A NUMERICAL APPROACH TO CONSIDER EFFECTIVENESS OF TMDS ON NONLINEAR BEHAVIOR OF REINFORCED CONCRETE FRAMES

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ABSTRACT
The Tuned Mass Damper (TMD) is a classical engineering device consisting of a mass, a spring and a viscous damper attached to a vibrating main system in order to attenuate any undesirable vibrations. The vast area of major researches show the effects of TMD in elastic structures .This paper aims to evaluate the application of TMD as a passive controlling system for structures considering nonlinear behavior. Tow 4 & 8 story reinforced concrete buildings designed based on Iranian code are modeled for time history analysis using different intensities of Tabas records. Three kinds of TMDs specified according to some literature proposals, are installed on the roof floor. In the numerical simulation procedures, tuned mass damper contributes to dynamic equations as an interaction force calculated in each time step. Hysteretic energy absorption and a criterion introduced for floor local displacement during vibration (RMS) are studied to illustrate the seismic effectiveness of TMD compare to the case without using TMD for structural systems.

KEYWORDS: Tuned mass damper, Time history analysis, Reinforced concrete frame, nonlinear behavior,

1. INTRODUCTION

Tuned mass dampers are categorized as passive structural systems used to suppress undesirable vibrations. The device can be installed in one or more than one story floor in the building. It also can be regarded as a mean for retrofitting purposes. The basic conceptions of TMD appeared in vibration mitigation's studies by Frahm issued in 1909[1]. Ormondroyd & Denhartog developed the theory in 1928[2]. In 1956, Denhartog presented the formulation of absorbers in his book ' mechanical vibrations '[3]. He discussed the case that the TMD device connected to SDOF undamped main structure subjected to harmonic excitations. Bishop & Welborn extended the theory to damped SDOF structure equipped with TMD[4]. Falcon and his colleagues introduced optimum parameters for determining TMD specifications based on Bishop's studies[5]. After that some of researches represented tables tell how to design TMD parameters. Others investigated the effects of deterioration in TMD's specifications on its performance. Various topics are studied to find out how to use vibration absorbers more efficiently[6,7].

2. MODELING

Fig. 1 shows the schematic view of TMD attached to the main structure. TMD illustrated as a single degree of freedom added to the structure. It starts to move while the main structure is being excited by ground motion caused by earthquake. The parameters M, C, K stand for mass, damping coefficient and stiffness respectively. The subscripts d and s refer to damper and structure respectively. The response of the structure will be influenced by TMD if its parameters tuned properly. These parameters have been discussed through many researches.

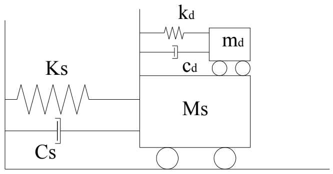

Figure 1 Subsystem TMD attached to the main structure

2.1. Governing the equations of Motion

Special criterions proposed to find the damper's specifications so that increase its contribution to attenuate the structural motions. At the first step to consider the way how TMD intervenes in equation of motion, the interactive force between the structure and TMD can be expressed as

$$P(t) = k_d Z(t) + c_d \dot{Z}(t) \tag{2.1}$$

P (t) is the interactive force between TMD and the structure. The force applied at the story where the device is installed. Z (t) denotes the displacement of TMD relative to its support. If the $\ddot{u}_N(t)$ is the acceleration of the floor where the device is installed, The TMD may be considered as a sub system subjected to the excitations of the Nth floor. It means that the total acceleration that is received by TMD is calculated by adding the accelerations of the story to the ground acceleration. So the equation of motion for TMD can be written as:

$$m_d \ddot{Z}(t) + c_d \dot{Z}(t) + k_d Z(t) = -m_d \left(\ddot{u}_g(t) + \ddot{u}_N(t) \right) \tag{2.2}$$

It should be noted that tow excitation factor are applied to structure:
1-the forces generated caused by ground motion acceleration.
2-the force caused by TMD vibration.
The first one is the effective force due to ground motion called $\{F_g(t)\}$. The second is the interactive force induced by tuned mass damper motions called $\{P(t)\}$. The term $\{F_S(u,\dot{u})\}$ is the resistant force generated by structural elements calculated with considering hysteretic behavior of members. So the dynamic equation of the main structure is represented as:

$$[M_S]\{\ddot{u}(t)\} + [C_S]\{\dot{u}(t)\} + \{F_S(u,\dot{u})\} = \{F_g(t)\} + \{P(t)\} \tag{2.3}$$

2.2. Numerical process

Solving the equations (2.1) to (2.3) instantaneously in each time step, numerically, results in determining the interactive force. Time history dynamic analysis conducted with IDARC[10] software using Tabas and earthquake records. Figure 2 shows the numerical procedure how to find TMD forces in each time step. The method best fits the structures with nonlinear behavior[9].
At the beginning of each time step the interactive force is assumed to be zero. The incremental acceleration of the story is added to incremental acceleration operated on the base to form the total excitement acceleration applied to mass damper. Equation of motion for TMD leads to determine the incremental values of acceleration, velocity and displacements of TMD.

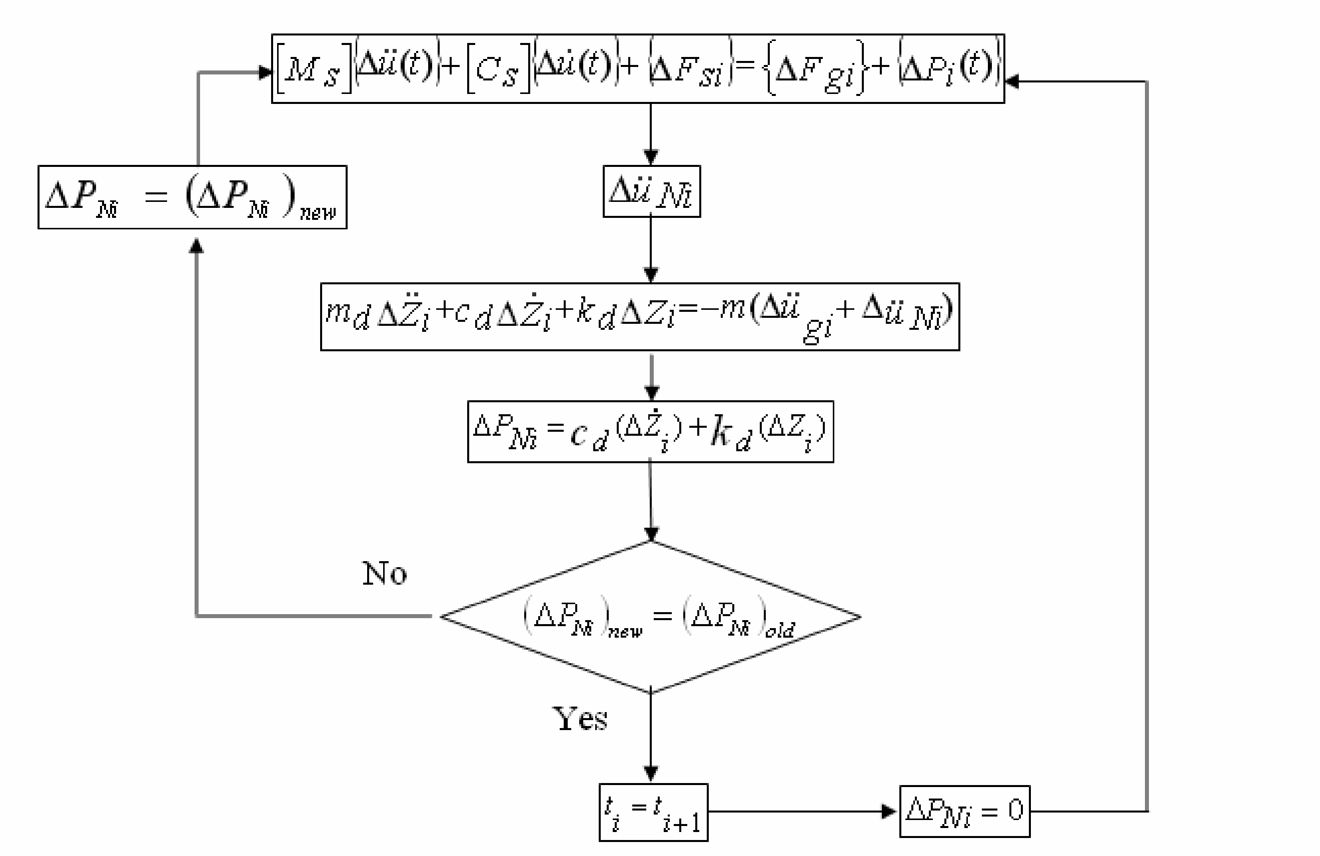

Figure 2 Numerical procedures for considering the effectiveness of TMD

. So it is possible to calculate the increment of interactive force applied on the story by mass damper. The force is fed back to the main structure. Iterative process is continued until the increment of TMD force is converged to the fixed value under the acceptable tolerance. The incremental displacement of the story is also approach converged Value.

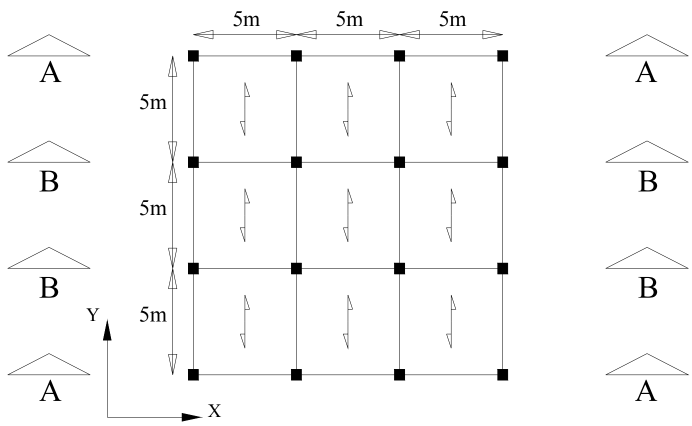

Figure 3 the plan of case study R/C buildings

3. EXAMPLES OF REINFORCED CONCRETE BUILDINGS

Tow different 4 and 8 story reinforced concrete buildings are represented to investigate the effectiveness of TMD in reducing responses. The nonlinear behaviors of the structural concrete members are considered in software. The height of the first story is 3.8 meters and the height of other stories is 3.2 meters. The plan has 3 bays in each orthogonal direction. The length of spans is 5 meters. The dead load on the floors is 600 Kg/m^2 and the live load is 200 Kg/m^2. For the roof the dead load and live load are 550 Kg/m^2 and 150 Kg/m^2 respectively. Figure 3 shows the plan of the case study buildings. Building properties are mentioned in the tables below.

Table 1 specifications of 4 story building

Beam section and rebar		Column section and rebar			
Section	story	External columns	Internal columns	story	frame
40cm x 30cm 4ϕ24 top 2ϕ24 bottom	1-2	45cm x 45cm 8 ϕ 20	45cm x 45cm 8 ϕ 20	1	Type A
		40cm x 40cm 8 ϕ 18	40cm x 40cm 8 ϕ 18	1-3	
40cm x 30cm 3ϕ24 top 2ϕ20 bottom	3-4	45cm x 45cm 8 ϕ 20	45cm x 45cm 8 ϕ 20	1	Type B
		40cm x 40cm 8 ϕ 18	45cm x 45cm 8 ϕ 20	2	
		40cm x 40cm 8 ϕ 18	40cm x 40cm 8 ϕ 18	3-4	

Table 2 specifications of 8 story building

Beam section and rebar		Column section and rebar							
Section	frame	External columns	Internal columns	story	frame	External columns	Internal columns	story	frame
50cmx40cm 6ϕ22 top 5ϕ22 bottom	1-3	60x60 12 ϕ 20	60x60 12 ϕ 20	1	Type B	60x60 12 ϕ 20	60x60 12 ϕ 20	1	Type A
		50x50 12 ϕ 20	50x50 12 ϕ 20	2		45 x45 8 ϕ 20	50x50 12 ϕ 20	2	
50cmx40cm 5ϕ22 top 4ϕ22 bottom	4-6	45 x45 12 ϕ 18	x5050 12 ϕ 20	3		45 x45 8 ϕ 20	45 x45 12 ϕ 18	3	
		45x45 12 ϕ 18	45x45 12 ϕ 18	4		45x45 8 ϕ 20	45x45 12 ϕ 18	4	
40cmx30cm 4ϕ22 top 3ϕ22 bottom	7-8	45x45 8 ϕ 20	45 x45 8 ϕ 20	5-6		40x40 8 ϕ 18	45x45 8 ϕ 20	5-6	
		40x40 8 ϕ 18	40x40 8 ϕ 18	7-8		40x40 8 ϕ 18	40x40 8 ϕ 18	8-7	

4. TUNED MASS DAMPER SPECIFICATIONS

For each building three types of TMD designed based on Tsai and Lin proposals[8]. The ratios of damper masses to the first modal mass of the buildings are determined to be 0.01, 0.02 and 0.03. Three types of TMD were designed for each building. The damping ratios of main structures were sat to 0.005. Other parameters of TMD, damping coefficient and stiffness were calculated based on optimum parameters for fixed-acceleration support excitation indicated by Tsai and Lin investigations.

Table 3 three types of TMD properties for 4 story building

Weight (KN)	Damping coefficient (KN.s/mm)	Stiffness (KN /mm)
36.07	0.00242	0.15924
72.13	0.00652	0.31242
108.20	0.01169	0.46047

Table 3 three types of TMD properties for 8 story building

Weight (KN)	Damping coefficient (KN.s/mm)	Stiffness (KN /mm)
72.69	0. 00372	0.18711
145.39	0. 01003	0.36710
218.08	0.01799	0.54107

5. CASE STUDY RESPONSES

The damper assumed to be installed on the top floor. The buildings were subjected to Tabas earthquake record with different intensities. Series of nonlinear time history analysis was performed in the case of with and without TMD. The peak ground acceleration (PGA) scaled from the values of 0.1 to 0.3 times the acceleration due to gravity (g) with increments of 0.05 for 4story building. For 8 story building the PGA scaled from 0.1g to 0.45g with increments of 0.05g.

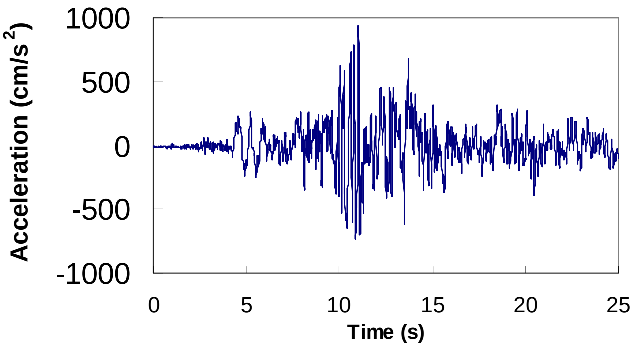

Figure 4 TABAS Earthquake record (1978 Iran)

As for investigating the effects of TMD in reducing the roof displacement, root-mean-square (RMS) displacements of the roof are plotted. The parameter m denotes the ratio of TMD mass to the first modal mass of the buildings. An inspection of roof responses reveals that TMD has positive effects on reducing displacements for the case of the PGA is lower than .2g for the 4story building and .35g for the 8story building. The more intensity of the earthquake is applied the less usefulness of TMD is observed. Severe earthquakes violate the tuning between the damper and the main structure due to developing inelastic deformations through the structural members.

It can be seen that the heavier TMD has performed better than others. This pattern deviates for intensities above 0.4g. The sharp reduction of TMD effectiveness in mitigating the roof vibration observed for PGA beyond .4g that explains heavier TMD is failed to control the structures under intensive earthquakes.

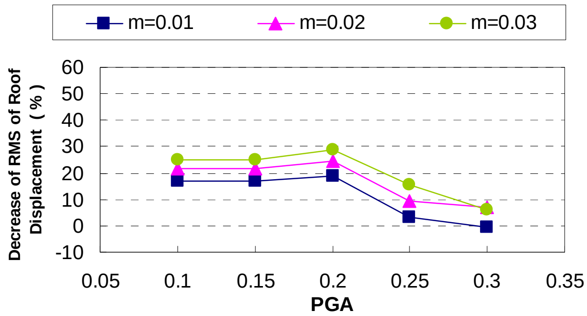

Figure 5 decrease percentage of RMS roof displacement for 4story building

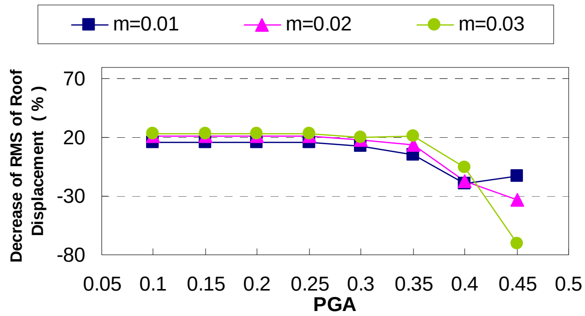

Figure 6 decrease percentage of RMS roof displacement for 8story building

The cyclic loads due to hysteretic behavior of the structure lead in energy dissipation. This cumulative absorption of energy can cause hazardous damage to the structural members. The total hysteretic energy absorbed by structure indicates another criterion for evaluating the performance of TMD. Figures 7 and 8 illustrate the total hysteretic energy dissipated by structures during the earthquake. The software calculates hysteretic energy for each element individually. To find the amount of the energy absorbed by the structure the summation of all the values obtained.

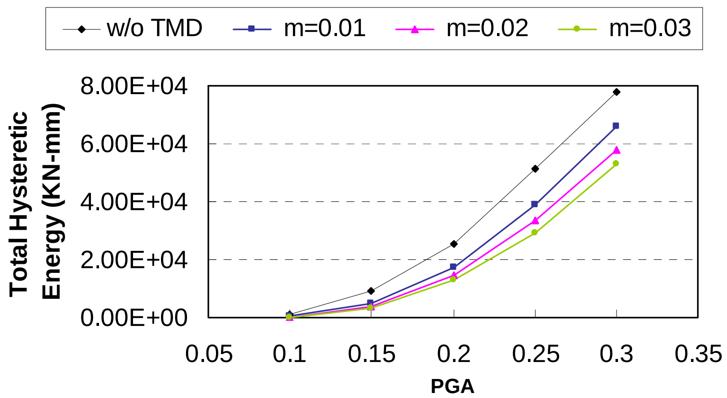

Figure7 hysteretic energy absorption by 4 story building

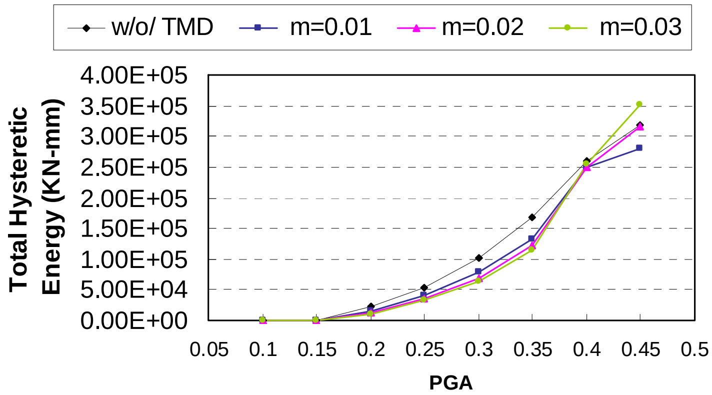

Figure8 hysteretic energy absorption by 8 story building

Figures above depict the hysteretic energy of the structure versus different intensities of Tabas records. It shows that the heavier TMD has absorbed less energy than the others. So it may be possible to say the structure equipped with heavier TMD has less inelastic deformations. So less damages has been occurred. On the contrary the building without TMD is imposed to more serious inelastic displacements so the damages might be more. The diagram shows in the earthquakes with PGA more than .35 with respect to gravity acceleration the pattern deviates and the heavier TMD has inverse effects in protecting the structure from damages.

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