \omega_f\, i\, e^{i\omega_f t}\ x_1$$

$$\ddot{x}_1 = -\omega^2{}_f\ x_1\ e^{i\omega_f t}$$

$$c = R.c_c$$

$$c = R.\ (2m\omega)$$

$$c_s = R_s\, m_s\, \omega_f$$

$$c_1 = 2R_1m_1\,\omega_1$$

$$\omega = \sqrt{}\ k/m$$

$$\frac{m_1}{m_s} = \mu_1;\ \frac{\omega_f}{\omega_s} = a;\ \frac{\omega_1}{\omega_s} = r_1$$

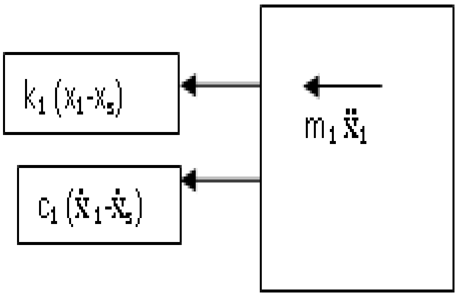


Fig 4 Mathematical Model for STMD

$$\therefore x_s = \frac{\left\lfloor F_0 /\ m_s\omega_s^{\ 2} \right\rfloor}{\left[\operatorname{Re}(x)\ +\ i\operatorname{Im}(z)\right]}$$

$$\operatorname{Re}(z) = 1 - \frac{\omega_f^{\ 2}}{\omega_s^{\ 2}} - [\mu_k a^2][r^2{}_k(r^2{}_k - a^2) + (2R_kr_ka)^2] / [(r^2{}_k - a^2)^2 + (2R_kr_ka)^2]$$

$$iI_m(z) = 2\ R_s\, R\ \frac{\omega_f}{\omega_s} + (2\mu_k r_k R_k a^5) / ([(r^2{}_k - a^2)^2 + (2R_kr_ka)^2])$$

Where, $Re(z)$ and $iI_m(z)$ are real and imaginary number respectively.

(B) Structure with Multiple Tuned Mass Damper

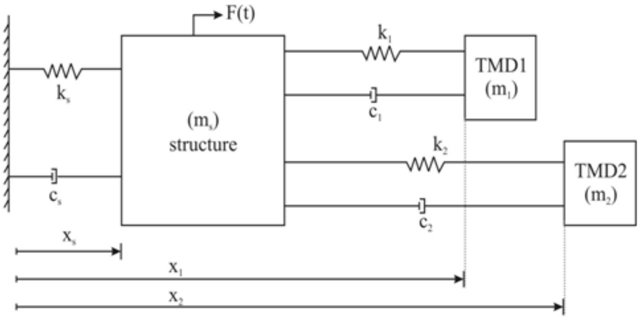


Fig 5 Idealized Structural model for MTMD

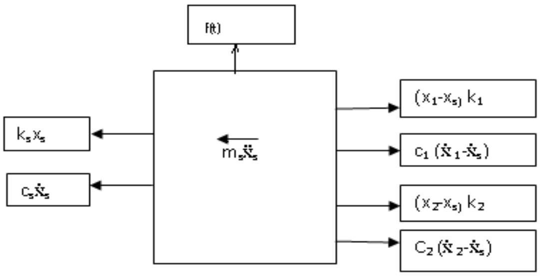


Fig 6 mathematical model for structure with MTMD

$$\therefore m_s\ddot{x}_s + c_s\dot{x}_s + k_sx_s - (x_1 - x_s)\,k_1 - (\dot{x}_1 - \dot{x}_s)c_1 - (x_2 - x_3)k_2 - (\dot{x}_2 - \dot{x}_s)c_2 = F_{(t)}$$

$$x_s = x_s\ e^{i\omega_f t}$$

$$\dot{x}_s = x_s\, i\ \omega_f\ e^{i\omega_f t}$$

$$\ddot{x}_s = x_s i^2\ \omega^2{}_f\ e^{i\omega_f t} = - x_s\, \omega^2{}_f\ e^{i\omega_f t}$$

$$c = R.c_c$$

$$c = R.\ (2m\omega)$$

$$c_s = R_s\, m_s\, \omega_f$$

$$c_1 = 2R_1m_1\,\omega_1$$

$$\omega = \sqrt{}\ k/m$$

$$\frac{m_1}{m_s} = \mu_1;\ \frac{\omega_f}{\omega_s} = a;\ \frac{\omega_1}{\omega_s} = r_1,\ \frac{\omega_2}{\omega_s} = r_2$$

We have,

$$\therefore\quad x_1 = \frac{\left\lfloor r_1^{\ 4} - r_1^{\ 2}a^2 + 4R_{11}^{\ 2}r_1^{\ 2}a^2 - 2iR_{11}r_1a^3 \right\rfloor}{\left[\left(r_1^{\ 2} - a^2\right)^2 + \left(2R_{11}r_1a\right)^2\right]}$$

$$x_2 = \frac{\left\lfloor r_2^{\ 4} - r_2^{\ 2}a^2 + 4\ R_{12}^{\ 2}r_2^{\ 2}a^2 - 2i\ R_{12}r_2a^3 \right\rfloor}{\left[\left(r_2^{\ 2} - a^2\right)^2 + \ \left(2\ R_{12}r_2a\right)^2\right]}x_s$$

Where,

$$\mathrm{Re}(z) =$$

$$1-\left[\frac{\omega_f}{\omega_s}\right]^2 - \sum_{k=1}^{n} \frac{\left\lfloor m_k a^2 \left\lfloor r_k^{\,2}\left(r_k^{\,2}-a^2\right)\right\rfloor + \left(2\,R_{1k} r_k a\right)^2 \right\rfloor}{\left[\left[\left(r_k^{\,2} - a^2\right)\right] + \left(2\,R_{1k} r_k a\right)^2\right]}$$

$$\mathrm{iIm}(z) =$$

$$(2R_s)\left(\frac{\omega_f}{\omega_s}\right) + \sum_{k=1}^{n} \frac{\left\lfloor 2 m_k r_k R_{1k} a^5 \right\rfloor}{\left[\left(r_k^{\,2}-a^2\right)^2 + \left(2\,R_{1k} r_k a\right)^2\right]}$$

IV. COMPARATIVE STUDY OF STMD & MTMD

A. R.C.C ESR water tank having following data.

1) Capacity:-40m^3
2) L.D.L:-12.0
3) Free board :-0.3m
4) S.B.C of soil:-25 MT/ m^3
5) Seismic zone: IV

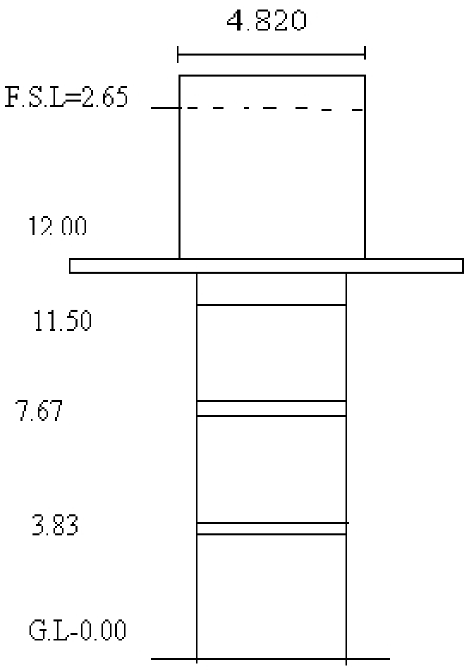


Fig 7 . Water Tank (ESR) Elevation

Using I. S. 1893-2000

Consider Rs= Damping of structure

= 5% = 0.05

Lateral displacement at top δ = 0.370 m

Period T = 2π x √ (0.37/9.81)=1.2sec

Ref I.S.1893,

Fig No 5 with 5% critical damping

Sa/g = 0.09

αh = 1.0 x 1.5 x 0.25 x 0.09 = 0.03375

Lateral force = W x (αh)= 97063 x 0.03375

= 3276 kg

Using concept *F* = k δ

k= *F* / δ

= 32760/0.37

= 88301.886N/m

So the required information is

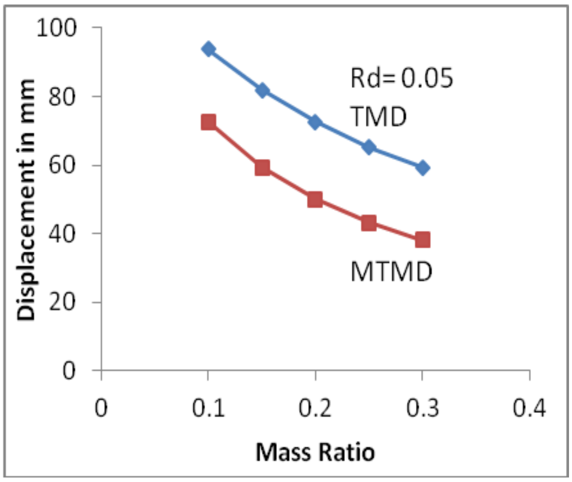
Mass of structure= 97063 kg

Stiffness of structure=88301.886 N/m.

B Using ESR structure attached with STMD and MTMD following results are obtained.

Table 4.2 (I) For Rd=0.05

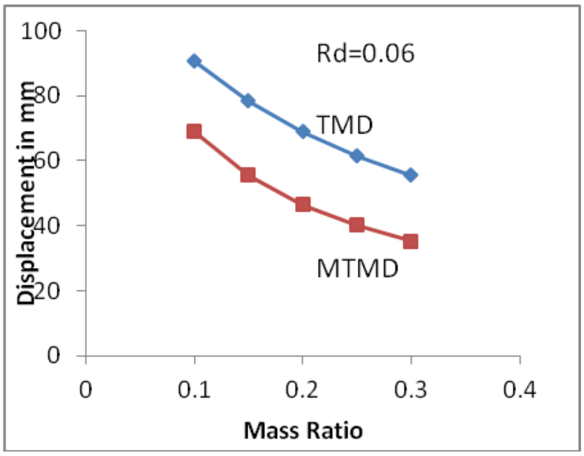
	Displacement in (mm)	
Mass Ratio	STMD	MTMD
0.1	93.8	72.59
0.15	81.8	92.1
0.2	72.59	49.99
0.25	65.22	43.25
0.3	59.21	38.124



Graph 1 for Rd=0.05

Table 4.2 (II) For Rd=0.06

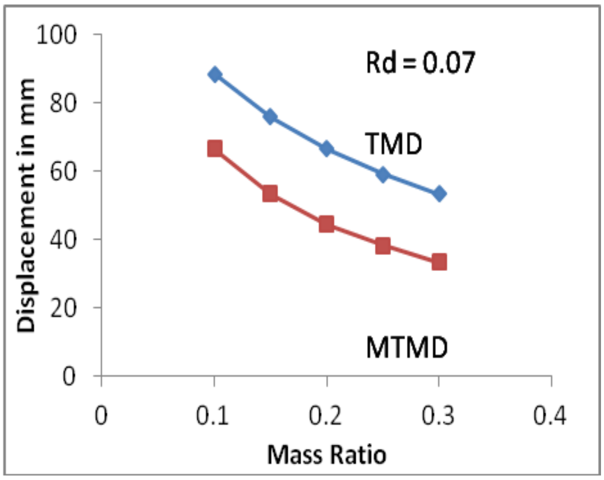
	Displacement in (mm)	
Mass Ratio	STMD	MTMD
0.1	90.6	68.9
0.15	78.31	55.5
0.2	68.9	46.56
0.25	61.53	40.07
0.3	55.5	35.16



Graph 2 for Rd=0.06

Table 4.2 (III) for Rd=0.07

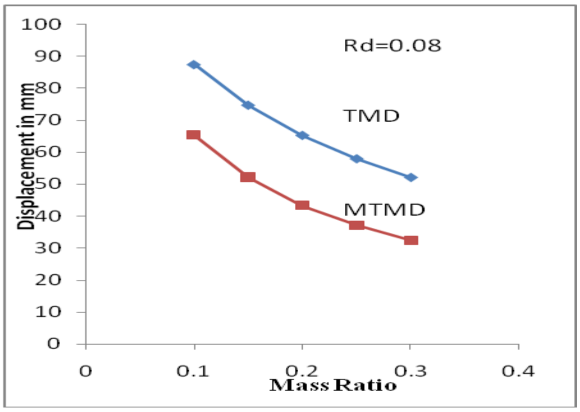
	Displacement in (mm)	
Mass Ratio	TMD	MTMD
0.1	87.42	65.22
0.15	74.7	52.02
0.2	65.22	43.26
0.25	57.88	37.028
0.3	52.022	32.36



Graph 3 for Rd = 0.07

Table 4.2 (IV) for Rd=0.08

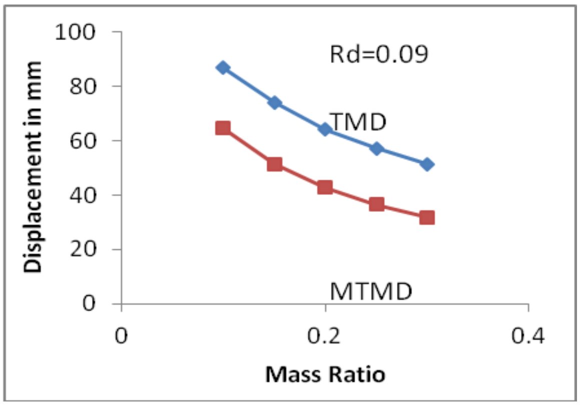
	Displacement in (mm)	
Mass Ratio	STMD	MTMD
0.1	88.6	66.58
0.15	76.03	53.31
0.2	66.58	44.46
0.25	59.21	38.129
0.3	53.33	33.37



Graph 4 for Rd = 0. 08

Table 4.2 (V) for Rd=0.09

	Displacement in (mm)	
Mass Ratio	TMD	MTMD
0.1	86.85	64.6
0.15	74.096	51.427
0.2	64.03	42.715
0.25	57.26	36.52
0.3	51.42	31.905



Graph 5 for Rd = 0.09

C. Tables for Comparative Study of Displacement For Main Structure and Structure with MTMD

Table 4.3 (I) for mass ratio =0.1

Damping ratio for damper	Displacement due to MTMD in (mm)	%reduction w.r.t Original structure
Rd =0.05	72.5	80.45
Rd = 0.06	68.9	81.40
Rd=0.07	66.5	82.07
Rd=0.08	65.2	82.42
Rd=0.09	64.6	82.58

Table.4.3 (II) For Mass Ratio =0.15

Damping ratio for damper	Displacement due to MTMD in (mm)	% reduction w.r.t Original structure
Rd =0.05	59.2	84.04
Rd = 0.06	55.5	85.040
Rd=0.07	52.3	85.90
Rd=0.08	52.0	85.98
Rd=0.09	51.4	86.145

Table.4.3 (III) For Mass Ratio =0.20

Damping ratio for damper	Displacement due to MTMD in mm	%reduction w.r.t Original structure
Rd =0.05	49.9	86.51
Rd = 0.06	46.56	87.45
Rd=0.07	44.4	88.03
Rd=0.08	43.263	88.33
Rd=0.09	42.71	88.48

Table.4.3 (IV) For Mass Ratio =0.25

Damping ratio for damper	Displacement due to MTMD in mm	%reduction w.r.t Original structure
Rd =0.05	43.2	88.35
Rd = 0.06	40.719	89.11
Rd=0.07	38.129	89.72
Rd=0.08	37.0289	90.01
Rd=0.09	36.52	90.15

Table.4.3 (V) For Mass Ratio =0.30

Damping ratio for damper	Displacement due to MTMD in mm	%reduction w.r.t Original structure
Rd =0.05	38.124	89.723
Rd = 0.06	35.165	90.52
Rd=0.07	33.37	91.00
Rd=0.08	32.36	91.27
Rd=0.09	31.9056	91.40

V. CONCLUSION

The analyses of vibrations of an ESR structure with TMD Installations, which are tuned to selected modes of vibration, have been studied in this dissertation. The displacements of a structure with MTMD were determined. These calculations were compared with the displacement of the same structure with conventional TMD installed.

1 From the comparative result, it is noticed that, as mass ratio increases from 10% to 30% response or displacement of the structure is also reduced.

2 For Rd = 0.09, MTMD gives 37.96% reduction in displacement than using STMD only. (Table 4.2 V)

3 For the same mass ratio and variation in damping ratio, it has been observed that displacement of the structure reduces using MTMD.

4 For Rd = 0.09 and mass ratio 0.3 gives maximum reduction in displacement and it is 91.40% when compared with original structure. (Table.4.3 V)

5 Hence, from the comparative study it is concluded that using MTMD considering variation in parameters like change in mass ratio, change in stiffness coefficient of, both damper and main structure, we find that MTMD is more effective than STMD.

6 If we increase no of dampers more than 2, the project cost of ESR will increase, so optimum no of dampers to be used.

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