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EFFICIENCY OF TMDS AND TLDS FOR LOW-RISE AND MID-RISE BUILDINGS SUBJECTED TO NEAR-FIELD AND FAR-FIELD EARTHQUAKES

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SUMMARY: *Tuned mass dampers (TMDs) and tuned liquid dampers (TLDs) are the most well-known passive control systems used to decrease structural responses against earthquake excitations. In the present study, the performance of equipped low-rise and mid-rise buildings with these kinds of dampers was evaluated, and the effects of near-field and far-field earthquakes were compared. To this end, the dynamic analyses have been accomplished in both controlled and uncontrolled states using seven ground motion records of near-field and far-field. Furthermore, both TMD and TLD at these buildings have been modeled with five various mass, stiffness, and damping percentages. The results demonstrate that TMD has better performance as compared to TLD, and descending structural responses in a low-rise building in near-field ground motion are more than far-field earthquakes. However, the responses of a mid-rise building in far-field are less than the near-field records.*

KEYWORDS: *Tuned mass damper, Tuned liquid damper, near-field earthquake, far-field, earthquake, Sum of square roots*

1 Introduction

Today, the construction of medium and high-rise buildings in the world has significantly considerably expanded. Traditional structural systems alone do not necessarily ensure that a structure will respond dynamically so that to ensure the comfort and safety of occupants (Montuori, Nastri et al. 2015, Zeynali, Saeed Monir et al. 2018). Traditional structural systems also have very low natural damping, and various investigations have been performed using various mechanical tools to increase their damping and control the vibration of structures (Lee, Kim et al. 2016, Lee, Lho et al. 2016, Mirzai and Hu 2019). (Castaldo and

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Ripani 2017) used single concave sliding bearings for the seismic protection and minimizing superstructure displacement of the elastic isolated structural systems under earthquake excitations. The authors found the optimal values for the friction coefficient. Some control methods could be categorized as passive, active, semi-active, and hybrid systems (Soong and Dargush 1997, Lee, Ju et al. 2015, Giordano, Chisari et al. 2017, Petrone and Ferrentino 2017, Love and Tait 2019). Contrary to the other three control systems, passive control systems do not need an external force source to decrease earthquake or wind responses (Mansouri, Safa et al. 2016, Mirzai, Zahrai et al. 2017, Mirzai, Attarnejad et al. 2018). There are several passive control devices, including viscoelastic dampers, friction dampers, viscous fluid dampers, metallic yield dampers, tuned mass dampers (TMDs), and tuned liquid dampers (TLDs). Numerous studies have sought to find better performance and economical design against earthquake or wind forces (Mirzai, Attarnejad et al. 2019). TLDs and TMDs are the most well-known passive devices; these devices act as a secondary vibration system when connected to buildings (Rahman, Islam et al. 2017, Salvi, Rizzi et al. 2018). The TMD was firstly used by (Frahm 1909) to decrease the movements of the ship's hall. Thereafter, this concept was used in numerous other studies that evaluated this system to control the vibration of structures (Singh, Singh et al. 2002, Viet, Nghi et al. 2014). For instance, (Wong and Chee 2004) investigated mass damper as an energy dissipation system of the earthquake in structures. The results of this study showed that this damper is more efficient in descending the structural energy response with mean to the high time period than structures with a short time period. Also, ong and Chee (2004) found that mass damper is more effective in decreasing the maximum kinetic and strain energy. Furthermore, (Zahrai and Ghannadi-Asl 2008), in a study on installed mass damper on mid-rise buildings, showed that earthquake specifications have an essential influence on their efficiency. Besides, (Mirzai, Zahrai et al. 2017) proposed the optimum parameters of TMDs using GSA and PSO algorithms for drift reduction and uniformity in steel frames.

Until 2010, the stiffness and damping were two primary and significant parameters in designing the criteria of TMD, and the mass of dampers had a predetermined amount in these criteria 10. However, (Carlo Marano, Greco et al. 2010) suggested a complete design method in which the mass has been considered as a design parameter.

The general principles of performance of TLDs are similar to TMDs, and TLDs dissipate the vibration energy by liquid lumber movements. The specification of TLDs is designed to be compatible with structural characteristics and the liquid frequency adjusted to structure natural frequencies (Deng and Tait 2009, Morava, Haskett et al. 2012, Love and Tait 2013). TLD system was first used to control sea wave vibrations in oceangoing ships in the early 20th century. TLD was also used in satellites to control the fluctuations and free motions with the high time period in the second half of the 20th century (Li and Tang 2017, Javidialesaadi and Wierschem 2018). Considering that TLDs are designed so that their principal fluctuation should be equal to the structure vibration frequencies. There are also many fluctuations and excitation in underneath water at the tanks with high depth (Love and Tait 2019, Colucci, De Simone et al. 2020). However, due to the participation of almost all liquid mass in fluctuations in shallow tanks, the amount of damping and energy dissipation there is higher in shallow tanks; accordingly, shallow tanks are used as a TLD in order to achieve more dissipation (Li, Li et al. 2002, Ikeda and Harata 2017). Modelling of nonlinear water waves through intense dynamic excitations in a tank is the most important issue at TLDs. In this respect, (Fujino, Sun et al. 1992) developed a two-dimensional nonlinear model to the movement of liquid with low depth in quadrilateral tanks. The results of the harmonic loading of a structure equipped with liquid dampers showed high consistency with this model. Furthermore, (Banerji, Murudi et al. 2000) showed that, if TLD parameters are correctly selected, this system can influentially control seismic responses of structures. In this study, sun shallow water theory (Sun, Fujino et al. 1992) was used for numerical modelling. The most previous laboratory tests on TLDs were conducted with small domain base motions (Koh, Mahatma et al. 1994, Li, Li et al. 2002). However, (Li, Yin et al. 2003) accomplished some research on multilateral liquid dampers to control seismic responses of tall structures. In their modelling, the dynamic pressure of the liquid fluctuating inside the tank was obtained using the fluid volume method. The structure’s response was obtained based on solving the state equations. (Li, Yin et al. 2003) observed an approximately 40 % decrease at the structure displacement in the numerical model and experimental work. Furthermore, (Banerji 2004) experimented with a series of single degree of freedom structures equipped with a liquid damper and showed that this damper is influential in controlling the structure response with broad-banded excitations. Furthermore, in these experiments, it was shown that depth and mass ratio were truly influential parameters in the liquid damper.

In many previous studies, TMDs and TLDs were employed separately to assess structural responses with various characteristics. Furthermore, these devices were considered only with regard to far-field or near-field ground motions. The main aim of the present study was a comparison of the efficiency of TMDs and TLDs in short and medium height buildings. To investigate the effect of change in the ground motion characteristics, selected records were sorted in near-field and far-field in time history analyses, and the performance of each damper was evaluated separately. Finally, the change in the specification of each damper using five various mass percentages was studied.

2 Optimum parameters of dampers

The primary purpose in the design of TMDS and TLDs is the determination of parameters, mass, damping, and stiffness appropriate for each structure. The performance of these dampers depends both on its parameters and on the entered loading. Therefore, it is necessary to determine proper and optimal parameters for a significant decrease in the structural response to earthquake load. In previous research, different methodologies and equations have been introduced to optimize the design of these dampers in structures with linear behaviour (Den-Hartog 1947, Villaverde 1985, Sun, Fujino et al. 1992, Sadek, Mohraz et al. 1997). In this paper, the methods proposed by (Sadek, Mohraz et al. 1997) and (Novo, Varum et al. 2014) was used to calculate optimum parameters of TMDs and TLDs, respectively.

2.1 Equations of the tuned mass damper

(Sadek, Mohraz et al. 1997) suggested some equations for optimum TMD parameters under the excitation of the earthquake by modifying (Villaverde 1985) method. The investigation of (Villaverde 1985) method illustrated that the structure’s damping ratio to the mass damper at the first two modes would not be equal in mass ratios of above 0.005. Therefore, Sadek et al. (1997) obtained the optimal amounts of frequency and damping ratios to minimize the difference between damping of the first two modes of structure and damper. The authors achieved optimum ratios for systems with 0.02 and 0.05 amounts of damping and 0.005 to 0.15 mass ratios of the damper. Eq. (1)-(2) were suggested for single degree of freedom system:

$$f = \frac{1}{1+\mu}\left[1 - \beta\sqrt{\frac{\mu}{1+\mu}}\right] \tag{1}$$

$$\xi = \frac{\beta}{1+\mu} + \sqrt{\frac{\mu}{1+\mu}} \tag{2}$$

where $f = \omega_t/\omega_s$ (tuning ratio) is denoted as the ratio of the fundamental frequency of the TMD to the fundamental frequency of the structure. $\xi = c/2m\omega_t$ is TMD damping ration $\beta = \frac{C}{2M\omega_s}$ is the structural damping ratio. $\mu = \mathrm{m}/\mathrm{M}$ is the mass ratio of damper (m) to structure (M). The errors of Eq. (1)-(2) are 0.2 % and 0.4 %, respectively.

Figure 1 illustrates the optimum variables of frequency and damping ratios for various mass ratios and three structural dampings. Figure 1 demonstrates that, by increasing structures damping ratios, the tuning ratio decreases, while the TMD damping increases. This figure could also use to determine the tuning and damping ratios.

To study the usefulness of the suggested method in the determination of TMD parameters for seismic excitations, (Sadek, Mohraz et al. 1997) investigated 30 SDOF structures with the time period between 0.1 to 3 seconds. The structures had damping ratios between 2% and 5 %, and 52 ground motion records were used in numerical analyses. (Sadek, Mohraz et al. 1997) achieved the following results:

- The structure equipped with a mass damper decreased displacement response and structure's acceleration, and this reduction was remarkable in the damper with 2% damping ratio.
- Increasing mass ratios decreased the structure response.
- The mass damper had more influence on the structures with a low damping ratio.
- While the damping of the damper was low, its movement was high in comparison with the structure, and this issue should be considered in the design.
- (Sadek, Mohraz et al. 1997) presented equations for optimum parameters of the damper in multi-degree of freedom structures as well; in this way, these structures' mass ratio (Eq. (3)) is considered as the damper mass ratio to the main structure mass.

$$\mu = \frac{M}{\emptyset_1{}^T \mathbf{M} \emptyset_1} \tag{3}$$

where **M** and $\emptyset_1$ is mass matrix and eigenvector, respectively.

Numerical investigations on a 3-story structure with zero damping ratio, 6-story structure with 5% damping ratio, and 10-story structure with 2% damping ratio showed that the tuning ratio, f, for an MDOF structure with μ mass ratio is equal to the tuning ratio of an SDOF structure with φμ mass ratio (φ is the amplitude of the first mode of vibration for a unit modal participation factor computed at the location of TMD).

Equations 3 and 4 are presented the tuning ratio and mass ratio respectively.

$$f = \frac{1}{1+\mu\varphi}\left[1 - \beta\sqrt{\frac{\mu\varphi}{1+\mu\varphi}}\right] \tag{4}$$

The damping optimum ratio is equal to the damping ratio of an SDOF system for an MDOF system φ.

$$\xi = \varphi \left[\frac{\beta}{1+\mu} + \sqrt{\frac{\mu}{1+\mu}} \right] \tag{5}$$

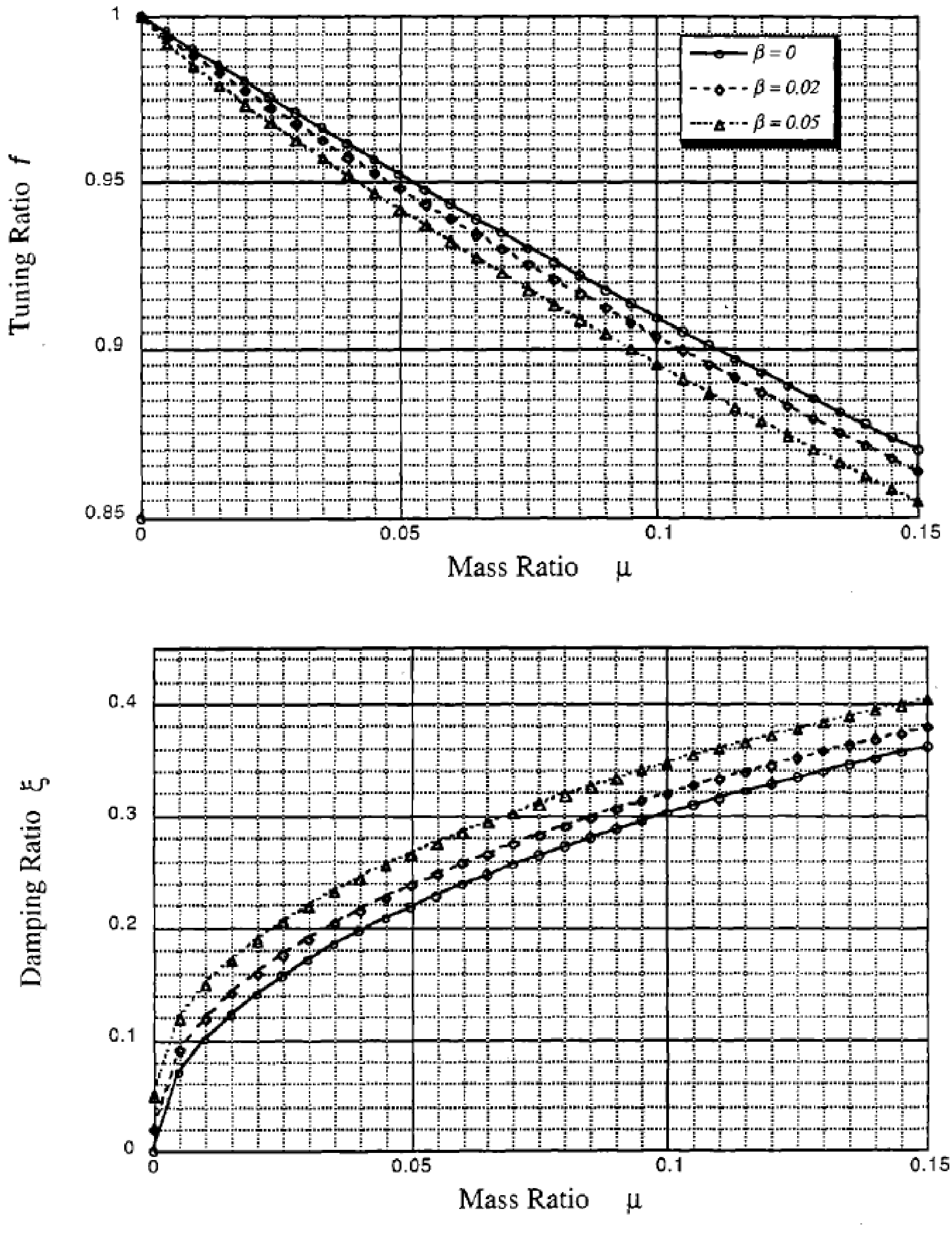

Figure 1 - *Optimum TMD parameters for various damping and mass ratios (Sadek, Mohraz et al. 1997)*

2.2 Equations of tuned liquid damper

Several methods, such as the mass aggregation approach and linear wave theory, have been proposed for simulation of TLDs. In these methods, the walls of TLDs were assumed to be rigid. Hydrodynamic pressure stood by liquid sloshing in the tank, as the dynamic loading was assumed separately as impulsive pressure and sloshing pressure. The impulsive pressure was proportional to the tank acceleration, but in the opposite direction. Sloshing pressure depends on wave height and viscosity frequency of liquid. Therefore, both hydraulic pressures can simulate by two equivalent masses linked to the tank (Novo, Varum et al. 2014).
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Figure 2 shows a schematic representation of the lumped mass model where M_0 is rigid mass connected to the tank at an elevation H_0 and $M_1$is impulsive mass connected to springs with stiffness k at an elevation H_1. (Newmark and Rosenblueth 1971) and Jin et al. (Jin, Li et al. 2007) presented Eq. (6)-(9) for estimation of these parameters.

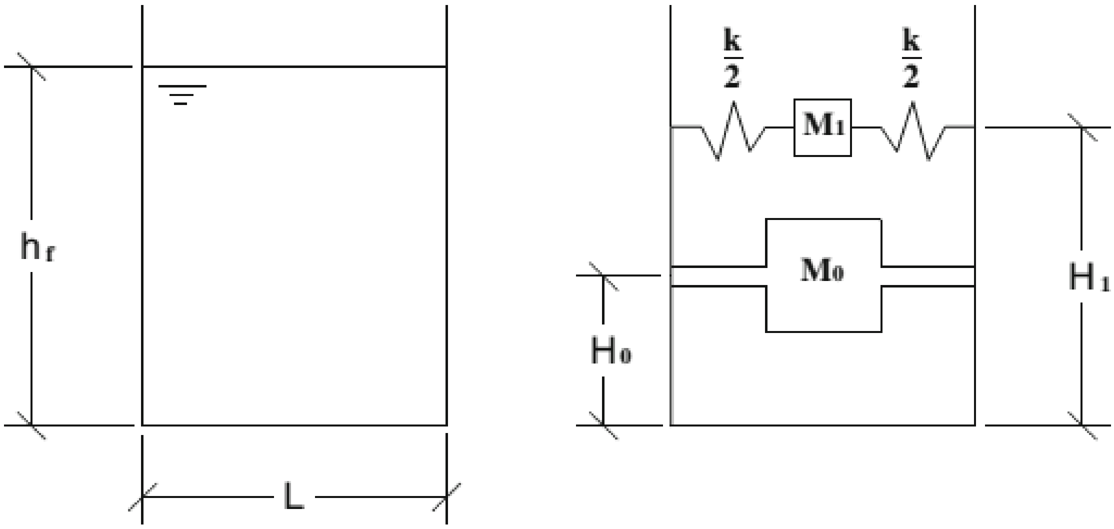


Figure 2 - *Model of lumped mass for rectangular TLD (Novo, Varum et al. 2014)*

$$\mathrm{M}_0 = \frac{\tanh(1.7(\frac{\mathrm{L}}{2})/\mathrm{h_f})}{1.7(\frac{\mathrm{L}}{2})/\mathrm{h_f}}\mathrm{m_f} \tag{6}$$

$$M_1 = \frac{0.83\ .\ tanh(1.6h_f/(\frac{L}{2}))}{1.6*h_f/(\frac{L}{2})}\mathrm{m_f} \tag{7}$$

$$H_0 = 0.38\,.\,h_f.\left[1+\alpha\ \left(\frac{m_f}{M_0}-1\right)\right] \tag{8}$$

$$H_1 = h_f.\left[1-0.33.\ \frac{m_f}{M_1}.\ \left(\frac{L/2}{H_f}\right)^2 +\ 0.63.\beta.\frac{(\frac{L}{2})}{h_f}.\ \sqrt{0.28.\left(\frac{m_f.\ L/2}{M_1.\ h_f}\right)^2}\right] \tag{9}$$

where m_f is the interior liquid mass of each tank, $\beta = 2$ and $\alpha = 1.33$ are parameters due to hydrodynamic moment on the tank base, h_f, and b, and L are liquid height and tank dimensions, respectively.

3 Definition of the structural model

In this paper, 4 and 12-story buildings with a special steel moment frame system and residential occupancy were considered. The buildings were located in a zone with a very high level of relative seismic hazard. Dimensions of buildings in the plan were 20×15 m, and their story's height was considered to be 3.3 m. The resisting system against earthquakes was a special moment frame. Plan and structure fronts are shown in Figure 3. Iranian National Building Code part 6 (Loads in Buildings) was used in order to estimate gravity loading. The structures were designed according to ANSI/AISC 360-10 and ANSI/AISC 341-10. Further design details can be found in (Shokrgozar, Mansouri et al. 2018). Table 1 lists the designed structural elements.

The first-mode period of 4- and 12-story buildings amounted to 0.921 and 1.87 seconds, respectively. Likewise, the total mass of structures was 207 and 635.25 tons.

Table 1 – *Cross sectional properties of modelled stuctures*

Building	Story No.	Column	Beam
4-story	1, 2	Box 240x240x30	IPE 400
	3, 4	Box 240x240x20	IPE 360
12-story	1 ~ 6	Box 300x300x30	IPE 550
	7, 8	Box 300x300x25	IPE 500
	9	Box 300x300x25	IPE 450
	10	Box 260x260x30	IPE 450
	11	Box 260x260x30	IPE 300
	12	Box 220x220x20	IPE 300

4 Designing and modelling of dampers

4.1 Tuned mass damper

The mass is one of the most important parameters in the design of TMDs. Typically, damper's mass is computed as a percent of whole structure's mass (see Eq. (10)).

$$\mathrm{m_d} = \mu \times \mathrm{m_s} \tag{10}$$

where μ and m_s indicate mass ratio and total mass of the structure, respectively.

The damper stiffness is another influential parameter at the modelling of TMDs. Eq. (11) was proposed by (Zahrai and Ghannadi-Asl 2008).

$$k_\mathrm{d} = 4\pi^2 \mu f^2 \frac{m_s}{\mathrm{T_s}^2} \tag{11}$$

where T_s and f are the main time period of the structure and the TMD tuning ratio, respectively.

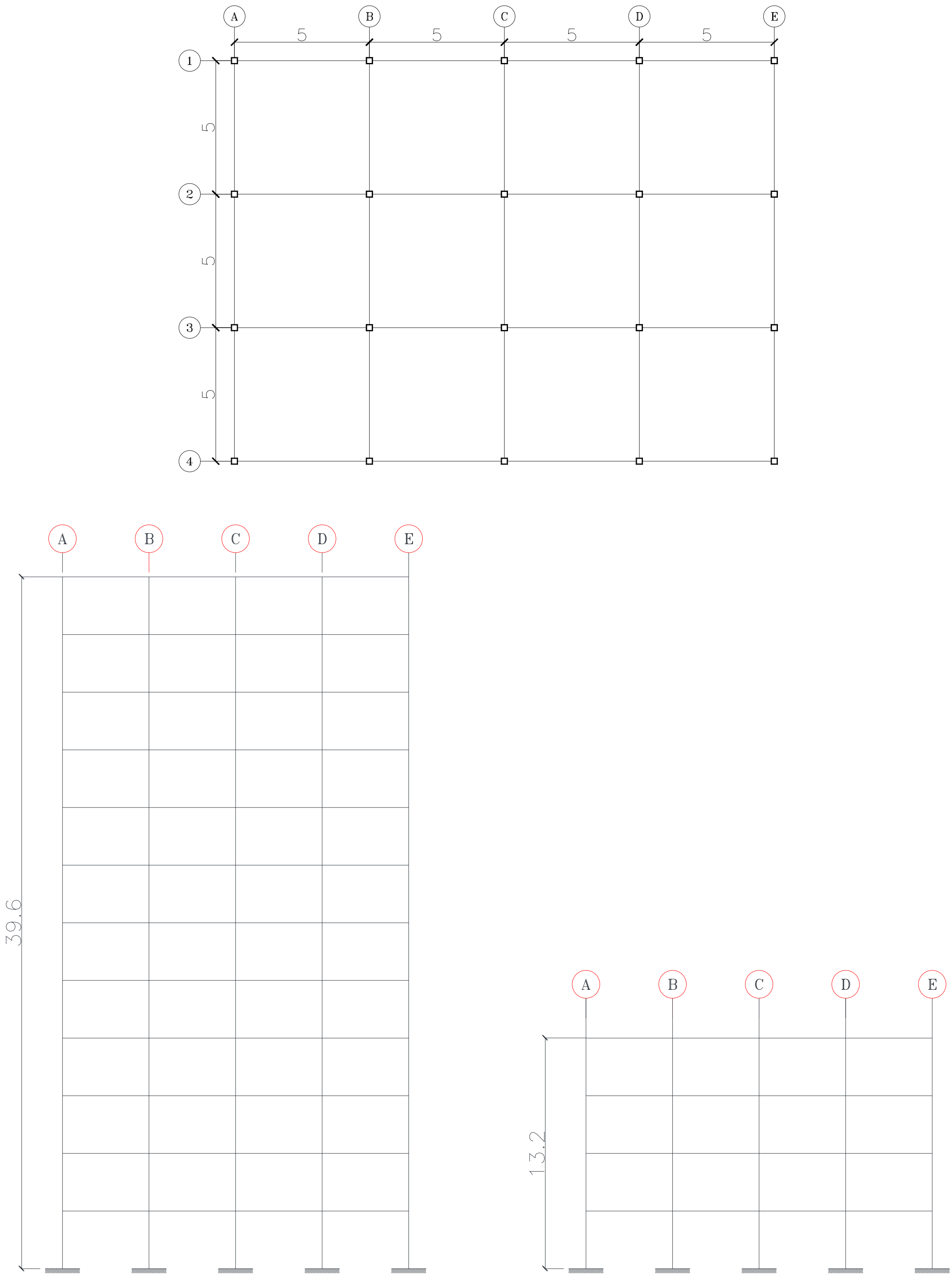


Figure 3 - *Plan and views of 4- and 12-story buildings*

TMD tuning ratio is considered according to the MDOF relation (Eq. 4). The last influential parameter on the behaviour of this kind of dampers is the damping factor. Equation 12 has also been proposed by (Zahrai and Ghannadi-Asl 2008)

$$c_{\mathrm{d}} = 4\pi\mu f\xi\frac{m_s}{\mathrm{T_s}} \tag{12}$$

where ξ is called a TMD damping ratio. This ratio is considered according to the MDOF relation (Eq. 5). In this paper, five structural models for each building with mass ratios 1, 3, 5, 7, and 9 percent were used. The TMD was located at the last story. The specifications of mass dampers by different mass ratios are presented in Table 2.

4.2 Tuned liquid damper

The sloshing frequency of the fluids is one of the significant parameters on the performance of TLs, which can be obtained using Eq. (13) (Novo, Varum et al. 2014).

$$f_f = \frac{1}{2}\sqrt{\frac{g}{\pi.L}tanh\left(\frac{\pi.h_f}{L}\right)} \tag{13}$$

In this paper, the sloshing frequency of the fluid was considered to equal the first natural frequency of buildings. The first natural frequency of 4 and 12 stories building were 1.085 and 0.534 Hz, respectively.

Table 2 - *Properties of TMD*

Location of damper	μ	k_d (kg/s^2)	c_d (kg/s)
4th story	0.01	93784.5	3600.52
	0.03	269376	16342.9
	0.05	430781	32957.6
	0.07	579442	52011.6
	0.09	716539	72759.3
12th story	0.01	69813.8	5441.99
	0.03	200525	24701.4
	0.05	320677	49813.5
	0.07	431341	78612.6
	0.09	533397	109972

The damping of surface wave in a rectangular tank can be calculated using Eq. (14) (Novo, Varum et al. 2014):

$$\zeta_f = \sqrt{\frac{v_f\omega_f}{2}}.\left[1+\left(\frac{2.h_f}{b}\right)+S\right].\frac{L}{h_f\sqrt{g.\ h_f}} \tag{14}$$

where v_f is liquid kinematic viscosity, and S is a surface contamination factor that can alter between 0 and 2. In this study, S was assumed to equal to 1.0, which corresponds to a thoroughly contaminated surface. Therefore, damping factor and substitute stiffness of each tuned liquid damper can be obtained as shown in Eq. (15)-(16), respectively (Novo, Varum et al. 2014).

$$C = 2m_f \omega_f \, \zeta_f \tag{15}$$

$$k = \frac{3.\ g.\ {M_1}^2 h_f}{m_f L^2} \tag{16}$$

The number of required tanks (*N*) can be determined using Eq. (17) (Novo, Varum et al. 2014).

$$N = \frac{\mu\ .\ m_s}{m_f} \tag{17}$$

where m_s is the total mass of structure in vibration mode, and m_f is the mass of fluid in each tank (see Eq. (18) (Novo, Varum et al. 2014).

$$m_f = \rho . h_f . b . L \tag{18}$$

where ρ, h_f, b and L are fluid density (1000 kg/m^2), fluid depth, width, and length of the tank, respectively. The TLDs characteristics and the number of required tanks for five various mass percent (1, 3, 5, 7 and 9 percent) in this study are summarized in Tables 3-4.

Table 3 - *Properties of TLD*

		4-story	12-story
Dimension of tank (m)	h_f	0.0436	0.18
	Building	1	1
	L	0.291	1.202
m_f (kg)		12.68	216.36
fζ		0.03931	0.01535
M_0 (kg)		2.23	37.41
M_1 (kg)		9.78	167
k (kg/s^2)		114.46	472.6
C (kg/s)		6.79	22.27

Table 4 - *Number of estimated tanks for different mass ratios*

4-story	µ (%)	1	3	5	7	9
	N	163	490	816	1143	1469
12-story	µ (%)	1	3	5	7	9
	N	29	88	147	205	264

4.3 Dampers mechanical modeling

In this paper, the SAP2000 software was used for the modelling of dampers. TMDs and TLDs were modelled using the link element as shown in Figures 4 and 5, respectively. The TMD mass was assigned as a concentrated mass at node 1. The TLD rigid mass was assigned to nodes 1 and 3, and the impulsive mass was assigned to node 2.

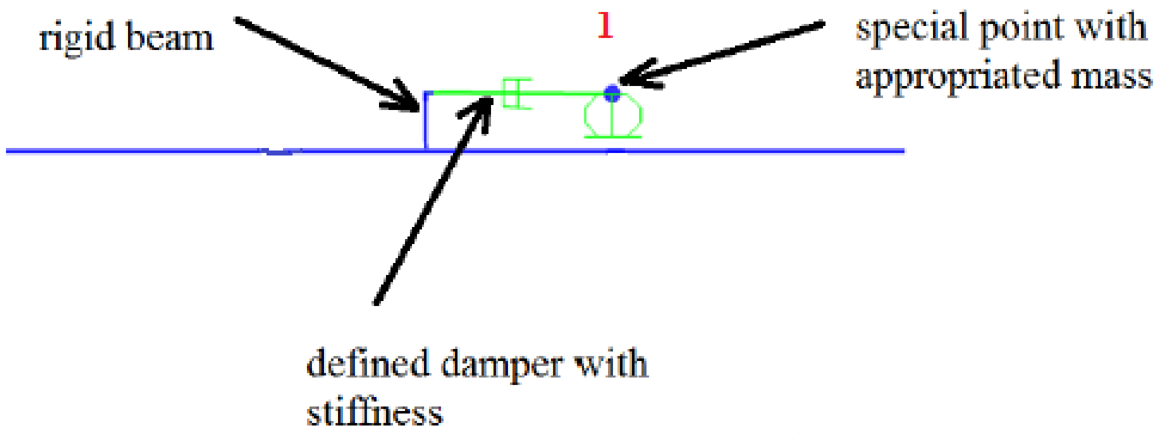


Figure 4 - *Macro-model applied to TMD*

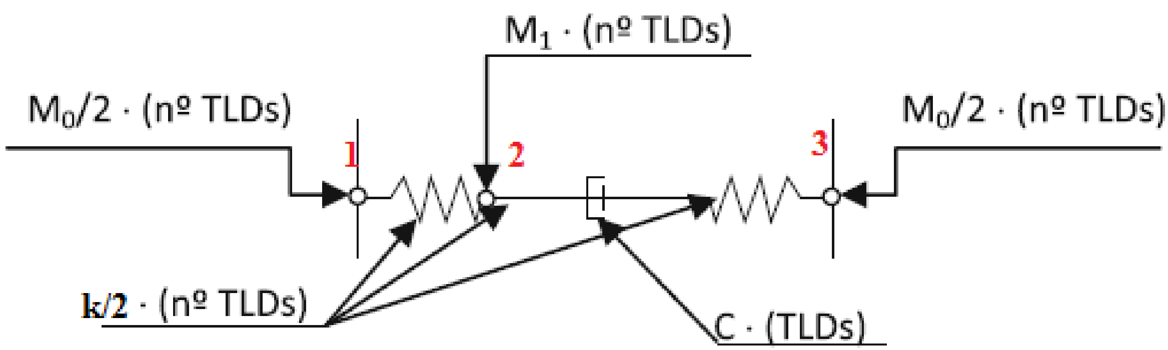


Figure 5 - *Macro-model of TLD*

5 Linear time history analysis

In this paper, the seismic response of all structures was calculated using linear time history analysis (LTHA). LTHA is a step-by-step process where the loading and the response histories are measured at each time step. The direct integration method is selected at a time history type. The number of time step is varied between 20 to 30 seconds depended to each ground motion duration. The roof acceleration, velocity, displacement, and total base shear forces in the uncontrolled models and the controlled models by TM and TL dampers and uncontrolled models were estimated. The mentioned moment resisting frames were subjected to two sets of selected earthquakes. The selected earthquakes were separated into near-field and far-field ground motions. All earthquakes were of magnitude above six, and near-field sets had short epicentral distances of less than 20 km. The properties of selected earthquakes are summarized in Table 5.

6 Evaluating the results of LTHA

The structural responses in an elastic system are continually changing from zero up to the positive peaks, or through zero to the negative peaks and then back to zero again. Clearly, for most of the time, it is less than the peak. The peak of structural responses ignores information on the duration of responses and response time history. Root mean square (RMS) of responses is coupled with the response duration and describes its properties during the entire duration. The peak response is not a good measure of its real effect. Instead, RMS of responses used for describing the response properties. It is also clear that the control effectiveness is generally better for root-mean-square (RMS) responses as opposed to peak responses (the peak response occurs just in a moment). Therefore, in order to illustrate the efficiency of TMD and TLD, the root mean square (RMS) of each structure response was estimated and compared. The root mean square was calculated as follows (see Eq. (19)):

$$Y_{RMS} = \sqrt{\frac{\sum_{i=1}^{i=n} {y_i}^2}{n}} \tag{19}$$

where y_i is the structural response in time t_i and n shows the number of time steps in which the structure response is estimated. The results of acceleration, velocity, displacement and base shear responses of all models are extracted and used to compare the control-ability of TMD and TLD. Figures 6 and 7 show the time history of acceleration and velocity of 4-story buildings, respectively. Figures 8 and 9 also illustrated the time history of roof displacement and base-shear force of 12-story building, respectively. In these figures, the mass ratio is 1 percent.

Table 5 - *Properties of selected ground motion*

Type of record	Earthquake	Station	Year	M_w	Distance to field rupture (km)
Far-field	Kobe	Nishi-Akashi	1995	6.9	28.7
	Superstition Hills	EL Centro Imp. Co.	1987	6.5	35.8
	Hector Mine	Hector	1999	7.1	26.5
	San Fernando	LA - Hollywood Stor	1971	6.6	39.5
	Friuli	Tolmezzo	1976	6.5	20.2
	Manjil	Abbar	1990	7.4	40.4
	Landers	Yermo Fire Station	1992	7.3	23.6
Near-field	Loma Prieta	Saratoga-Aloha	1989	6.9	17.2
	Cape Mendocino	Petrolia	1992	7	4.5
	Northridge	Sylmar-Olive View	1994	6.7	16.8
	Kocaeli	Izmit	1999	7.5	5.3
	Gazli,USSR	Karakyr	1976	6.8	12.8
	Chi-Chi	TCU084	1999	7.6	8.9
	Nahanni	Site2	1985	6.8	6.5

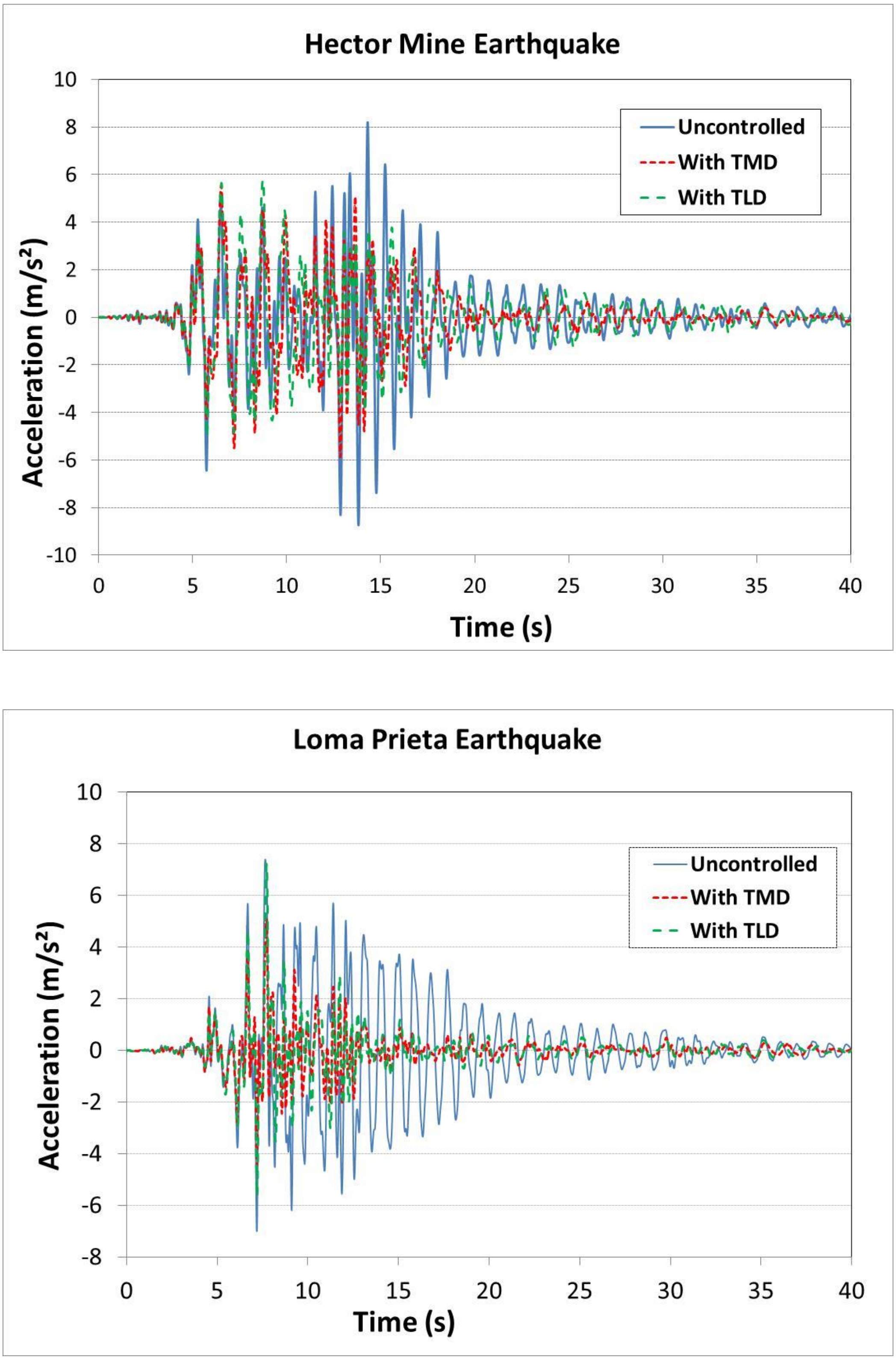
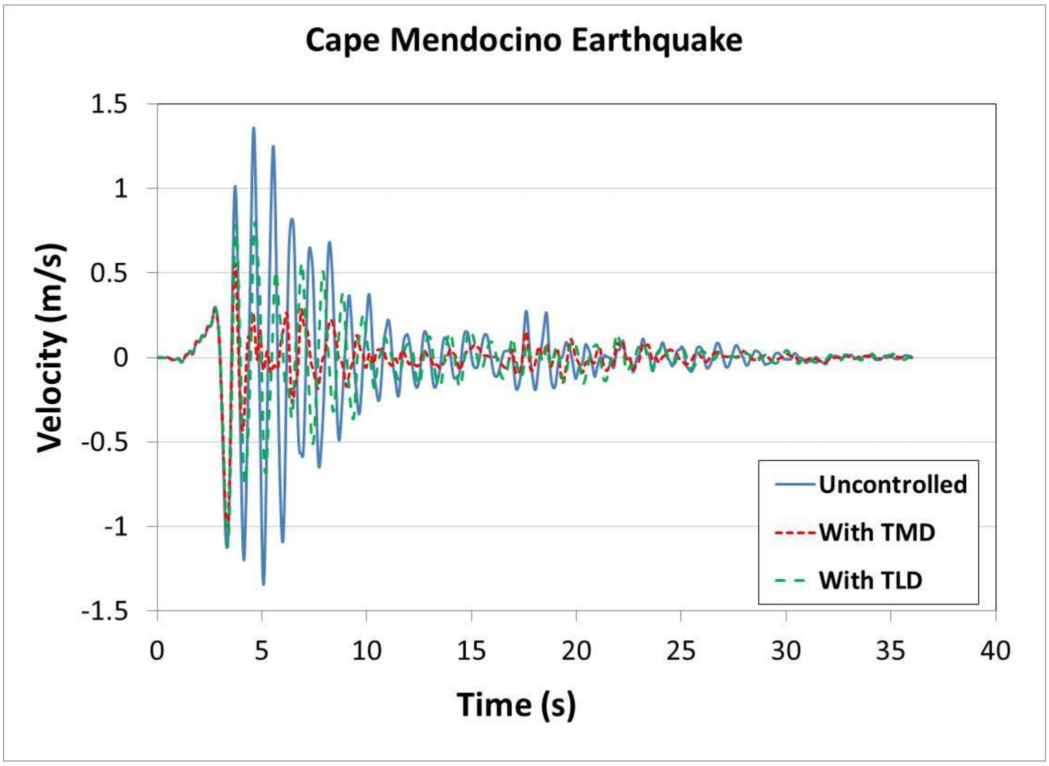


Figure 6 - *Acceleration time history of roof story of the 4-story building for controlled and uncontrolled states subjected to Hector Mine and Loma Prieta earthquakes*



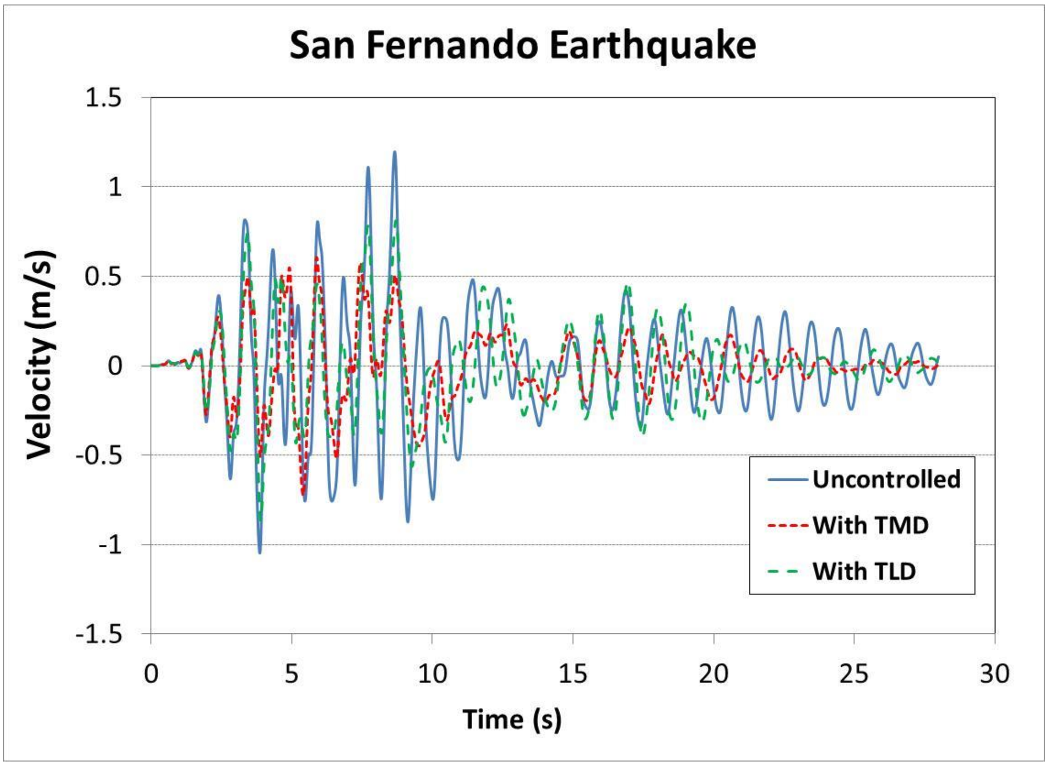


Figure 7 - *Velocity time history of roof story of the 4-story building for controlled and uncontrolled states subjected to San Fernando and Cape Mendocino earthquakes*

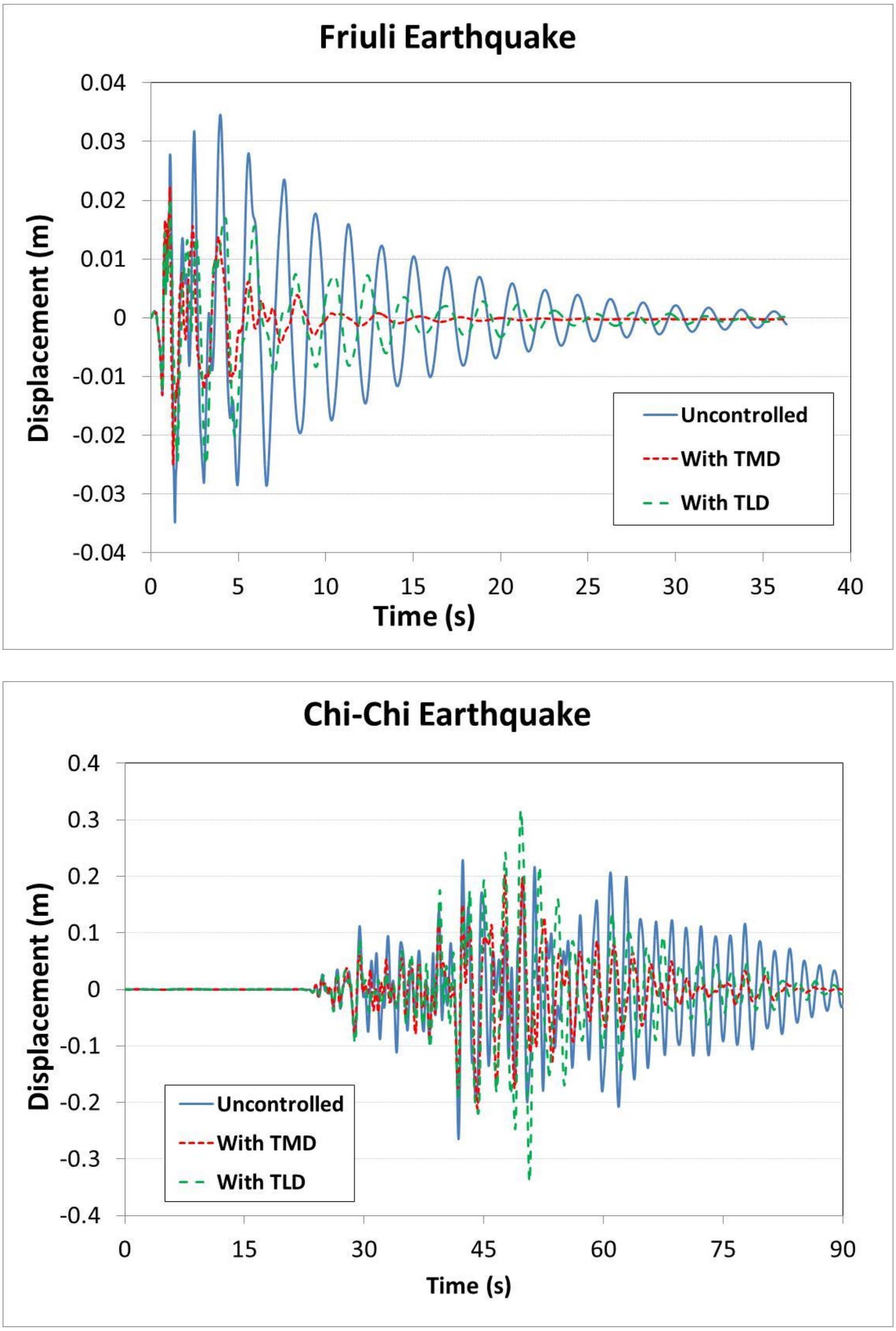


Figure 8. *Displacement time history of roof story of 12-story building for controlled and uncontrolled states subjected to Friuli and Chi-Chi earthquakes*

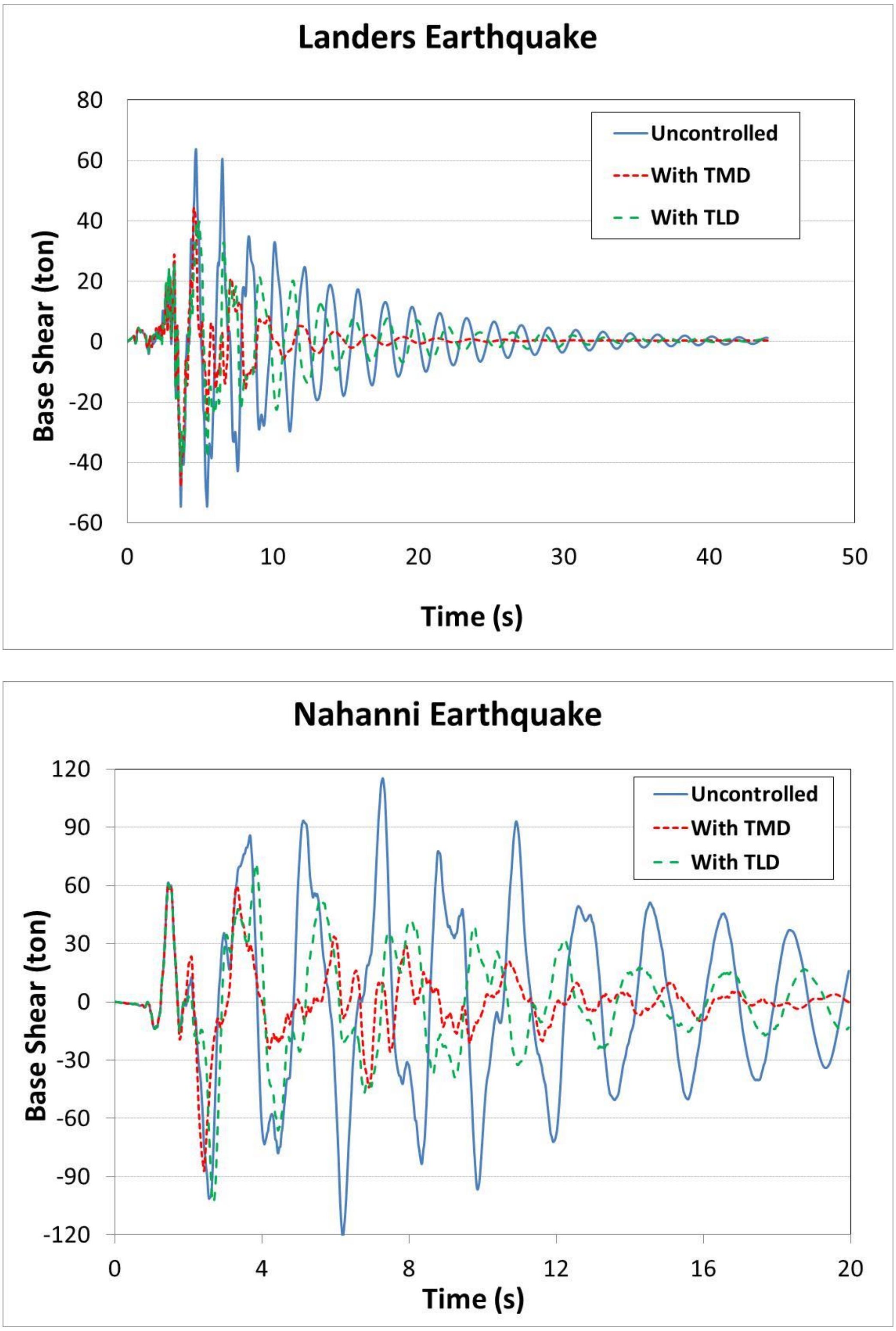


Figure 9 - *Base shear time history of the 12-story building for controlled and uncontrolled states subjected to Landers and Nahanni earthquakes*

As can be seen in Figures 6- 9, the performance of both TMD and TLD was suitable and noticeable in decreasing the structural responses of 4- and 12-story buildings. Moreover, it can be concluded that, to some extent, TMD has a better performance than TLD. The RMS ratio of structure responses with TMD and TLD to one without damper was proposed by Torki and Halabian (2010) to evaluate the tuned liquid and mass damper effect. In this study, the corresponding percent of changes (reduction or increment, Ψ) at RMS of acceleration, velocity, displacement, and base shear responses were calculated as follows (see Eq. (20)):

$$\Psi(\mathrm{Y}) = \frac{Y_{\text{with TMD or TLD}} - \mathrm{Y}_{\text{without TMD or TLD}}}{\mathrm{Y}_{\text{without TMD or TLD}}} \times 100 \quad (20)$$

In Figures 10-13, the corresponding percent changes of 4- and 12-story building responses, controlled with TMD, are shown under near-field and far-field earthquakes for different masses percent.

According to Figure 10, in the four-story building, the maximum reduction of the acceleration response was 59.3 and 70.3 percent subjected to near-field and far-field ground motions for 9 percent mass ratio, respectively. Likewise, the maximum reduction of at the velocity response was 31.2 percent in the far-field earthquake for a 5 percent mass ratio and 54.5 percent in the near-field earthquake with a 3 percent mass ratio. According to Figure 11, in the 4-story building, the maximum reduction at the displacement response was 27.8 and 57.5 percent in far-field and near-field earthquakes for a 1 percent mass ratio, respectively. These amounts for base shear response were 31.8 and 58.8 in far-field and near-field earthquakes, respectively.

According to Figure 12, in the 12-story building, the maximum reduction at the acceleration response was 73.9 percent under near-field and far-field earthquakes for 9 percent mass ratio. The maximum reduction at the velocity response was 41.6 percent under the far-field earthquake for a 3 percent mass ratio and 56.8 percent under near-field earthquake for 9 percent mass ratio. According to Figure 13, the maximum reduction at the displacement response achieved was 50.3 and 44.7 percent under far-field and near-field earthquake for a 3 and 1 percent mass ratio, respectively. These amounts for base shear response were 49.45 and 43.19 percent subjected to near-field and far-field earthquakes for a 3 percent mass ratio, respectively. Therefore, it can be safely concluded that TMD in near-field earthquakes demonstrates a better performance than in far-field earthquakes.

In Figures 14-17, the corresponding percent changes of 4- and 12-story building responses, controlled with TLD, are shown under near-field and far-field earthquakes for different masses percent.

According to Figure 14, in the 4-story building, the maximum reduction at the acceleration response was 37.8 and 58.5 percent subjected to near-field and far-field records for 9 and 5 percent mass ratio, respectively. Likewise, the maximum reduction at the velocity response was 17.6 percent under far-field earthquake for 1 percent mass ratio and 44.3 percent under near-field earthquake for 3 percent mass ratio, respectively. According to Figure 15, the maximum reduction at the displacement response was 12.1 percent under far-field earthquake for a 1 percent mass ratio and 35 percent under near-field for a 3 percent mass ratio. These amounts for base shear response were 17.2 percent under far-field earthquake for 1 percent mass ratio and 41.4 percent under the near-field earthquake for a 3 percent mass ratio.

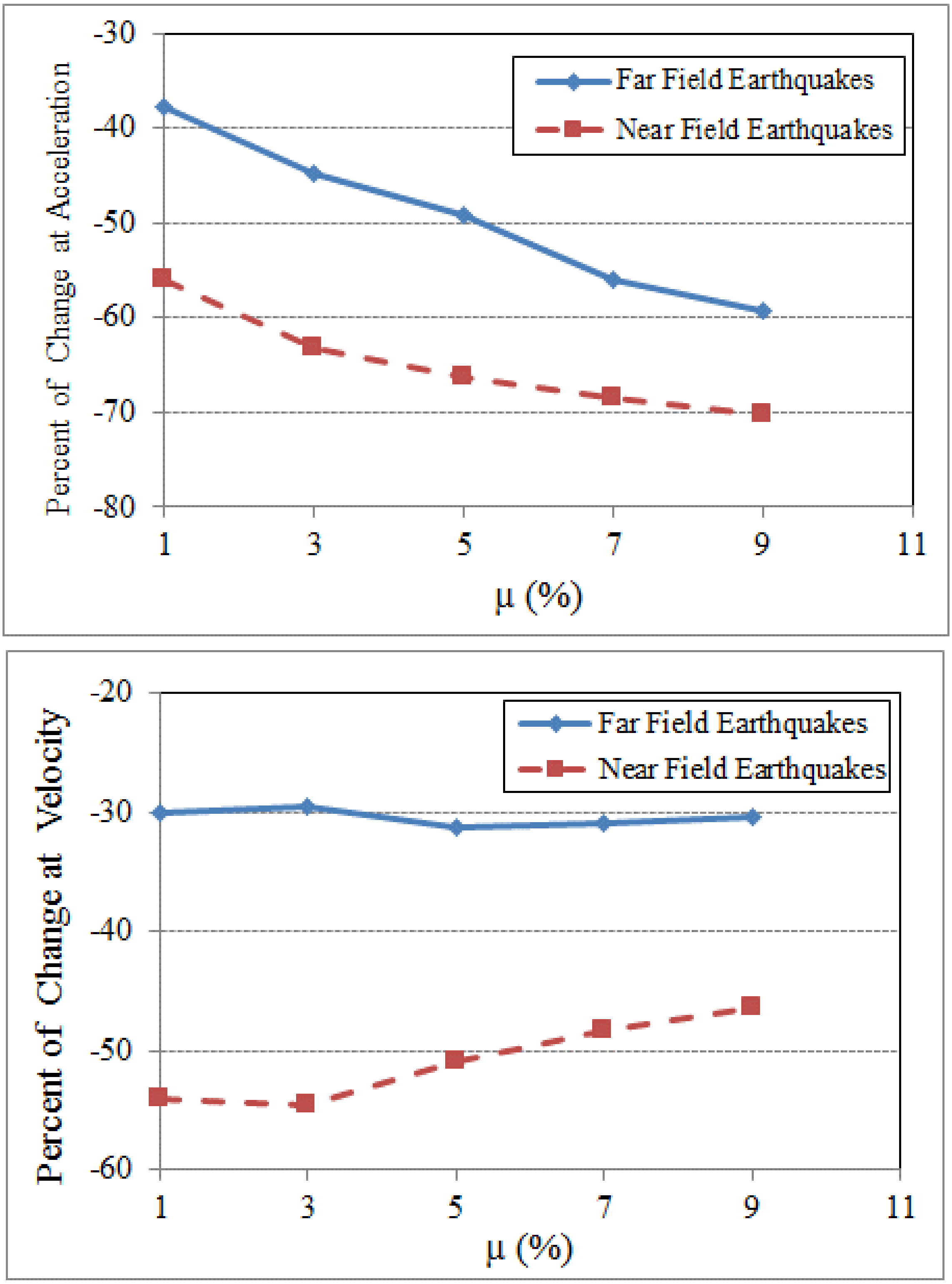


Figure 10 – *Percent of changes at acceleration and velocity of the 4-story building controlled by TMD subjected to far and near-field records*

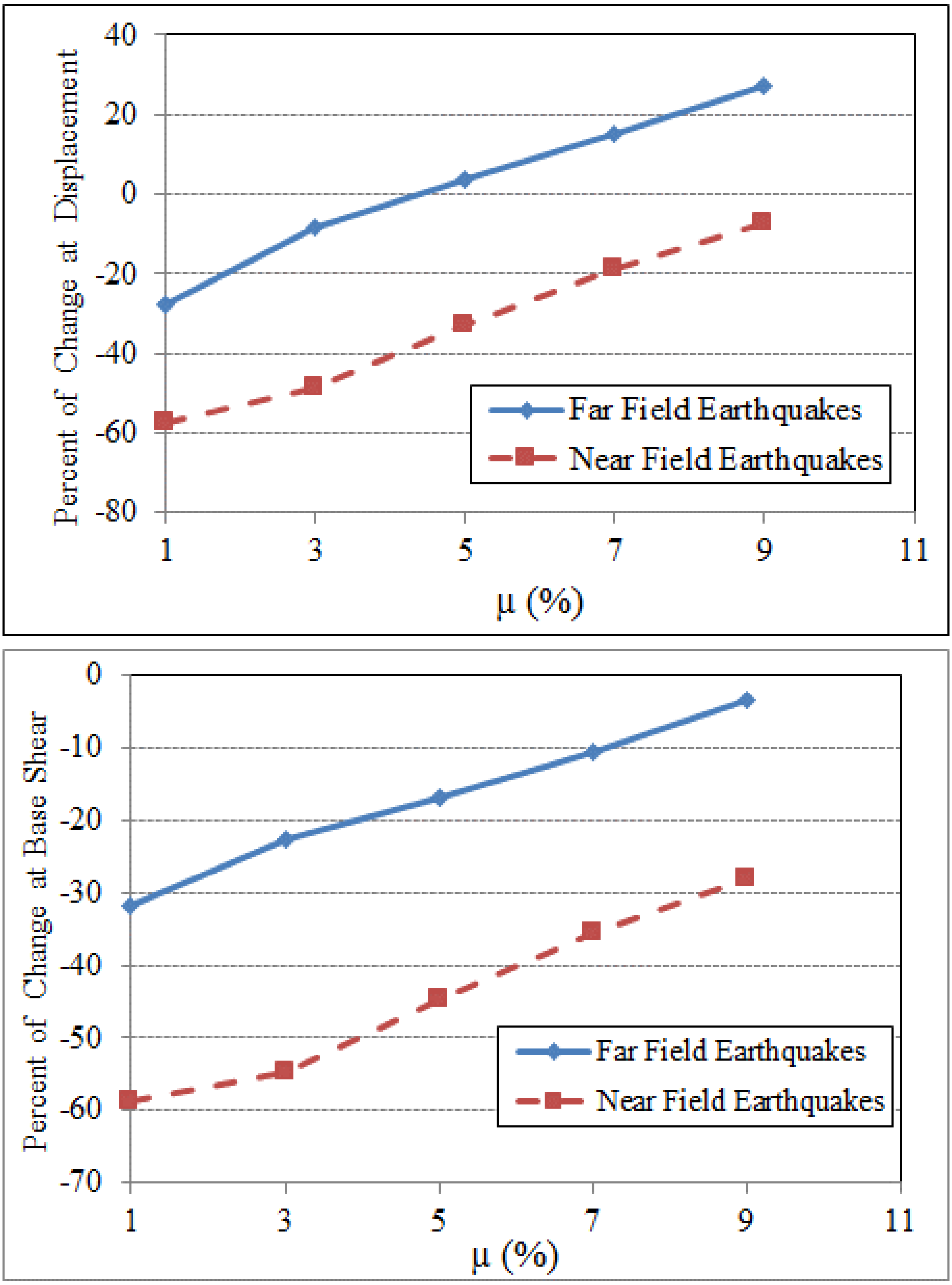
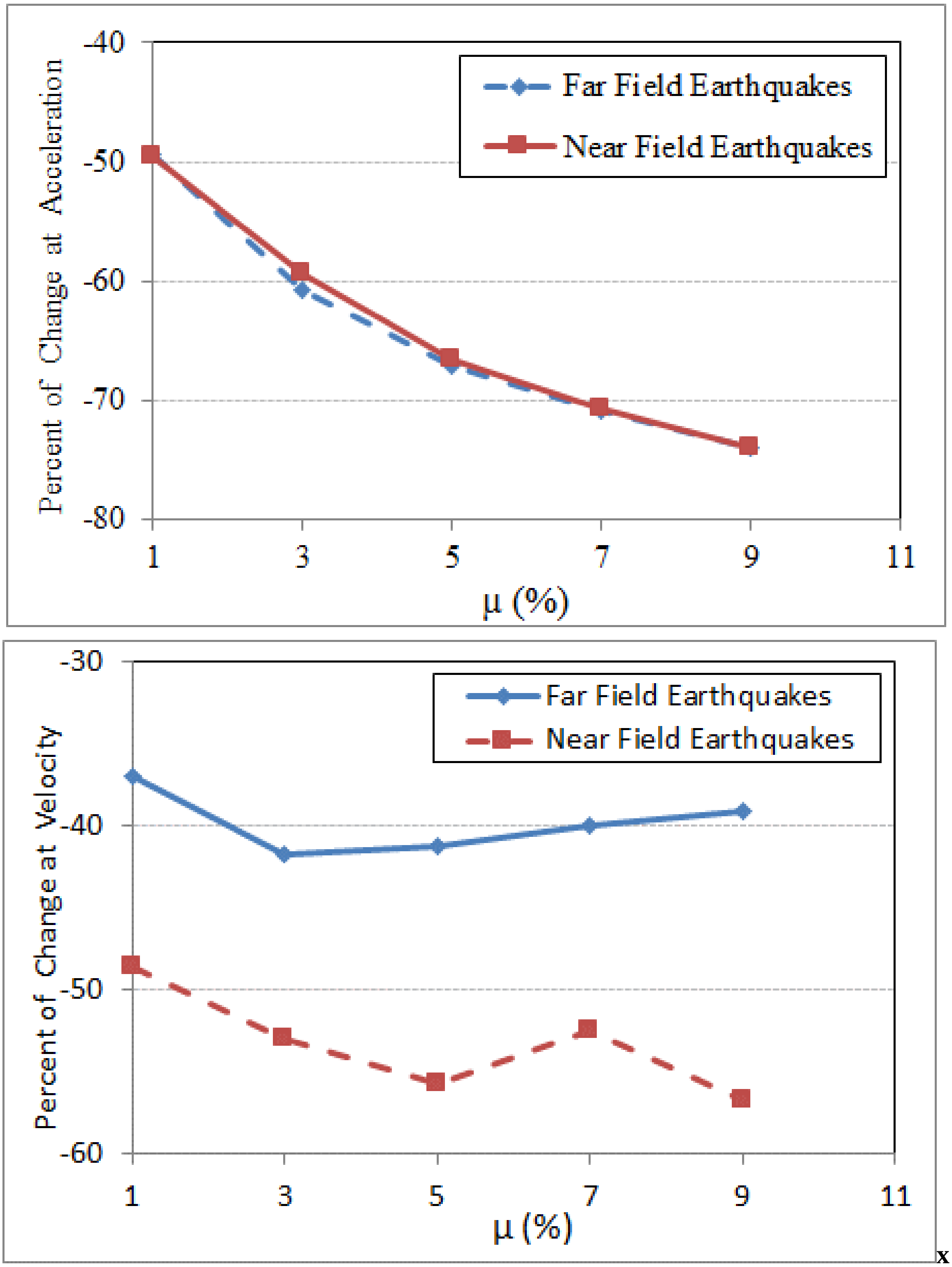


Figure 11 - *Percent of changes at displacement and base shear of the 4-story building controlled by TMD subjected to far and near-field records*



x

Figure 12 - *Percent of changes at acceleration and velocity of the 12-story building controlled by TMD subjected to far and near-field records*

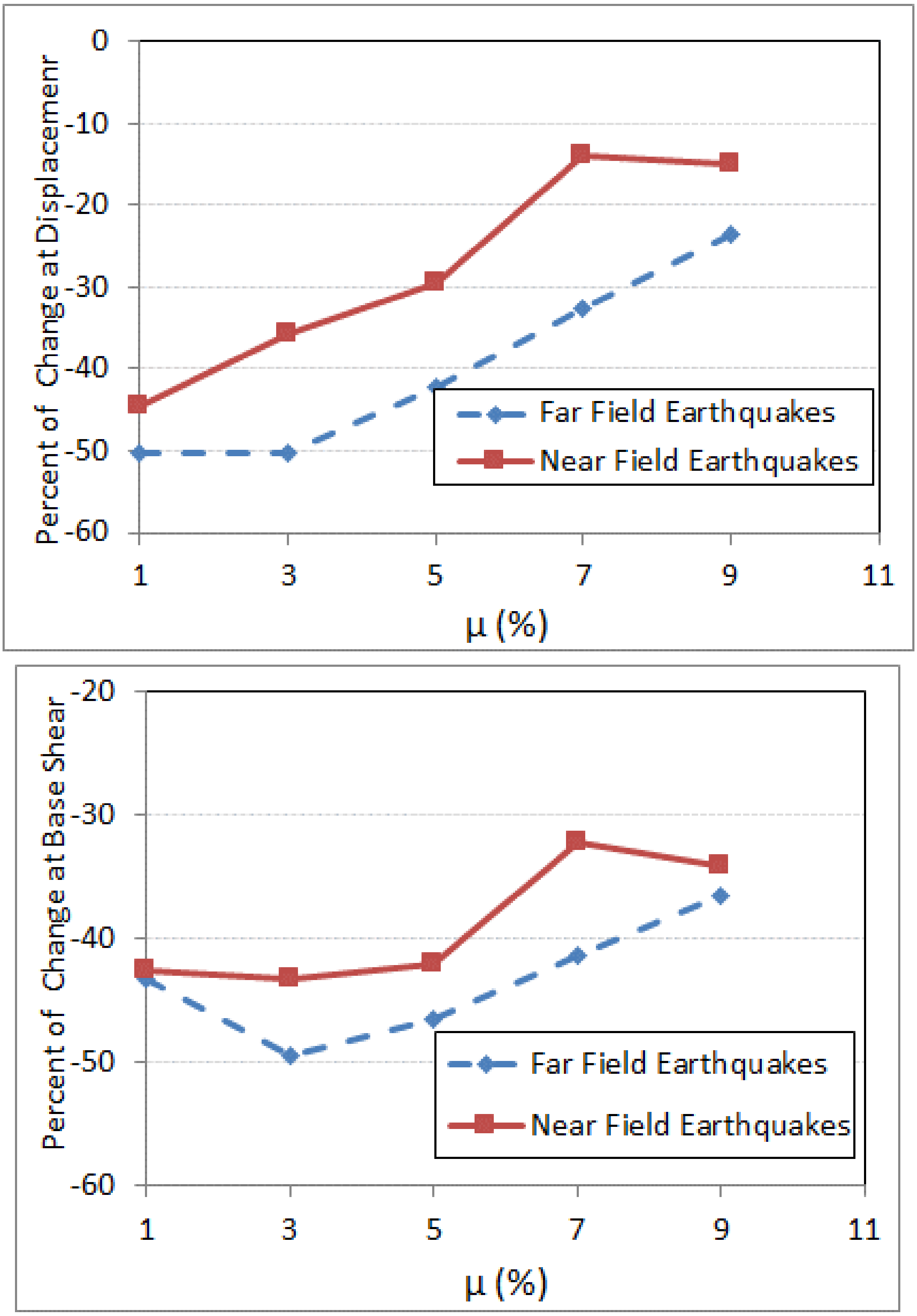


Figure 13 - *Percent of changes at displacement and base shear of the 12-story building controlled by TMD subjected to far and near-field records*

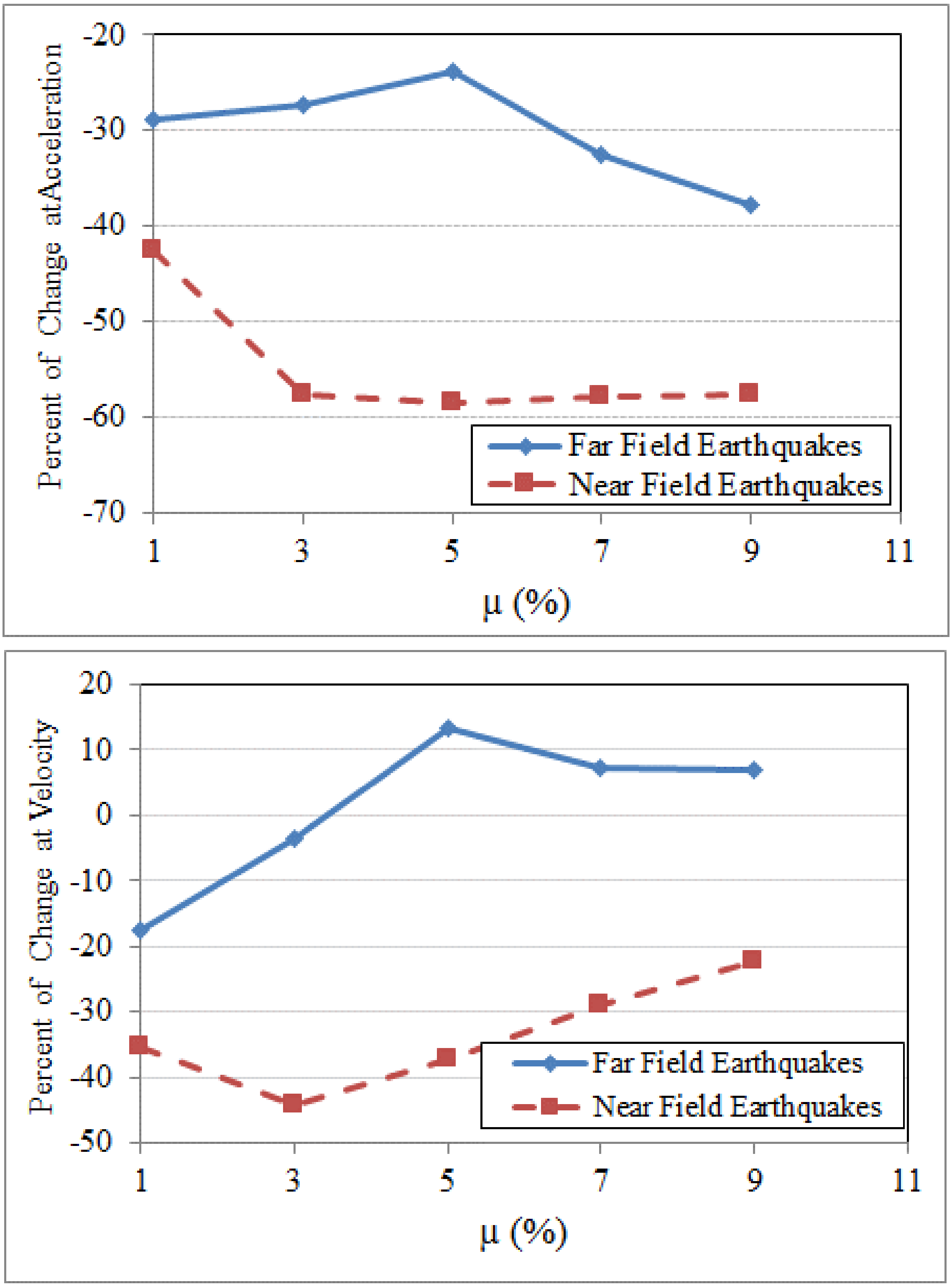


Figure 14 -- *Percent of changes at acceleration and velocity of the 4-story building controlled by TLD subjected to far and near-field records*

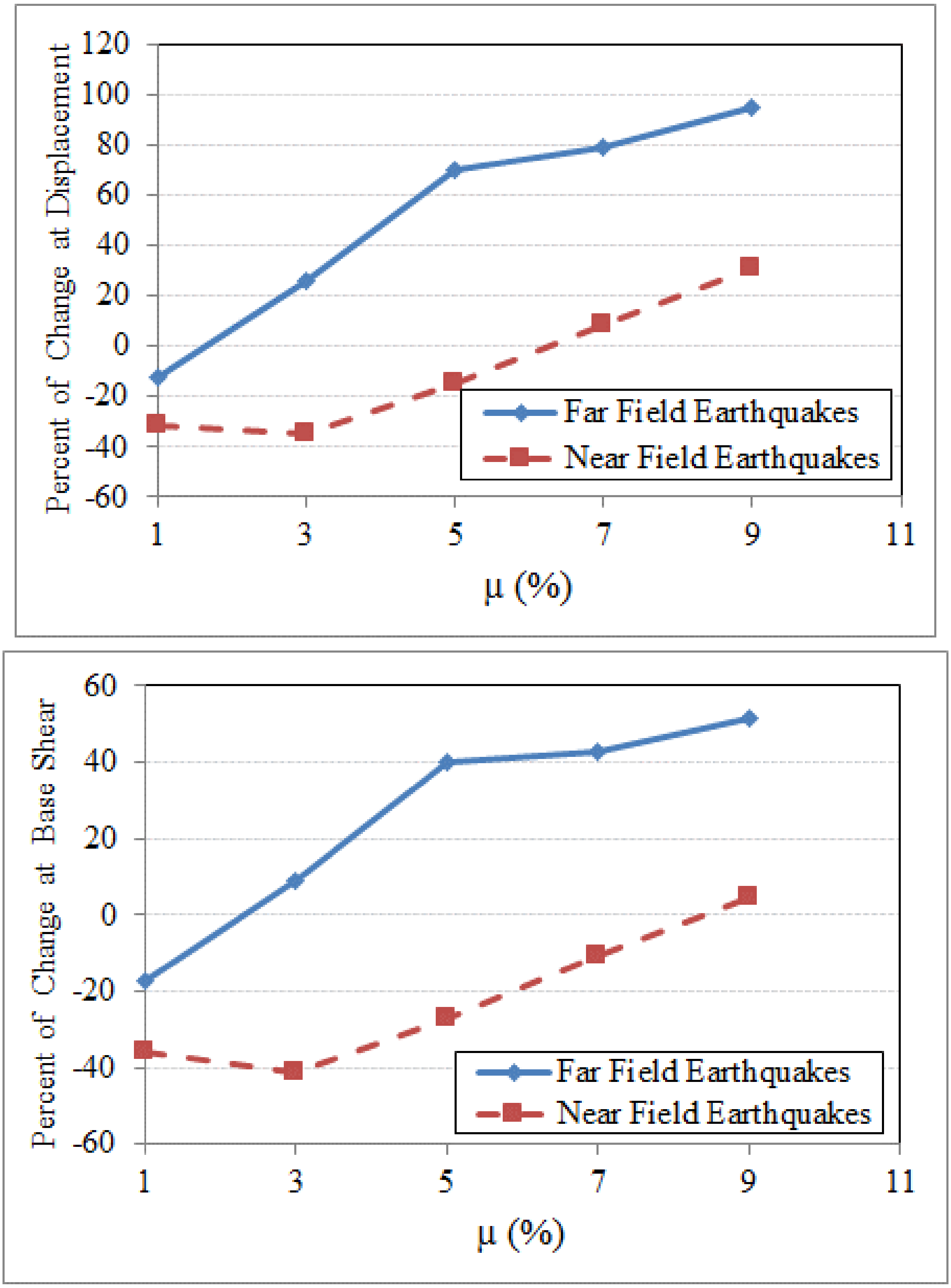
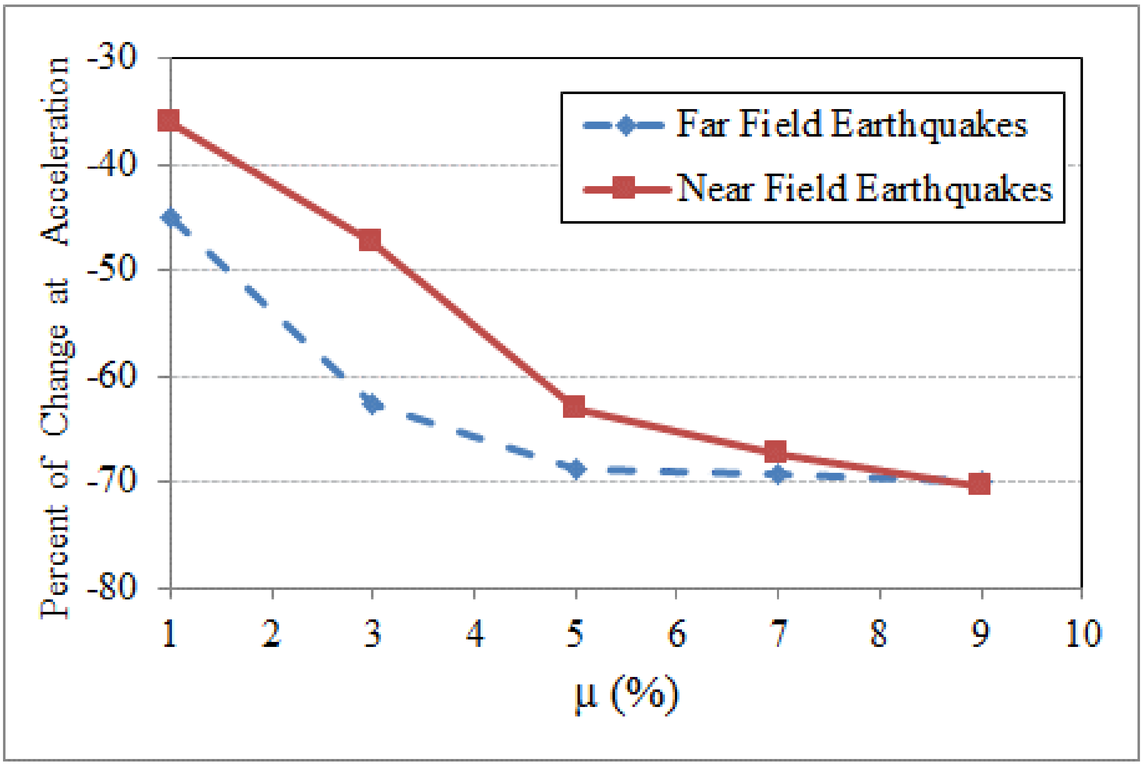


Figure 15 - - *Percent of changes at displacement and base shear of the 4-story building controlled by TLD subjected to far and near-field records*



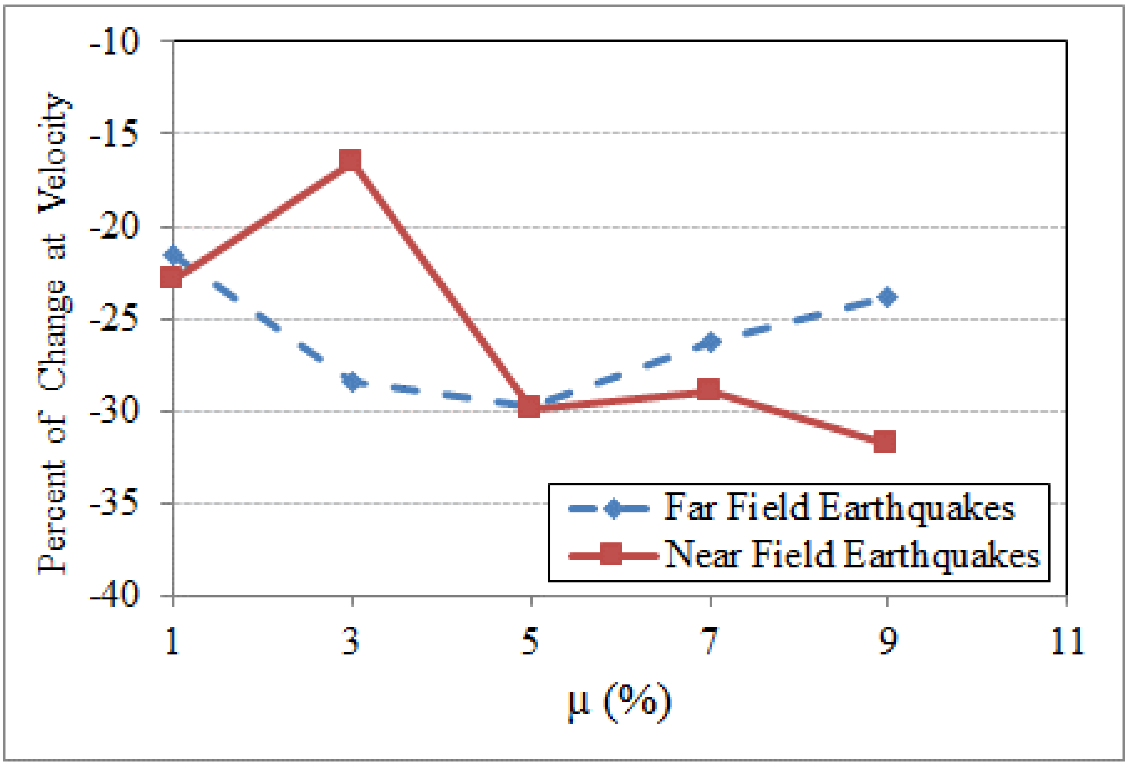


Figure 16 - - *Percent of changes at acceleration and velocity of the 12-story building controlled by TLD subjected to far and near-field records*

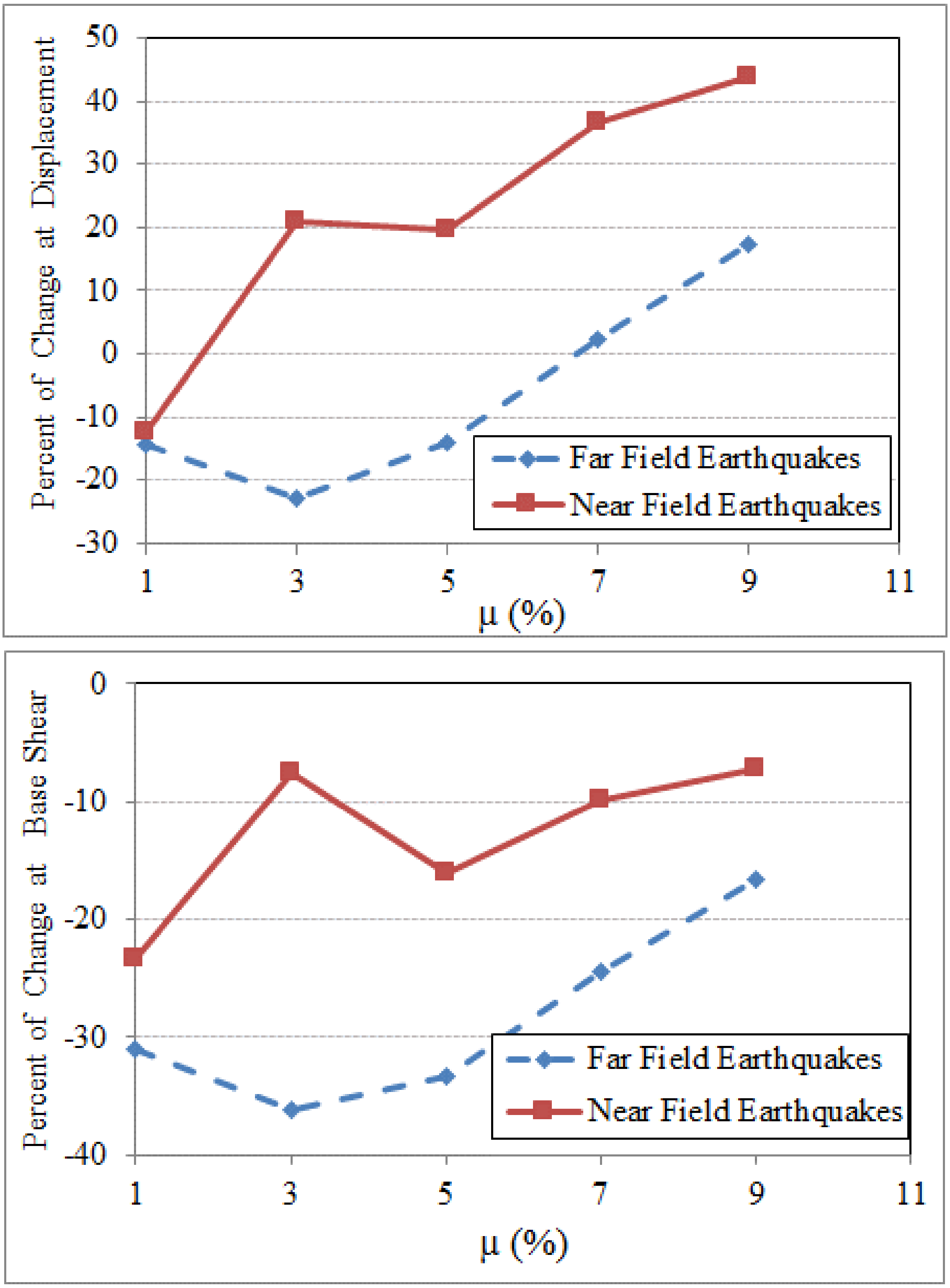


Figure 17 - - *Percent of changes at displacement and base shear of the 12-story building controlled by TLD subjected to far and near-field records*

According to Figure 16, in the 12-story building, the maximum reduction at the acceleration response was 70 and 70.4 percent subjected to near-field and far-field ground motions for a 9 percent mass ratio. The maximum reduction at the velocity response was 29.8 percent under the far-field earthquake for a 5 percent mass ratio and 31.8 percent under near-field earthquake for 9 percent mass ratio. According to Figure 17, the maximum reduction at the displacement response was 22.9 percent under the far-field earthquake for a 3 percent mass ratio and 12.5 percent under near-field earthquake for 1 percent mass ratio. These amounts for base shear response were 36.2 percent under far-field earthquake for 3 percent mass ratio and 23.4 percent under near-field earthquake for 1 percent mass ratio. Similar to the obtained results for TMD, it can be mentioned that TLD has better performance in near-field earthquakes than the far-field record. The reduction amount at the acceleration, velocity, displacement, and base shear responses at four and 12-story buildings are shown at Figures 18-25 under near-field and far-field earthquakes. According to Figures 18-25, the reduction of the structural response of studied buildings in the controlled state with the TMD system was higher than the same state with TLD. Likewise, 4-story building under near-field earthquakes and 12-story building under far-field earthquakes had better performance in the controlled state with each TMD or TLD system.

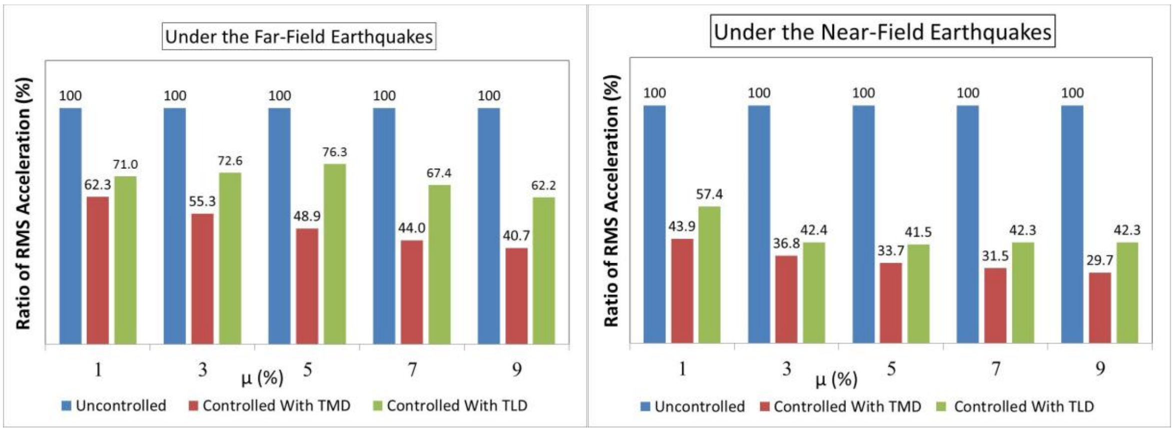


Figure 18 - *Ratio of RMS roof acceleration of the 4-story building in controlled by TMD and TLD to uncontrolled state subjected to far and near-field records*

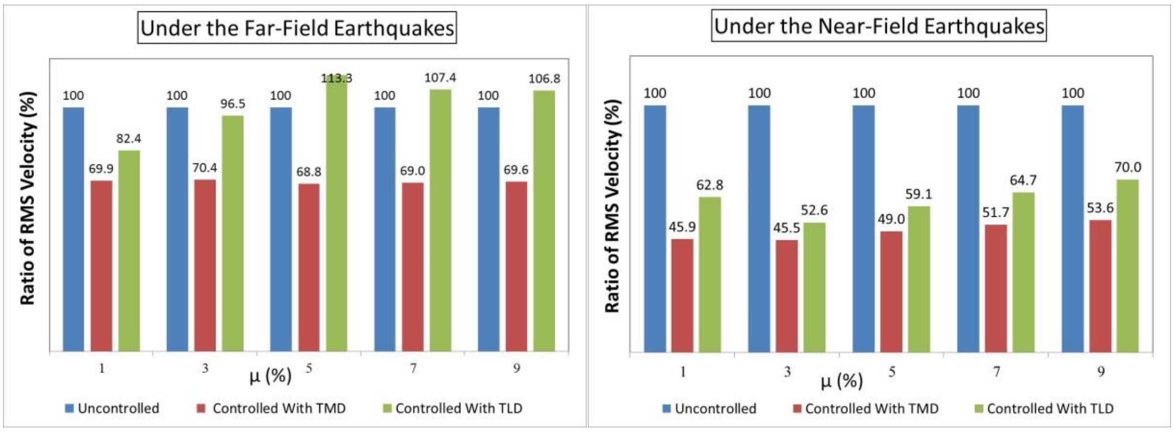


Figure 19 - *Ratio of RMS roof velocity of the 4-story building in controlled by TMD and TLD to uncontrolled state subjected to far and near-field records*

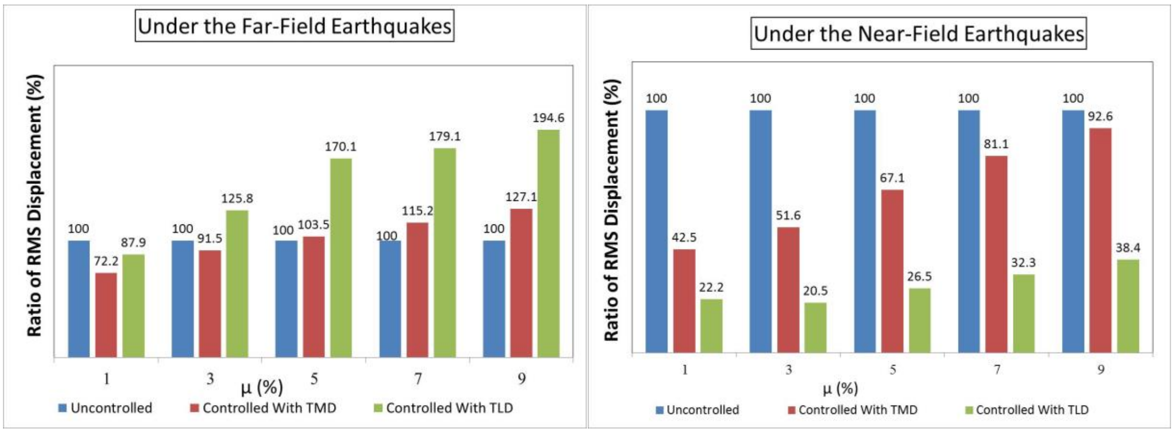


Figure 20 - *Ratios of RMS roof displacement of the 4-story building in controlled by TMD and TLD to uncontrolled state subjected to far and near-field records*

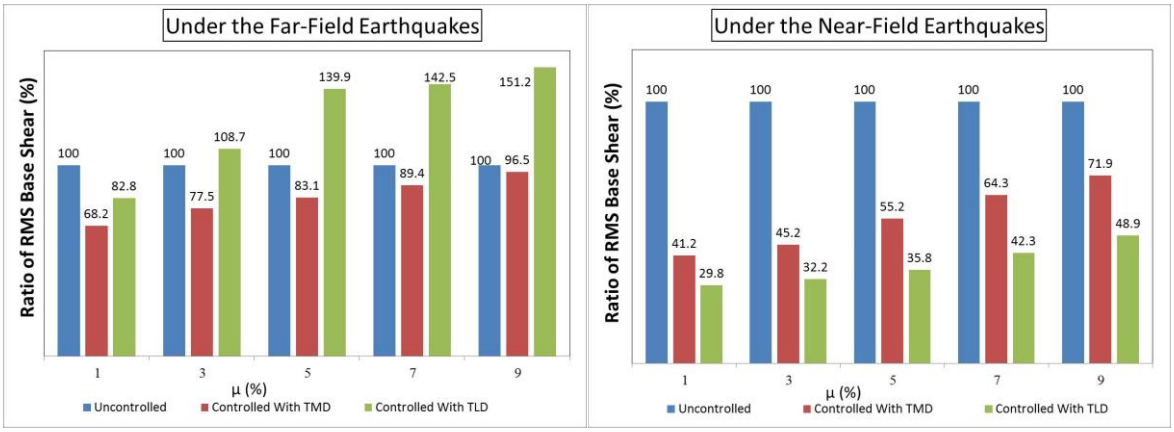


Figure 21 - *Ratios of RMS base shear of the 4-story building in controlled by TMD and TLD to uncontrolled state subjected to far and near-field records*

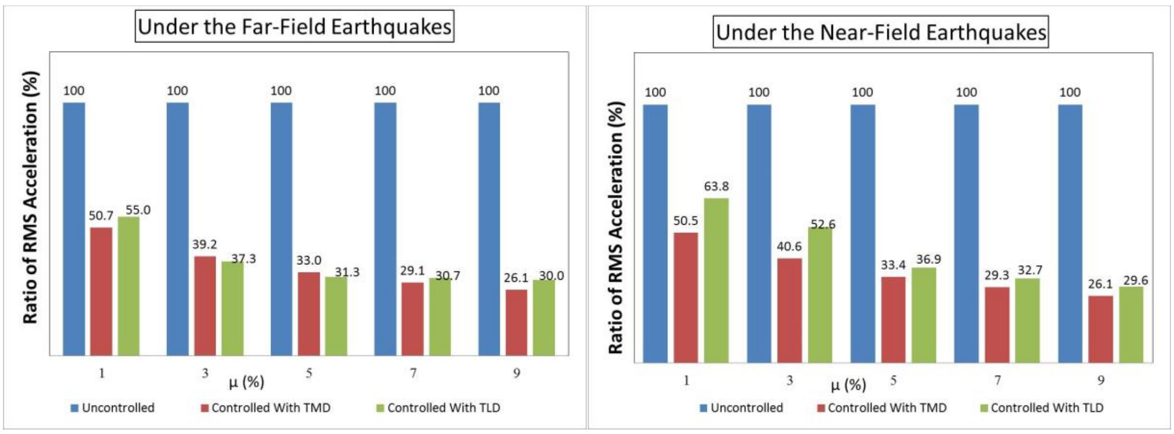


Figure 22 - *Ratio of RMS roof acceleration of the 12-story building in controlled by TMD and TLD to uncontrolled state subjected to far and near-field records*

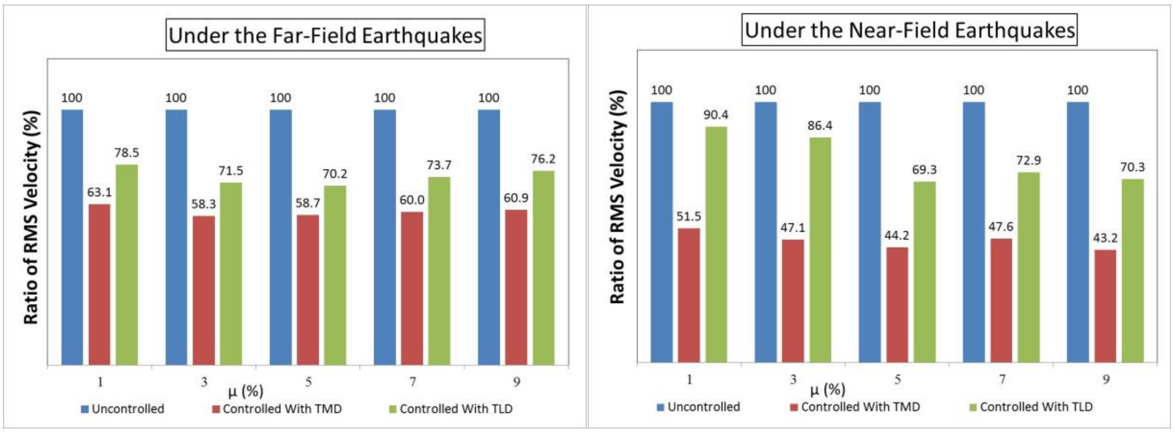


Figure 23 - *Ratio of RMS roof velocity of the 12-story building in controlled by TMD and TLD to uncontrolled state subjected to far and near-field records*

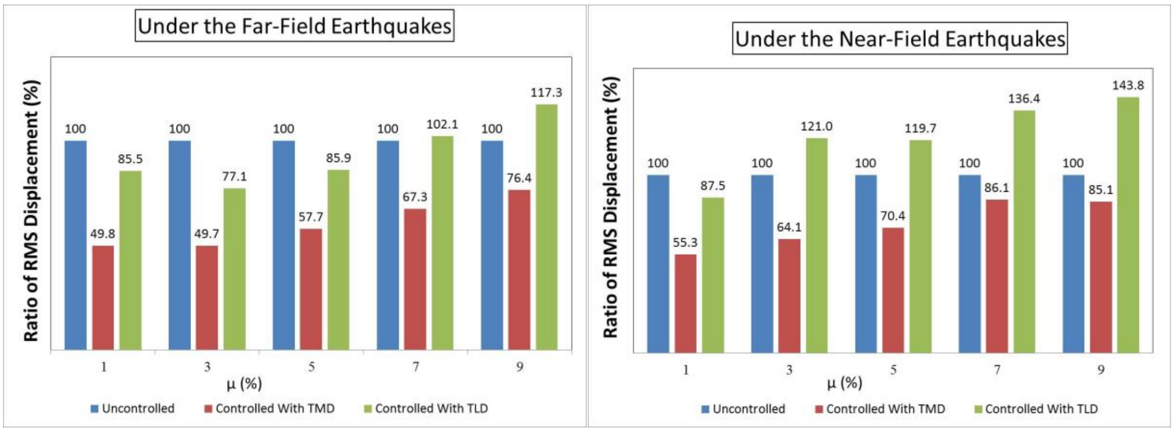


Figure 24 - *Ratio of RMS roof displacement of the 12-story building in controlled by TMD and TLD to uncontrolled state subjected to far and near-field records*

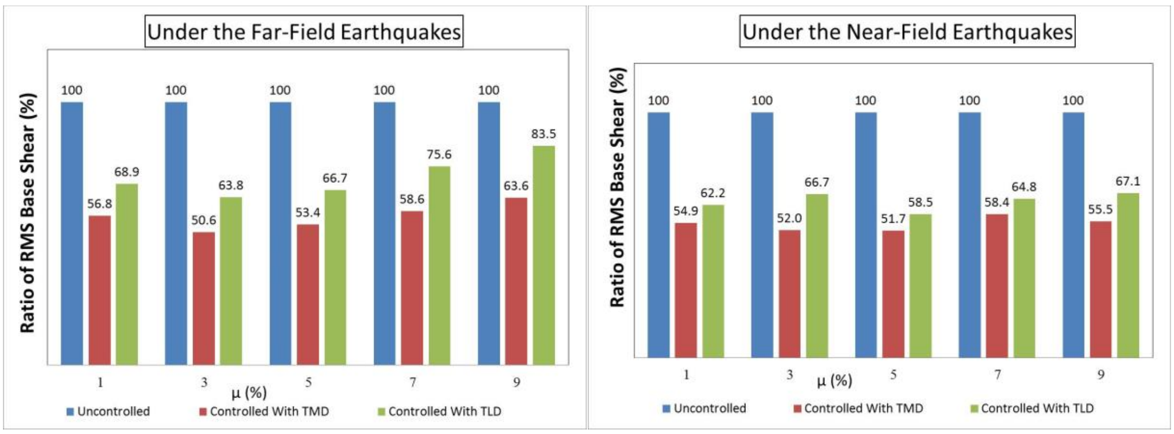


Figure 25 - *Ratio of RMS base shear of the 12-story building in controlled by TMD and TLD to uncontrolled state subjected to far and near-field records*

7 Conclusions

The present study investigated the effects of TMD and TLD as passive vibration reduction devices for low-rise and mid-rise buildings. To this end, 3D models of 4-story and 12-story buildings were simulated in SAP2000. Then, in order to evaluate the performance of these dampers, the optimum parameters of TMD and TLD were determined based on (Sadek, Mohraz et al. 1997) and ((Novo, Varum et al. 2014) approaches, respectively. The results can be summarized as follows:

- By comparing the behavior of 4-and 12-story buildings with TMD subjected to far-field and near-field ground motions, we observed that using TMD remarkably decreases the structural responses, and this reduction in the 4-story structure subjected to near-field records was higher than far-field records; in contrast, in the 12-story structure the responses of building subjected to far-field ground motions are lower than near-field records.
- Responses of 4-and 12-story buildings with TLD subjected to far-field and near-field records decreased, and this reduction in the 4-story building subjected to near-field earthquakes was higher than far-field records; however, in the 12-story building, the responses of building subjected to far-field ground motions were lower than near-field records.
- TLD-TMD did not decrease responses (acceleration, velocity, displacement, and base shear) equally, and the decrease percentages were different in each one of them, as though the number of responses decreased by mass damper was higher than the amount of liquid damper.
- The investigation of various mass ratios for both considered dampers demonstrated that the structural responses of studied buildings do not reach an optimum amount in 1 percent mass, as though each response reaches the optimum amount in a different mass ratio. Similarly, the acceleration and velocity in higher mass ratios and displacement and base shear in lower mass ratios had a more considerable reduction.
- Acceleration and velocity had the maximum reduction in higher mass ratios. In addition, displacement and base shear had the maximum reduction in lower mass ratios.
- TMD always showed a better performance than TLD, except in low-rise buildings where TLD had a better response in the displacement and base shear, at near-field earthquakes.
- TMD always showed a better performance than TLD, except in low-rise buildings where TLD had a better response in the displacement and base shear, at near-field earthquakes.

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L'EFFICIENZA DEI TMD E DEI TLDS PER GLI EDIFICI BASSI E MEDI SOGGETTI A TERREMOTI NEAR-FIELD E FAR-FIELD

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SOMMARIO: *I tuned mass dampers (TMD) ed i tuned liquid dampers (TLD) sono i sistemi di controllo passivo più noti utilizzati per ridurre la risposta strutturale contro le azioni sismiche. Nel presente studio, sono state valutate le prestazioni di edifici bassi e di media altezza equipaggiati con questo tipo di ammortizzatori e sono stati confrontati gli effetti dei terremoti near-field e far-field. A tal fine, le analisi dinamiche sono state condotte sia in stati controllati che incontrollati utilizzando sette registrazioni accelrometriche near-field che far-field. Inoltre, sia i TMD che i TLD in questi edifici sono stati modellati con cinque diverse percentuali di massa, rigidezza e smorzamento. I risultati dimostrano che i TMD hanno prestazioni migliori rispetto ai TLD e che le risposte strutturali diminuiscono per gli edifici bassi in near-field. Tuttavia, le risposte di un edificio di media altezza in far-field sono inferiori a quelle near-field.*

KEYWORDS: *Tuned mass damper, Tuned liquid damper, Near-field earthquake, far-field, effetti sismici.*

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