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An investigation on the effects of using TMD for vibration control on the response of high-rise buildings to seismic excitation

Uma investigação sobre os efeitos do uso de TMD para controle de vibração na resposta de edifícios altos à excitação sísmica

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ABSTRACT
This paper demonstrates that a tuned mass damper (TMD) is capable of effectively reducing vibration in high-rise buildings during seismic events. This study examines the effects of vibration control on the displacements and accelerations of controlled and uncontrolled buildings. It analyses their modal responses using an algorithm in MATLAB software. This study utilised instances of vibration control in models of a six-story and twelve-story skyscraper. The dynamic response of six-story buildings was assessed using two historical earthquakes, namely El Centro (1940) and Boumerdes (2003). The twelve-story skyscraper experienced two further significant earthquakes, namely Northridge (1994) and Kobe (1995). The building has

undergone digital simulation, specifically modelling the displacement of the top story. Consequently, the structure equipped with the Tuned Mass Damper (TMD) system exhibits reduced displacement and acceleration compared to the structure without TMD. The implemented TMD system resulted in a displacement reduction of less than 45% in high-rise buildings subjected to seismic excitation.

Keywords: earthquakes, building, tuned mass damper, vibration control, displacement, accelerations reduction rates.

RESUMO
Este artigo demonstra que um amortecedor de massa sintonizado (TMD) é capaz de reduzir efetivamente a vibração em edifícios altos durante eventos sísmicos. Este estudo examina os efeitos do controle de vibração sobre os deslocamentos e acelerações de edifícios controlados e não controlados. Ele analisa suas respostas modais usando um algoritmo no software MATLAB. Este estudo utilizou instâncias de controle de vibração em modelos de um arranha-céu de seis e doze andares. A resposta dinâmica de edifícios de seis andares foi avaliada usando dois terremotos históricos, nomeadamente El Centro (1940) e Boumerdes (2003). O arranha-céu de doze andares experimentou dois terremotos mais significativos, nomeadamente Northridge (1994) e Kobe (1995). O prédio passou por simulação digital, modelando especificamente o deslocamento da história principal. Consequentemente, a estrutura equipada com o sistema de amortecedor de massa ajustado (TMD) exibe deslocamento e aceleração reduzidos em comparação com a estrutura sem TMD. O sistema TMD implementado resultou em uma redução de deslocamento de menos de 45% em edifícios altos sujeitos a excitação sísmica.

Palavras-chave: terremotos, construção, amortecedor de massa ajustado, controle de vibração, deslocamento, taxas de redução de acelerações.

1 INTRODUCTION

Djedoui et al were used a PID controller against earthquakes when simulation was carried out on a six degrees of freedom base-isolated frame structure using MATLAB. For controlling the vibration of buildings an active hybrid control combining base isolation and active tuned mass damper AMD installed on the lowest floor of a base-isolated frame building was investigated. Compared results with base-isolated structure and base-isolated structure equipped with a passive and active tuned mass damper TMD/ ATMD under El Centro, Northridge, and Loma Pietra earthquakes. As mainly results, the active hybrid control system is more efficient and reduction of base displacement and velocity, respectively. From the objective of reducing the structural response, the active hybrid control system is more effective than hybrid control systems [1].

Sinan et al were studied in practice the production of small TMDs is easier than the production of a huge TMD, multiple positioned tuned mass dampers for structures. A tuned mass damper TMD positioned on a story may cause to exceed axial force capacity of a story. Four cases are studied two degrees of freedom structures to take the optimum parameters of multiple positioned tuned mass damper- single TMD parameters with 50-ton mass and other with 100-ton mass, and without TMD and case of 15-story structure with a flexible first story, and case of 10-story structure with equal story properties, and finally case 10-story structure with different story properties. According to the results, the effective comparing with the use of single heavy TMDs on the top of a structure to reduce structural vibrations originating from seismic sources, As a conclusion, the multiple positioned TMDs are effective on base-isolated structures if the upper structure has a low period, The placement of TMDs with the same properties is not effective, but may want to use a single TMD tuning for structures. As cited a finally remark that the performance of multiple positioned TMDs is also effective on impulsive motions [2].

Kaveh et al were studied a optimum parameters of tuned mass dampers for minimize the dynamic response of multi-story building. A MATLAB program and a Simulink model are developed for numerical optimization and time domain simulation subjected to El-Centro seismic and sine wave. Multi-stories shear building structure with single TMD on the top floor. As mainly results, the maximum top story displacement is reduced for all examples presented when interested in finding the optimum value of the TMD parameters and the corresponding reduction in displacement values [3].

Chen et al [4] were studied the optimal placement of multiple TMD for seismic structures for responses of a six-story building structure are studied, under 13 earthquake records. As mainly results, that time-history analyses indicate that the multiple dampers weighing 3% of total structural weight can reduce the floor acceleration up to 40%, and the multiple dampers can effectively reduce the acceleration of the uncontrolled structure by 10–25% more than a single damper, are cited.

Zheng et al [5] were studied the optimal parameters of the TMD and PD are designed by the classical optimization method and DE algorithm, respectively. The development of a new kind of passive control device named a particle damper, which has a very similar configuration and application method to the tuned mass damper; however, the damping mechanisms are different. The particle damper, which has a very similar configuration and application method to the tuned mass damper. The TMD_{opt} and PD_{opt} systems are attached to three cases as the primary structures, including the single-degree-of-freedom structure, 5-story linear-elastic steel frame and 20-story nonlinear benchmark building to evaluate the vibration control effects of the two damping devices. In conclusion, the properly designed particle damper system can achieve a comparable or slightly better vibration control effect than appreciated, compared with the optimal tuned mass damper system, the optimal particle damper as well as its better robustness, can reduce the relative displacement between primary structure and the damper itself.

Jaballah et al [6] were studied a base-isolated buildings equipped with ATMD when the comparative study establishes a hybrid vibration control system of structure and compares structural response and active tuned mass damper performance. Using two different control algorithms (PID and LQR), According to the numerical studies for a 5-storey building, To minimize the structural responses as mainly results, more than 50% of the top floor displacement is reduced by using the hybrid control system.

Khatibinia et al [7] were studied tuned mass dampers on ten story shears building subjected to the continuous stationary critical excitation. Three examples as cited, the first one a ten-story shear building with a TMD attached on the top story used to optimize the parameters of TMD using Genetic Algorithm (GA). The optimal parameters of TMD subjected to seismic of El Centro 1940 are obtained the optimum value. The second, the same building used when the mass of TMD is taken as constant value (a benchmark problem). Finally, the optimal design of the TMD for the second example is investigated subjected to the critical excitation. The main contribution results, the results reveal that the optimal parameters of the TMD system for a structure can be obtained based on the concept of the critical excitation.

Saman et al were studied an inelastic tuned mass dampers with eliminating its viscous damper to establish a new seismic response control system. When six earthquakes' records used for numerical studies. A comparison between optimum TMD and proposed P-TMD are presented. The structures are assumed to have three variable damping ratios. As mainly results, the maximum displacements and accelerations are compared to those of optimum TMD systems as well as those obtained from uncontrolled ones, and the electiveness of the P-TMD in reducing the seismic responses is similar to the optimum TMD, which increases as the mass ratio increases and decreases as the main system's damping increases [8].

Mazzon et al [9] were studied a tuned mass damper (TMD) was installed at the top of a five-story reinforced concrete (RC) building. Cross-sections of structural members and type of finite element used for their modeling. Horizontal accelerogram used in seismic analyses of the building. The building equipped with TMD1-TMD2, when TMD was designed to be installed on the rooftop of a medium-rise building. As mainly results cited as when therefore demonstrated that a TMD is a valid solution for the retrofit of medium-rise existing buildings and consequently, a reduction in flexural and shear actions of at least 50% at the base of the walls and of at least 55% at the base of the columns was achieved. The optimal masses of TMD1 and TMD2 were 25% and 12% of the total mass of the building, respectively.

Di Matteo et al were studied the tuned mass damper inerter (TMDI) to control the response of base isolated structures under stochastic horizontal base acceleration. Comparison of optimal TMDI design parameters: analytical solution vs numerical solution to the response to the Imperial Valley earthquake and response to the L'Aquila earthquake, with TMDI and without TMDI control, controlled at the base through a TMDI. From concluding remarks that the TMDI, properly optimized with the proposed procedure, can effectively reduce the response of base isolated structures even under earthquakes, the control performance of the TMDI device connected to the base-isolated structure has been further examined employing two recorded ground accelerations with different features, and considering a 5-story benchmark base-isolated planar frame structure. It has been shown that the TMDI device designed with the proposed approach can effectively lead to a reduction of the base isolation displacements [10].

Khazaei et al [11] were studied an optimal location of multiple tuned mass dampers in regular and Irregular (L-shaped and U-shaped) tall steel buildings using 1-damper, 2-damper, and 4-damper. Subjected to seven earthquakes Near-field and Far-field to carried out the maximum displacement and acceleration reduction percentage of roof in the regular and irregular 10-story and 20-story models. As mainly results, multiple dampers in the earthquake domain have a better performance in reducing the acceleration of the models, which is also true for floor displacements. In irregular shaped structures, the damper optimal position approaches the centre of mass to reduce the eccentricity, and improves the results significantly.

Using TMD control in many fields derived from his performance as well as N. Hoanga et al [12] were studied a Bridge employed a floor deck isolation system. Using the optimal design of a tuned mass damper for seismic applications of single-degree-of-freedom structures. As result, the optimal TMD has lower tuning frequency and higher damping ratio with increasing mass ratio. With a large mass ratio, a TMD becomes very effective in minimizing the primary structure response. The performance is very robust with respect to uncertainty in the system parameters as well as the excitation frequency range, and Qiong Wu et al [13] were studied the stability of offshore platform for safely engineering operations. Tuned-mass damper (TMD) technology has been adopted to reduce vibrations from which and earthquake influences. A 4-column offshore platform was built according to the actual size of approximately 1:200 ratios, and a TMD system was prepared for the experiment. The most result clear that TMD system used can effectively suppress the earthquake stimulus and keep the stability of offshore platform.

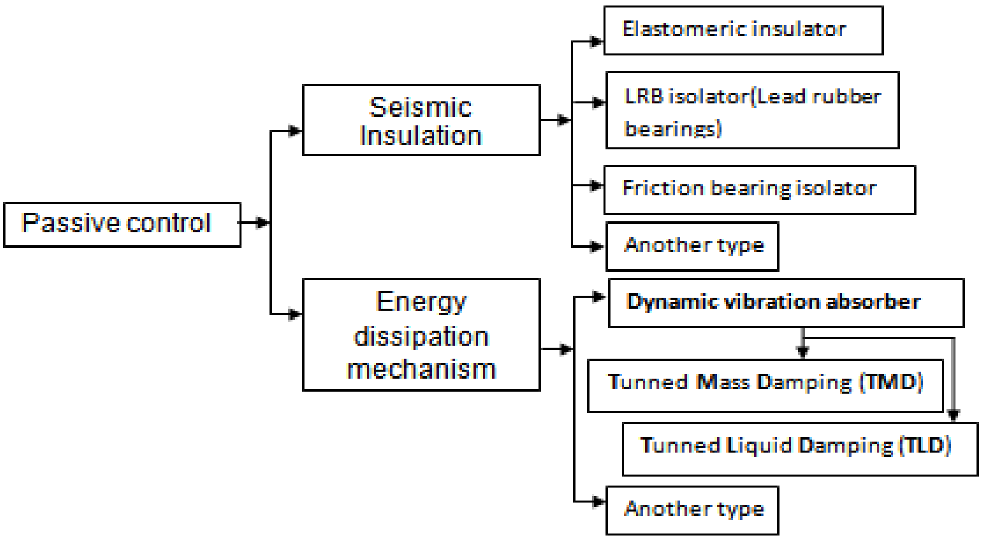
Xiaofang et al [16] were studied connect two adjacent buildings with parallel and serial TIDs and discusses the seismic performance of the vibration control system. under the action of EL Centro, Taft, San Fernando, Northridge. Using code in MATLAB for extracting of peak displacement of the left and the right building, dynamic energy of TID at optimizing the left building and the right building. From Conclusions remaks increasing the mass ratio of adjacent buildings helps to improve performance of the vibration control system used. The vibration control system based on parallel TID dissipates seismic energy mainly by large damping, while the vibration control system based on serial TID protects buildings mainly by converting seismic energy into dynamic energy.

In this article briefly, TMD controllers are designed to control vibration of buildings with six and twelve-stories subjected to four seismic motions. The displacements and accelerations reductions rates responses are illustrated and compared for controlled and uncontrolled buildings studied. The equations of motion are formulated than and the structure’s and TMD properties are cited. The comparison and discussion of results with numerical studies while taking the top story displacement as a purpose state. The numerical simulation is done where displacements, and with the acceleration reduction rate responses of the controlled and uncontrolled buildings with using algorithm in order to investigate the efficiency completing with conclusions.

2 PASSIVE CONTROL

In the figure 1 briefly, where they are cited, the passive control including (Tuned Mass Damping) TMD control seen on the corresponding flowchart examples to be followed below:

Figure 1 - Passive control



Source: Authors.

3 MATHEMATICAL MODEL

The equations of dynamic motion can be written equation (1) and equation (2) respectively as follow:

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} = -[M]\{r\}\{\ddot{x}_g(t)\} \quad (1)$$

$$m_d\{\ddot{x}_d\} + c_d\{\dot{x}_d\} + k_d\{x_d\} = -m_d\{\ddot{x}_g(t)\} \quad (2)$$

Where

[M], [C] and [K] are the structural mass, damping and stiffness matrices, respectively.
{r}: Vector of earthquake influence on the structure with dimension (1x n).

$\{\ddot{x}_g(t)\}$: Vector of gravity acceleration as function of time. ξ: Damping ratio.
$\{x\}$, $\{\dot{x}\}$, $\{\ddot{x}\}$: Vector relative displacement, velocity, acceleration of the floors, respectively.
$\{x_d\}$,$\{\dot{x}_d\}$,$\{\ddot{x}_d\}$: Vector relative displacement, velocity, acceleration of TMD, respectively.
m_d, C_d, k_d: are the TMD mass, TMD damping and TMD stiffness valor, respectively.

Mass and stiffness modeled matrices are presented respectively as follow:

$$[M] = \begin{bmatrix} m_1 & & & & & & \\ & m_2 & & & & & \\ & & m_3 & & & & \\ & & & \ddots & & & \\ & & & & m_{n-1} & & \\ & & & & & m_n & \\ & & & & & & m_d \end{bmatrix}$$

$$[K] = \begin{bmatrix} K_1 + K_2 & -K_2 & & & & & \\ -K_2 & K_2 + K_3 & -K_3 & & & & \\ & -K_3 & K_3 + K_4 & \ddots & & & \\ & & -K_4 & \ddots & -K_4 & & \\ & & & \ddots & K_{n-1} + K_n & -K_n & \\ & & & & -K_n & K_n + K_d & -K_d \\ & & & & & -K_d & K_d \end{bmatrix}$$

Also, damping matrix is given as follow:

$$[C] = \begin{bmatrix} C_1 + C_2 & -C_2 & & & & & \\ -C_2 & C_2 + C_3 & -C_3 & & & & \\ & -C_3 & C_3 + C_4 & \ddots & & & \\ & & -C_4 & \ddots & -C_4 & & \\ & & & \ddots & C_{n-1} + C_n & -C_n & \\ & & & & -C_n & C_n + C_d & -C_d \\ & & & & & -C_d & C_d \end{bmatrix}$$

Equations (3), (4) and (5) are presented mass ratio (μ) and frequency (f_{tmd}) with TMD stiffness(k_{tmd}) below when could be arranged as follow:

$$\mu = \frac{m_{tmd}}{m_s} \qquad (3)$$

$$f_{tmd} = \frac{f_s}{(\mu+1)^2} \qquad (4)$$

$$k_{tmd} = f_s \, m_{tmd} \qquad (5)$$

Also TMD damping coefficient (c_{tmd}) and TMD auxiliary system natural frequency could be written as equation (6) and equation (7) respectively as below:

$$c_{tmd} = \sqrt{\frac{3\mu}{8(\mu+1)^3}} \qquad (6)$$

$$\omega_{tmd} = \sqrt{\frac{k_{tmd}}{m_{tmd}}} \qquad (7)$$

4 NUMERICAL STUDY

In numerical study, the parameters of the TMD control used as mass ratio (μ) when is equal to 5%, stiffness and damping of the TMD are chosen assuming a passive device tuned to the first mode of the structure are presented in table1.While, the Peak Ground Acceleration are presented in table2, from chooses four historicals earthquakes Northridge-1994 and Kobe-1995, also El-centro-1940 and Boumerdes-2003, respectively.

Table 1 – Numerical parameters of structure and TMD

		Mass(t)	Stiffness(KN/m)	Damping(KN.s/m)
6 Floors	Floor	298.5	29.3 x10^3	31
	Tuned mass damper	89.55	7.15	0.675
12 Floors	Floor	298.5	29.3 x10^3	31
	Tuned mass damper	89.55	7.15	0.675

Source: Authors.

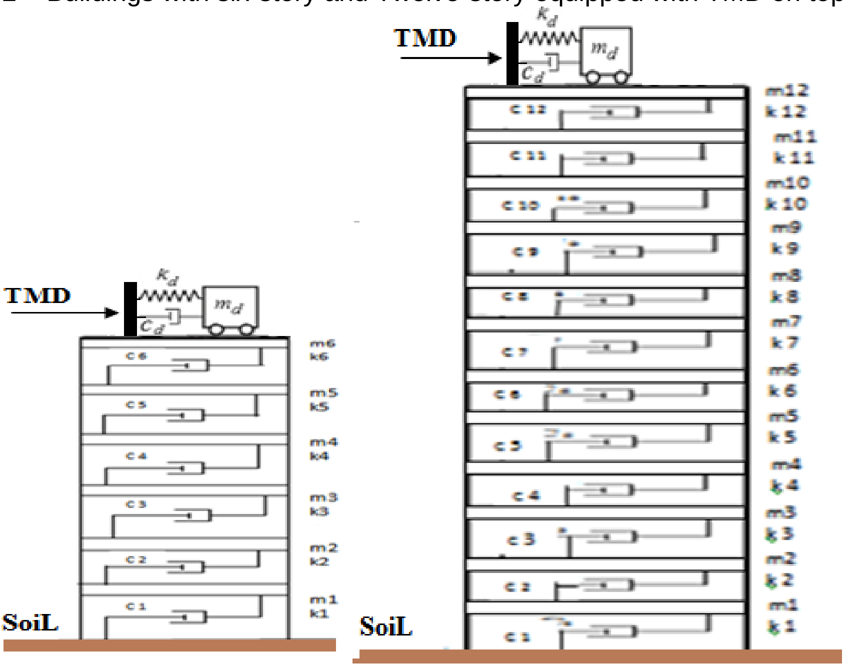
Table 2 – Numerical earthquakes and Peak Ground Acceleration

Earthquake	Date of occurrence	Station	PGA/g
Northrige	1994	Canyon country-WLC	0.48
Kobe	1995	Takarazuka- JMA	0.425
El-Centro	1940	El-Centro	0.342
Boumerdes	2003	KEDDARA *AFPS-2003	0.29

*Referenced at [14;15] AFPS-2003 **http://www.afps-seisme.org**.
Source: AFPS, 2003.

Figure 2 is presented the Buildings with six-storey and Twelve-storey equipped with TMD on top floors.

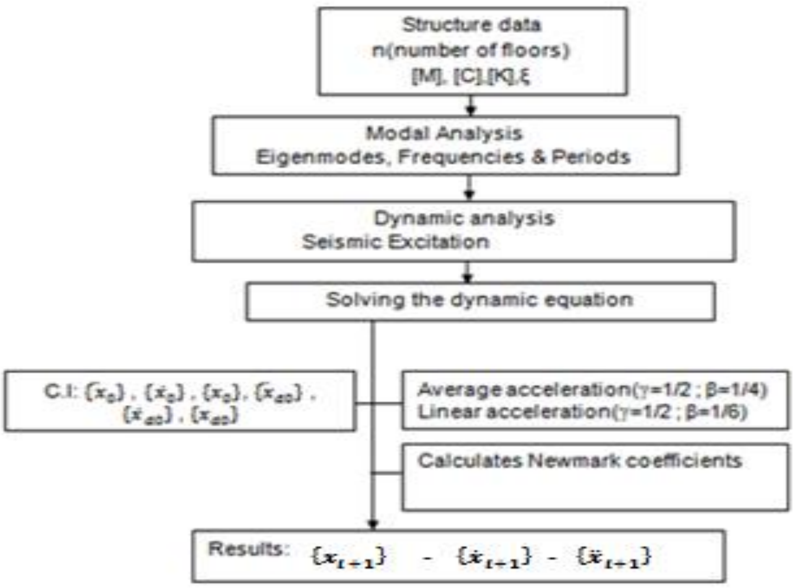
Figure 2 – Buildings with six-story and Twelve-story equipped with TMD on top floors



Source: Authors.

For investigated the seismic responses, figure 3 presented the structure algorithm flowchart of calculus on MATLAB software as below:

Figure 3 – Structure of Algorithm flowchart briefly of calculus



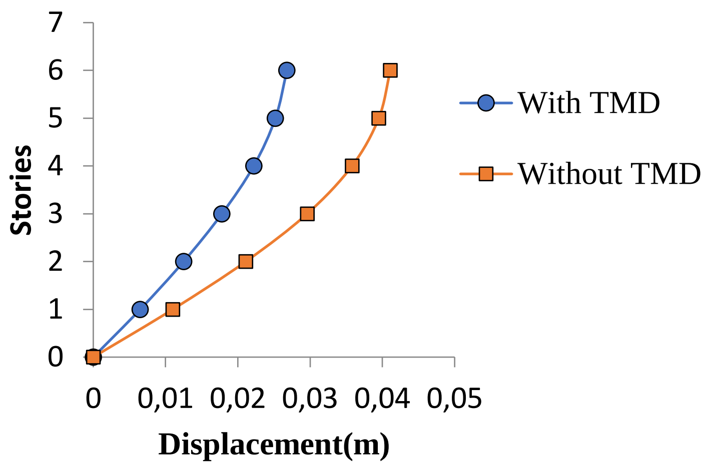
Source: Authors.

5 COMPARISON AND DISCUSSION OF RESULTS

5.1 DISPLACEMENTS

A comparison of displacement vs floors under earthquakes El-centro-1994 and Boumerdes-2003 for the building with six-stories is showed in figure 4 and figure 5, respectively. In figure 4, the reduction of displacement their peak reach 37, 5% of El-Centro earthquake when using TMD control.

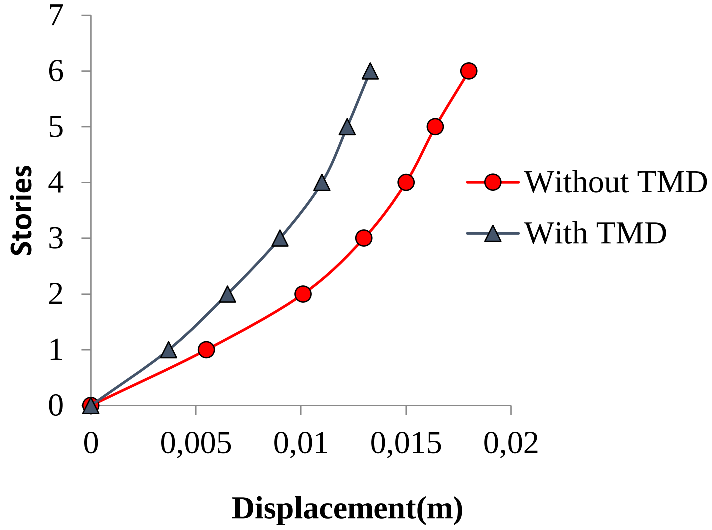
Figure 4 – Comparison of displacement vs floors under El-Centro earthquake of building with six-stories



Source: Authors.

While, the comparison shown in figure 5 when the displacement peak reduction for Boumerdes earthquake less or equal 35%. However, can see twice displacement peak without TMD under El-Centro earthquake presented than to the Boumerdes earthquake and close to the ratio of reduction between them, this is evidence for the effectiveness of damping motion in of the strongest cases. In general cases without TMD, the building giving bad performance and threaten their safety and collapse against studied earthquakes.

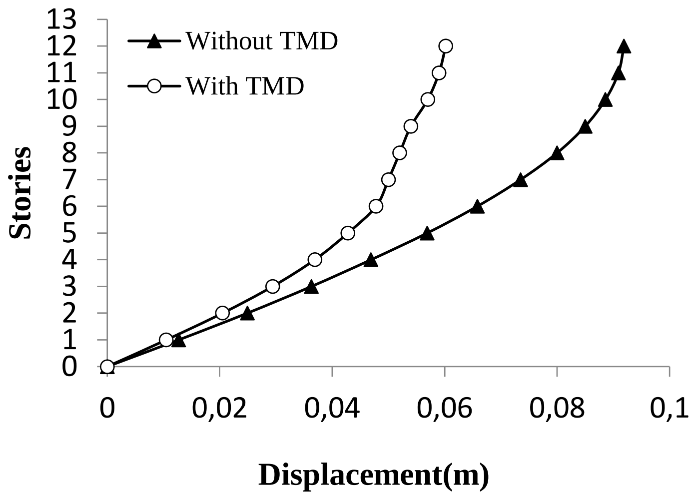
Figure 5 – Comparison of displacement vs floors under Boumerdes earthquake of building with six-stories



Source: Authors.

A comparison of displacement vs floors for building with twelve –stories under earthquakes Kobe -1995 and Northbridge -1994 are showed in figure 6 and figure 7, respectively. From the comparison, the displacement peak reduction ratio equal to 40% and while less than 25% under Kobe and Northbridge earthquakes, respectively. As a result, the best intervention of TMD control to attenuate vibrations is more effective for weak earthquake cases than the strong ones.

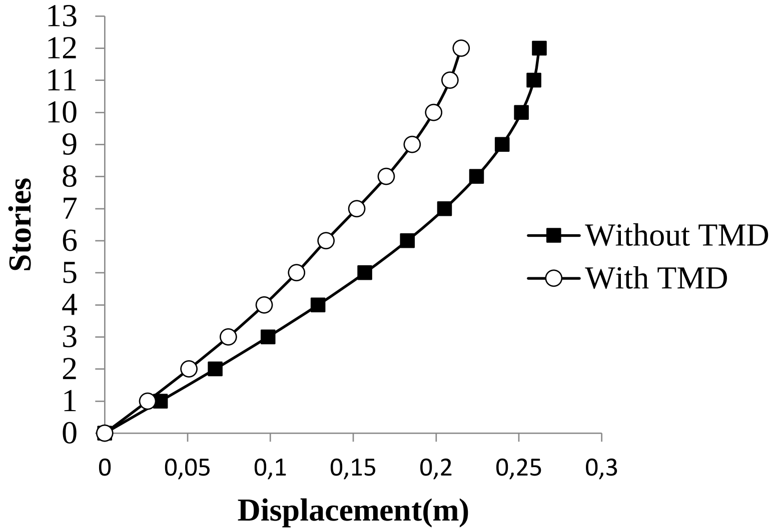
Figure 6 – Comparison of displacement vs floors under Kobe earthquake of building with twelve - stories



Source: Authors.

Also, the building with twelve –stories which lead to structure's weakness overtime and collapse or failure without TMD control, with an ratio equal to 47% when changed from Kobe to Northbridge earthquakes, respectively.

Figure 7 – Comparison of displacement vs floors under NorthRidge earthquake of building with twelve –stories

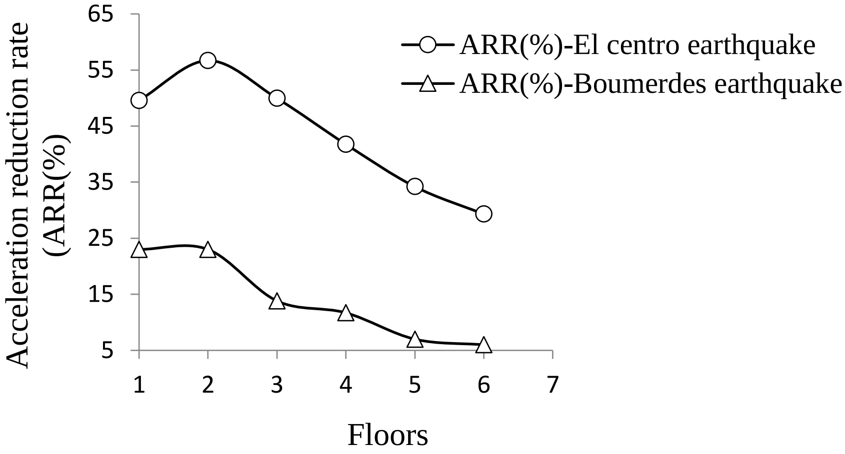


Source: Authors.

5.2 COMPARISON OF ACCELERATIONS REDUCTION RATES UNDER TMD CONTROL

In figure8, a comparison of accelerations reduction rates ARR (%) are presented the effectiveness of a percentage less than 45% and 25% on high building under El-Centro and Boumerdes earthquakes excitations, respectively. The TMD control where they have been used to reduce the accelerations better for the top floor than the lowest. Also, can be easily remarked that mitigate the vibration more effective for weaker seime in magnitude and damping to close of structure motion.

Figure 8 – Comparison of acceleration reduction rates vs floors under El centro and Boumerdes earthquakes of building with six –stories

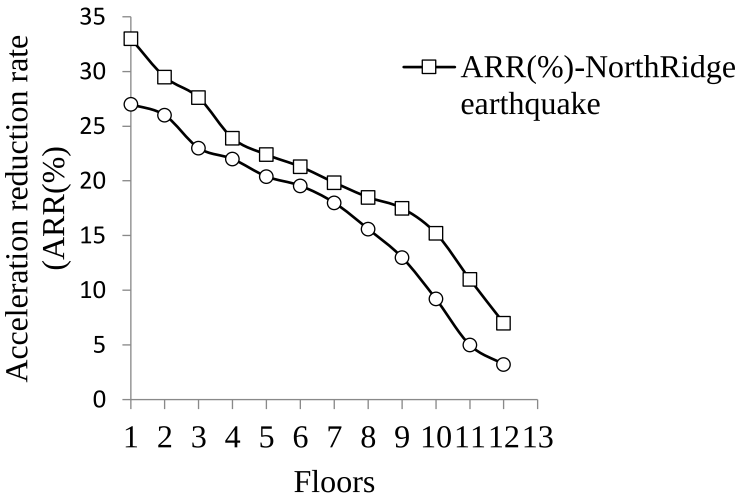


Source: Authors.

In figure 9 as shown as the comparison results of the accelerations reduction rates ARR (%) curves are presented a percentage less than 35% and 25% on high building with twelve –stories under Northbridge and Kobe earthquakes, respectively. However, The TMD control where they have been illustrated a variance be equal to 30% when comparing the two earthquakes.

In addition, can see to damping to close of structure motion. Furthermore, it can also be seen that the TMD has a decrease in their effective role when increasing the number of floors to close the movement of the structure. Because, a single disadvantage since their characteristics will be changed.

Figure 9 – Comparison of acceleration reduction rates vs floors under NorthRidge and Kobe earthquakes of building with twelve –stories



Source: Authors.

In addition, there is a varying correlation between the TMD of the structure where the higher of the seismic stress, the greater of the reduction in displacement and acceleration, especially for weak seismic excitations. The response produced by the TMD is proportional to the intensity of the earthquake. The TMD reduces displacements and accelerations at the head and at the base of the structures studied. The comparison results obtained showed the effectiveness of a TMD control of a structure for the reduction of the seismic response.

6 CONCLUSIONS

This paper is studied the effectiveness of TMD control on response of high building under changed earthquake excitation on vibration control. The results obtained show the efficiency of this external energy dissipator as well as its dependence on various parameters related to both the structure and the damper itself. Widely accepted control strategy when using tuned mass damper (TMD) control. The results lead to summarize in the following contribution conclusions:

1- From the results, make it possible to affirm that the TMD systems are effective in reducing the displacements induced by the earthquakes studied when the displacements and accelerations of the structure with TMD system are lower than those of the structure without TMD.

2-TMD system used reduced the displacement with a percentage less than 45% on high building under earthquake excitation.

3- Against earthquakes excitations, TMD system corresponding their using for controlled the best performance of the top story building followed to reducing the displacements.

4- In whole cases without TMD, the building giving bad performance against studied earthquakes.

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