*ISET Journal of Earthquake Technology, Paper No. 547, Vol. 56, No. 4, December 2019, pp. 123-134*

# INCREMENTAL DYNAMIC ANALYSIS OF BUILDING WITH WEAK STOREY AT TOP AS TMD

Atulkumar A. Manchalwar

Associate Professor, Gokaraju Rangaraju Institute of Engineering and Technology, Hyderabad
E-mail ID: *atulmanchalwar@gmail.com*

S.V. Bakre (Corresponding Author)

Associate Professor, Visvesvaraya National Institute of Technology, Nagpur
E-mail ID: *sachinbakre@gmail.com*

## ABSTRACT

Structures show inelastic non-linear behaviour under cyclic loads associated with natural activities like earthquakes and wind, which impart the external kinetic energy to them, consuming in the lateral movement of structures, such movement may be responsible for the failure or collapse of these structures. To prevent such a collapse, it is necessary to recognize the non-linear behaviour of the structure and adopt a suitable mechanism to control the response of them and this may be possible by dissipating the seismic energy which imparts on them. The study is devoted to the development of an efficient, feasible and economical tuned mass damper for moderately high buildings. This tuned mass damper (TMD) is in form of a weak storey at the top of the buildings for square and rectangle in the plan. Incremental Dynamic Analysis (IDA) was implemented to investigate the benefits of the TMD on structural behaviour. Using ten earthquakes scaled up to a maximum target multiplier two, with ten increments, damage measures such as storey drift. The fragility curves in this study are represented by lognormal distribution functions with two parameters (i.e., the mean spectral displacement and the standard deviation) and developed as a function of spectral acceleration ($S_a$). Comparison of the fragility curves indicated that the TMD is marginally effective in attenuating seismic structural response under various earthquake ground motions.

**KEYWORDS:** Tuned Mass Damper, Incremental Dynamic Analysis, Fragility Curves, Probability of Damage, Vibration Control

## INTRODUCTION

The present scenario is to construct the structure which can withstand earthquake forces. The response of a building to earthquake excitation depends on the intensity of the earthquake, building size, shape, mass, stiffness, and the ability of the structural system to dissipate energy. It is needed to control the seismic structural response by increasing 'ductility' and 'energy dissipation'. A seismic structural response can be mitigated by installing additional energy dissipation devices. Housner et al. [1] summarized the different type of energy dissipaters including active type, passive type, hybrid type, and semi-active. The use of energy-absorbing devices to dissipate the seismically induced energy is considered to be one of the most effective ways to mitigate the effects of earthquakes on buildings. Each of these techniques uses fundamentally different approaches for response control and is most effective for different types of structures. The response of the building can be controlled by increasing the damping of the structure. Damping can be increased by using dampers. Some dampers are designed as real damping devices. One of the common devices used for increasing the damping of the structure is tuned mass damper (TMD).

Sladek and Klinger [2] presented a comparison of optimum TMD parameters for harmonic and white noise base excitation. Idealized a building to non-linear multi degree-of-freedom (MDOF) and used a TMD mass ratio of 0.65 % and observed that optimum TMD made no contribution toward reducing lateral forces at the base of a building and do not give an appreciable reduction in the response of tall buildings. Sadek et al. [3] investigated the optimum parameters of tuned mass damper that result in a considerable reduction in the response to earthquake loading. Palazzo and Petti [4] proposed a new control strategy combining TMD with base isolation (BI). It was discussed that the dual system allows combining two filtering actions, one is the high-frequency filtering produced by BI and the other is the narrow frequency band reduction produced by TMD. Also, observed that the introduction of TMD also improves the superstructure response while introducing supplemental dissipation in isolators often contaminates the isolation. Wang et al. [5] employed Hamilton's principle and finite element method to formulate the new dynamic equation of a tall building subjected to earthquake excitations. A tuned mass damper (TMD) system is installed at the top to absorb the earthquake-induced vibrations. It is found that the rigid-body motion of the TMD and the transversal vibrations of the tall building were coupled and energy is transferred between them and the effects of several parameters on the rigid-body motion and transversal vibrations are presented and discussed. And also, concluded that for the tall building system, a two-dimensional problem can be reduced to a one-dimensional one via the simple flexure beam model. A complete analysis of the tall building associated with the TMD device should include both the rigid-body motion and transversal vibrations. Bakre and Jangid [6] derived optimum parameters of the TMD system attached to a viscously damped single degree-of-freedom main system, for various combinations of excitation and response parameters. The optimum parameters of the TMD system and the corresponding response quantities were obtained for different damping ratios of the main system and the mass ratios of the TMD system. Taniguchi et al. [7] investigated the effect of TMD on displacement demand of base-isolated structure and determines the optimal parameters for the design of the TMD by considering the response of the base-isolated structure with and without TMD. Found that under excitation a reduction of the order of 15 % - 25 % in the displacement demands of the base-isolated structure with TMD. It is also observed that TMD is more effective for lightly damped isolators. Chey et al. [8] discussed a case study on the seismic response of a multi-storey passive and semi-active tuned mass damper using 12-storey moment-resisting frame models. Demonstrated the validity of the segmented upper stories of the structures which are isolated as a TMD with controlled parameters and appropriate matching resettable TMD configurations. It is observed from the time history analyses and normalized reduction factor that building with above considerations shows the significant reduction on the control indices to all the seismic hazards at the cost of increasing the acceleration at the isolation interface. Hoang et al. [9] by numerical optimizer optimal design of a tuned mass damper for seismic application of the single degree-of-freedom structure was investigated. Matta [10] an analytical model of ground motion pulse was applied to the design and evaluation of TMD and introduced a new optimization method. The analytical pulse model proves an accurate and efficient tool for the assessment of TMDs under impulsive ground motions. Shariatmadar and Razavi [11] proposed an active tuned mass damper for seismic response control of the building and also used a standard optimization method for optimal parameters. Aly [12] proposed robust passive and active tuned mass damper design for vibration control; of high rise structure under the wind. Nigdeli and Bekdas [13] introduced the effectiveness of TMD for controlling pounding of an adjacent structure by two different methods. In the first part, independent TMDs on both structure and in the next part one single TMD coupled at top of both Structures. Sun et al. [14] studied two types of the smart tuned mass damper with different parameters which show a significant reduction in the response of the structure. Wen et al. [15] two types of tuned inerter based dampers (i.e., tuned viscous mass damper and tuned inerter damper) installed on MDOF structure and tuned to multiple modes were optimally designed according to the $H_2$ optimization method.

Incremental dynamic analyses (IDA) the method can become a valuable additional tool of seismic engineering and addresses both demand and capacity of structures [16]. Vamvatsikos and Cornell [17] introduced a fast and accurate method to estimate the seismic demand and capacity of first mode dominated multi degree-of-freedom systems by exploiting the connection between the static pushover and the incremental dynamic analysis. Azarbakht and Dolšek [18] introduced progressive incremental dynamic analysis which involves a precedence list of ground-motion records, which makes it possible to calculate the IDA curves progressively. Tirca et al. [19] studied the seismic assessment of low and middle rise concentrically braced frame using incremental dynamic analysis and fitted fragility curves. For two reinforced concrete (RC) buildings, which are designed for gravity loads and earthquake resistance by Eurocode 2 and 8 progressive collapse risk assessment has been done through IDA [20]. An efficient stochastic incremental dynamic analysis methodology for nonlinear/ hysteretic oscillators has been developed by resorting to nonlinear stochastic dynamics concepts and tools such as stochastic averaging and statistical linearization [21]. The previous study clearly demonstrates that the TMDs have a potential for improving the wind and seismic behaviors of prototype civil structures [22]. Elias [23] concluded that the use of the distributed tuned vibration absorbers (d-TVAs) is the most competent because it effectively dissipates the seismic energy. Taha et al. [24] investigated the efficiency of the torsional tuned mass dampers (T-TMDs) in response control of asymmetric buildings under bidirectional earthquake ground excitations. It is concluded that the T-TMDs are more effective in mitigating the torsional response of asymmetric buildings as compared with the bidirectional tuned mass damper (BTMD). Elias and Matsagar [25] observed that controlling the higher modal response by a TMD will be efficient to substantially mitigate the seismic response of the steel building.

The objective of the present study is to introduce new approach of TMD and study the effectiveness of TMD. TMD is constructed as a weak storey at the top of the building. Incremental dynamic analysis is carried out considering the rectangle building and square building.

## TUNED MASS DAMPER

The natural frequency of TMD is tuned to a frequency near to the natural frequency of the main system in the mode which is to be damped and to reduce vibration caused due to various dynamic loading. The vibration of the main system causes TMD to vibrate in resonance which results in the dissipation of vibration energy through the damping of TMD. A TMD is itself a single degree-of-freedom (SDOF) system which adds a mode of vibration to the base structure. The stiffness '$k$' and mass '$m$' of the TMD are chosen to put the natural frequency of the TMD just below the natural frequency of the target mode of the base structure which is to be damped. This causes the strong interaction between the TMD and the base structure.

### 1 Concept of Tuned Mass Damper using Two Mass System

The equation of motion for SDOF-TMD system as shown in Figure 1 is:

$$(1+\bar{m})\ddot{u} + 2\xi\omega m\dot{u} + \omega^2 u = \frac{p}{m} - \bar{m}\ddot{u} \quad (1)$$

where, $\bar{m}$ is defined as the mass ratio, $\bar{m} = m_d/m$.

$$\omega^2 = \frac{k}{m}, C = 2\xi\omega m, C_d = 2\xi\omega_d m_d$$

where, $\dot{u}$ is the velocity; $\ddot{u}$ is the acceleration; $\xi$ is the damping factor of the primary mass; $\omega$ is the natural frequency; $C$ is damping. The equation of motion for the tuned mass is given by:

$$\ddot{u}_d + 2\xi_d\omega_d\dot{u}_d + \omega_d^2 u_d = -\ddot{u} \quad (2)$$

The purpose of adding the mass damper is to control the vibration of the structure when it is subjected to a particular excitation. The mass damper is having the parameters: the mass $m_d$, stiffness $k_d$, and damping coefficient $c_d$. The damper is tuned to the fundamental frequency of the structure such that,

$$\omega_d = \omega$$
$$k_d = \bar{m}k$$

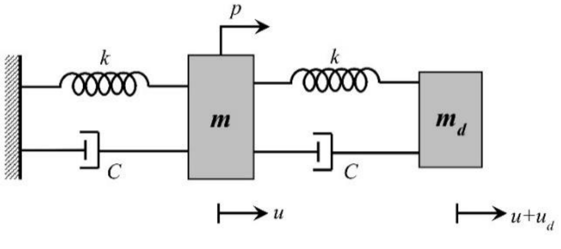


Fig. 1 SDOF-TMD system

### 2 TMD Parameters

Sadek et al. [3] proposed criteria for optimum TMD parameters. He formulated the optimum frequency ratio and optimum damping ratio for multi degree-of-freedom system. Proposed that effective mass ratio should be used for calculating optimum parameters of TMD. Effective mass is the ratio of the mass of TMD to a normalized modal mass of the building. As per Sadek et al. [3], effective mass ratio $(\mu)$, optimum frequency ratio $(f_{opt})$ and optimum damping ratio $(\xi_{opt})$ given by Equations 3-5 as follows:

$$\mu = \frac{m_d}{M_1} \quad (3)$$

$$f_{opt} = \frac{1}{1+\mu\varphi}\left[1-\beta\sqrt{\frac{\mu\varphi}{1+\mu\varphi}}\right] \quad (4)$$

$$\xi_{opt} = \varphi\left[\frac{\beta}{1+\mu}+\sqrt{\frac{\mu}{1+\mu}}\right] \quad (5)$$

where, $m_d$ = mass of TMD; $M_1$ = modal mass of building; $f_{opt}$ = $\omega_d/\omega$; $\omega_d$ = first natural frequency of TMD; $\omega$ = first natural frequency of building; $\beta$ = damping ratio of the main building; and $\varphi$ = amplitude of the first mode of vibration for a unit modal participation factor computed at the location of TMD.

## SPECIFICATION OF BUILDING

Two buildings, each having six stories (G+5) and different plan shape, i.e., rectangle and square are considered. The details and geometrical properties used for the study of the buildings are shown in Figure 2. Constant storey height of 3 m is considered above plinth level and the foundation level is assumed at 1.5 m below the plinth level as shown in Figure 3. The seismic force has been calculated as per Indian Standard (IS) 1893 (Part 1)-2016 [26]. The building is assumed to be situated on medium soil strata ($N$ value between 10 and 30) and located in the seismic zone V with peak ground acceleration (PGA) as 0.36 $g$ under maximum considered earthquake. The special moment resisting frame (SMRF) is considered with response reduction factor ($R$) as 5. The reinforced concrete slab thickness is assumed as 120 mm and thickness of unreinforced masonry brick infill as 230 mm. Preliminary sizes of the frame members have been considered based on the deflection criteria given as per Indian Standard (IS) 456-2000 [27] and IS 13920-2016 [28]. The dead load and live load has been calculated as per Indian Standard (IS) 875-1987 Part 1 and Part 2, respectively [29-30]. The grade of concrete with nominal characteristic compressive strength of 20 MPa and reinforcing steel having a yield strength of 415 MPa has been used in the design. The first model is the building without TMD and the second model is the building with the top weak storey as TMD.

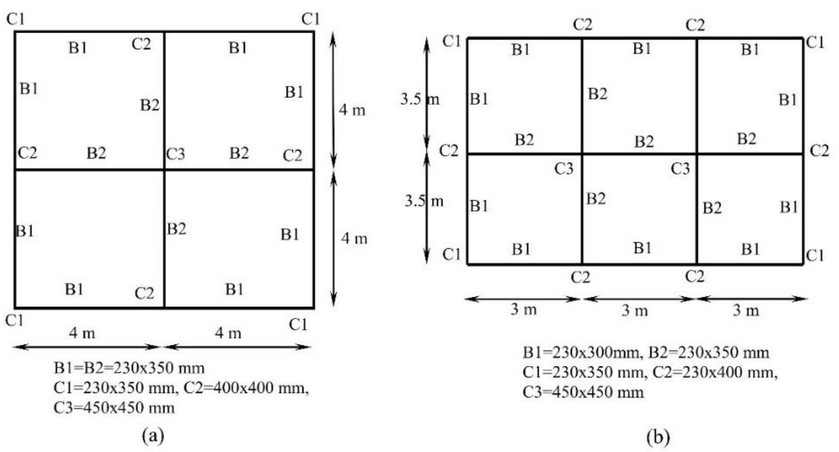


Fig. 2 Plan of six storey building (a) square shape and (b) rectangular shape

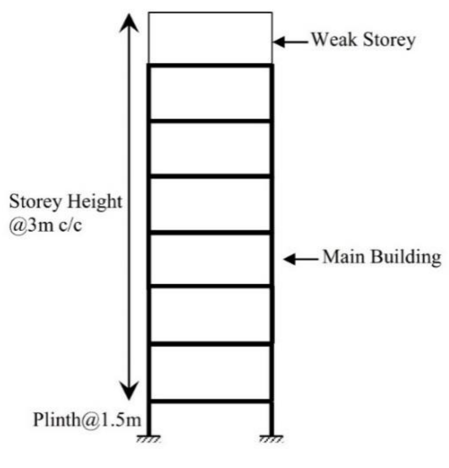


Fig. 3 Elevation of building with weak storey

## TUNING OF MASS DAMPER

The tuned mass damper is termed so because of tuning of its characteristics with the main building on which it is to be installed. Tuning of a mass damper is an iterative procedure of matching the fundamental frequency of TMD with the fundamental frequency of the main building. The tuning of the weak storey is made on the same guidelines. To arrive at properly tuned weak storey, first, a weak storey with same plan area as that of building and of the same height as that of other floor height of the building is considered. Column locations of this weak storey are same as that of the main building. The first natural period of this weak storey should match with that of building. Table 1 shows the member sizes of the weak storey thus devised for both buildings taken of the study. Table 2 shows the comparison of the fundamental period of building and corresponding weak storey.

**Table 1: Member Sizes of Weak Storey**

| Member | Member sizes for weak storey (mm) | | | |
|---|---|---|---|---|
| | Square Shape Building | | Rectangular Shape Building | |
| | Width | Depth | Width | Depth |
| Beam | 100 | 150 | 100 | 200 |
| Column | 100 | 200 | 100 | 200 |
| Slab | - | 120 | - | 120 |

**Table 2: Fundamental Period**

| Building Shape | Fundamental Period (sec) | |
|---|---|---|
| | Building | Weak Storey |
| Square | 1.01 | 0.99 |
| Rectangular | 1.01 | 1.00 |

## INCREMENTAL DYNAMIC ANALYSIS

IDA is the dynamic version of pushover analysis. An IDA curve is a plot of damage measure versus intensity measure. The spectral acceleration of the ground motions was used as the intensity measure in this study. The ground motions were made compatible with the design spectrum, they have scaled again for the IDA studies by using a target multiplier of 2.0 and 10 increments. Thus, the scale factor of 1.0 corresponds to the design basis earthquake (DBE) and the scale factor of 1.5 corresponds to the maximum considered earthquake (MCE). Maximum storey drift is used as damage measures. Also, IDA dispersion was studied to estimate the performance of the structures.

Ground motions should be properly scaled for the comparison of IDA results. IDA is very useful to produce a reliable estimate of the dynamic capacity of the structure, and it also helps the analyst to have a better understanding of the behaviour of the structure under severe or rare ground motion levels [16].

### 1 Ground Motion Scaling

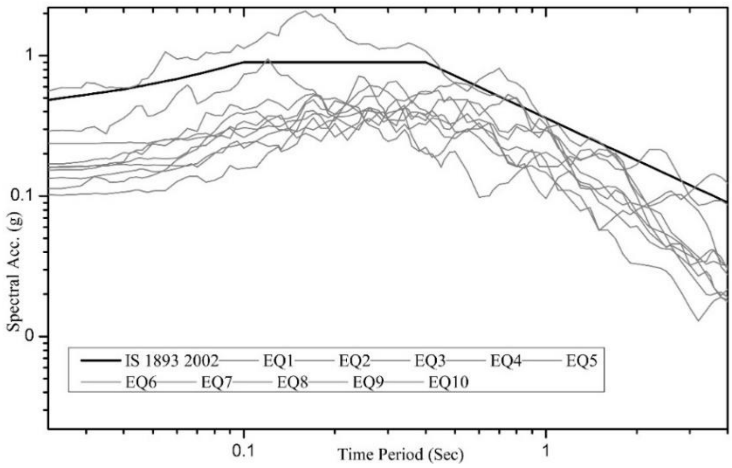


Fig. 4 Unscaled response spectra

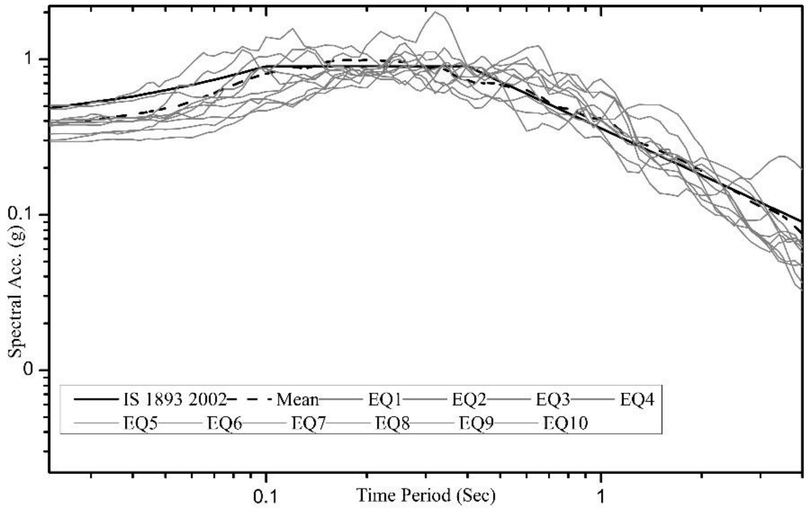


Fig. 5 Scaled response spectra

**Table 3: Scale Factors and Ground Motions Selected**

| Earthquake No. | Earthquake Name | Time Step (sec) | Scale Factor |
|---|---|---|---|
| EQ1 | San Fernando | 0.01 | 2.0009 |
| EQ2 | Imperial Valley-06 | 0.01 | 1.3114 |
| EQ3 | Corinth Greece | 0.01 | 1.029 |
| EQ4 | Loma Prieta | 0.005 | 0.9728 |
| EQ5 | Northridge-01 | 0.01 | 1.5945 |
| EQ6 | Duzce Turkey | 0.01 | 2.4294 |
| EQ7 | Manjil Iran | 0.02 | 0.4915 |
| EQ8 | Chuetsu-oki Japan | 0.01 | 1.3571 |
| EQ9 | Iwate Japan | 0.01 | 1.2303 |
| EQ10 | Darfield New Zealand | 0.005 | 1.2961 |

The scaling process in this study involves two steps. Before IDA, selected ground motions were scaled to match the spectrum at the $1^{st}$ mode period of vibration. Then, each scaled ground motion was scaled again for the IDA to reach the target multiplier 2.0 using 10 increments of 0.2. As a result, all 6 story designs were evaluated by 10 different ground motions, each having 10 different scale factors up to two times the design earthquake. Figures 4 and 5 show the unscaled response spectrum and scaled response spectrum, respectively. Table 3 shows the scale factors and ground motions selected for incremental dynamic analysis.

## 2 Modeling of Structure

Structural modelling, analysis and design have been performed in SAP2000 version 14.2.4 [31]. A detailed mathematical model has been prepared to represent the distribution of structural geometry of elements and loading in the plan as well as in elevation. The thickness of the slab at all floor levels and roof level has been assumed to be same and modelled as a rigid diaphragm. Cracking is incorporated by modifying the stiffness properties (viz., shear area and moment of inertia) of beam/ column using property modifier. The beams have been assigned with moment (M3) hinges and columns with coupled axial moment (P-M2-M3) hinges at the two ends. In modelling of plastic hinges in the frames, the default hinges properties defined by SAP2000 [31] as per FEMA 356 [32] have been used. The floor areas of both the buildings are made equal. This enabled the structures to achieve approximately the same time period as given in Table 2. Once the time period of buildings is made same it then became easy to compare the effectiveness of TMD.

## 3 Results and Discussion

Figures 6 and 7 show IDA curves for 10 different earthquakes which illustrate the effect of a tuned mass damper for both buildings square shape and rectangle shape in plan. It can be observed from Figures 6 and 7 that the storey drift is reduced when compared with building without TMD. It can be concluded from both the plots that top weak storey as TMD is effective to reduce the seismic response of the structure.

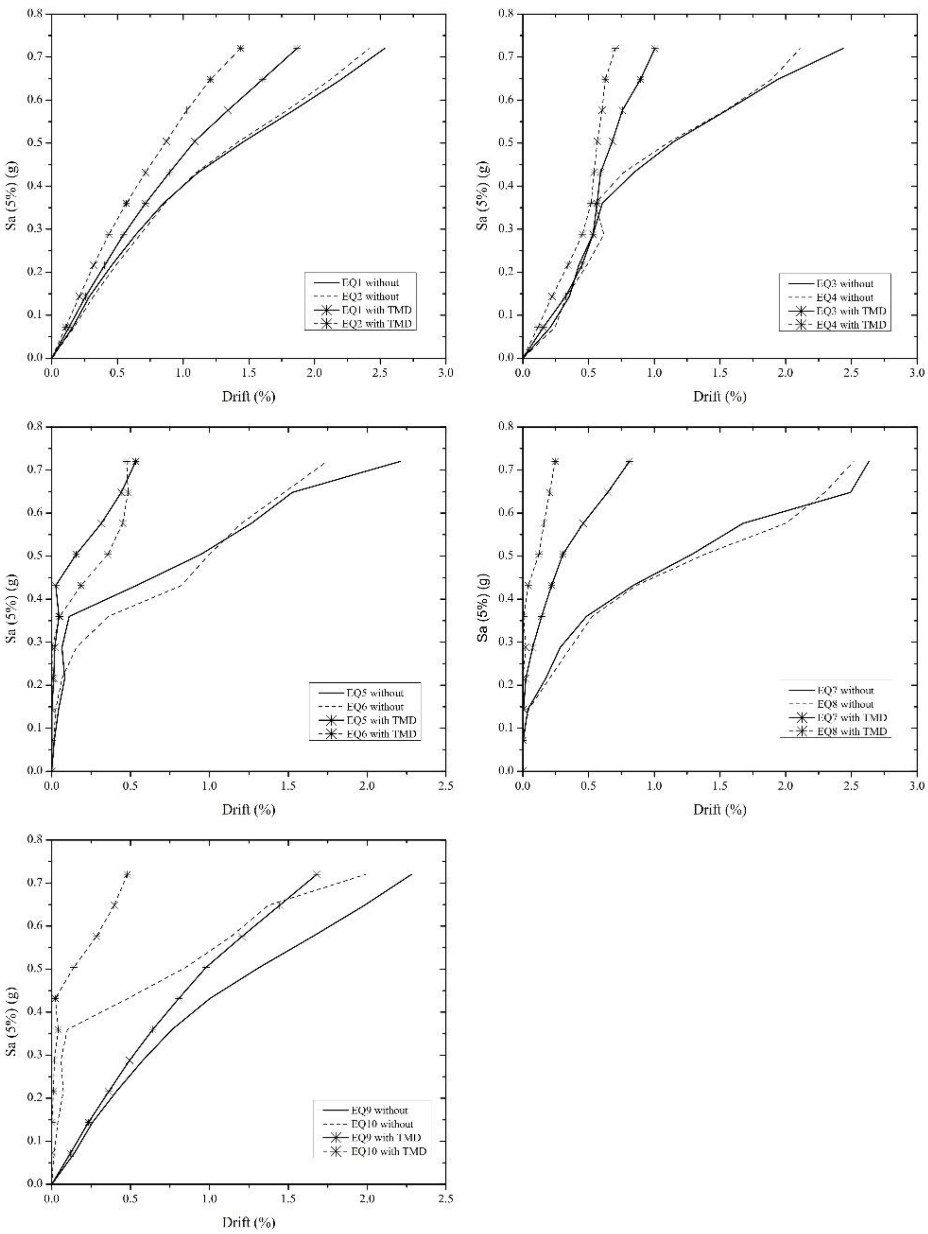


Fig. 6 IDA curve for square shape building with and without TMD

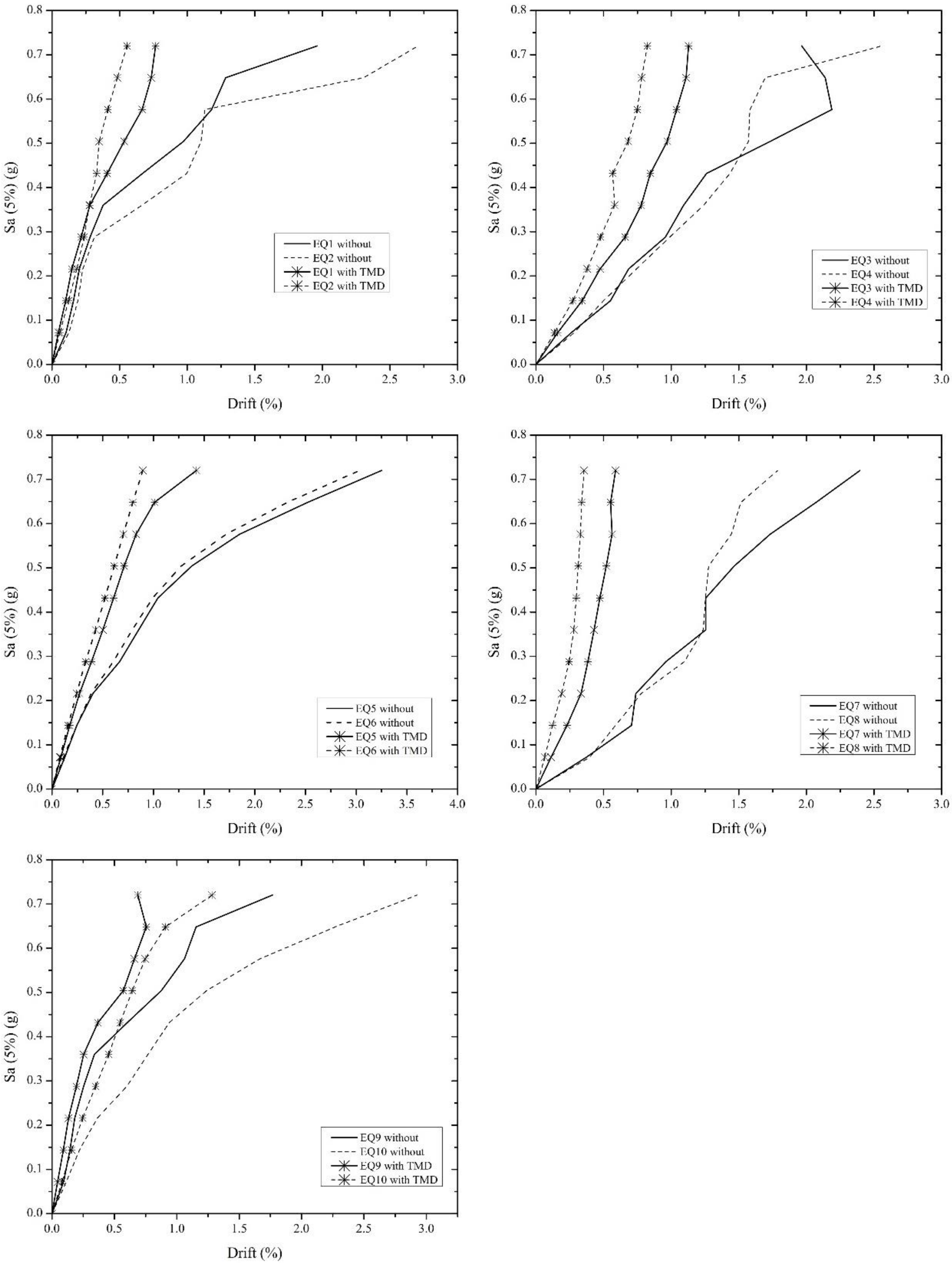


Fig. 7 IDA curve for rectangular shape building with and without TMD

## FRAGILITY ANALYSIS

The fragility curves express the probability of structural damage due to earthquakes as a function of ground motion indices. A random point on the fragility curve shows the conditional probability that the damage under an earthquake of a given intensity will exceed a certain damage state. It is assumed that the fragility curves can be expressed in the form of two-parameter (viz, the mean spectral displacement and the standard deviation) lognormal distribution functions. Based on this assumption, the cumulative probability of the occurrence of damage, equal to or higher than damage level *D*, is expressed in Equation 6 [33],

$$P[\leq D] = \emptyset\left[\frac{1}{\beta}\ln\left(\frac{X}{\mu}\right)\right] \quad (6)$$

where $\mu$ is the standard normal cumulative distribution function, $X$ is the lognormal distributed ground motion index (e.g., PGA, $S_a$ or $S_d$), and $l$ is the median value of ground motion index at which the building reaches the threshold of damage state $D$, defined using allowable drift ratios and $b$ is the standard deviation of the natural logarithm of ground motion index of damage state.

The fragility curves developed for without TMD and with TMD for four damage states in terms of spectral acceleration are given in Figures 8 and 9 for both the shapes of buildings. These figures show that the fragility curves for without TMD and with TMD having similar shapes, but with varying values for the different damage states. For all damage states, the physical improvement of the seismic vulnerability due to the addition of TMD becomes evident in terms of enhanced fragility curves shifting those associated with the existing building to the right when plotted as a function of spectral acceleration ($S_a$).

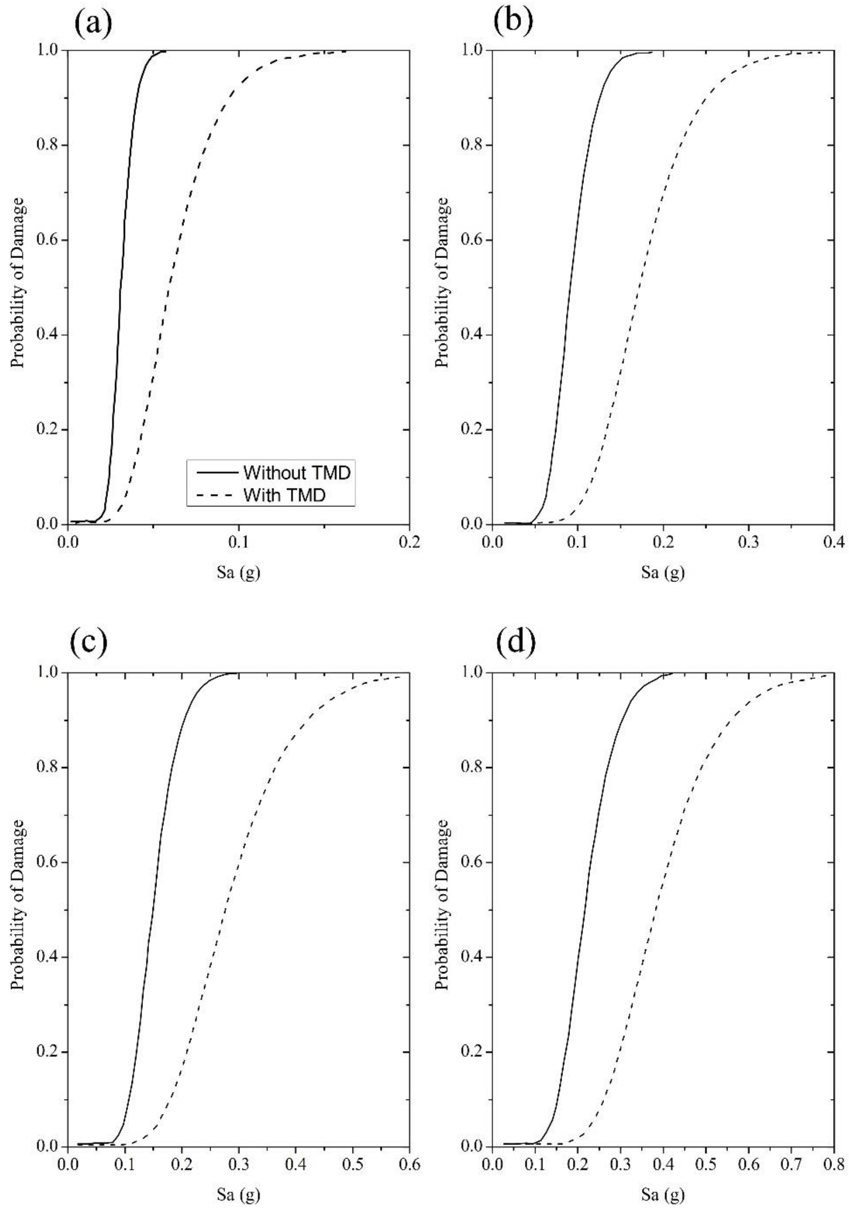


Fig. 8 Fragility curves of square shape building with and without TMD for (a) slight damage, (b) moderate damage, (c) major damage, and (d) collapse damage state in terms of spectral acceleration ($S_a$)

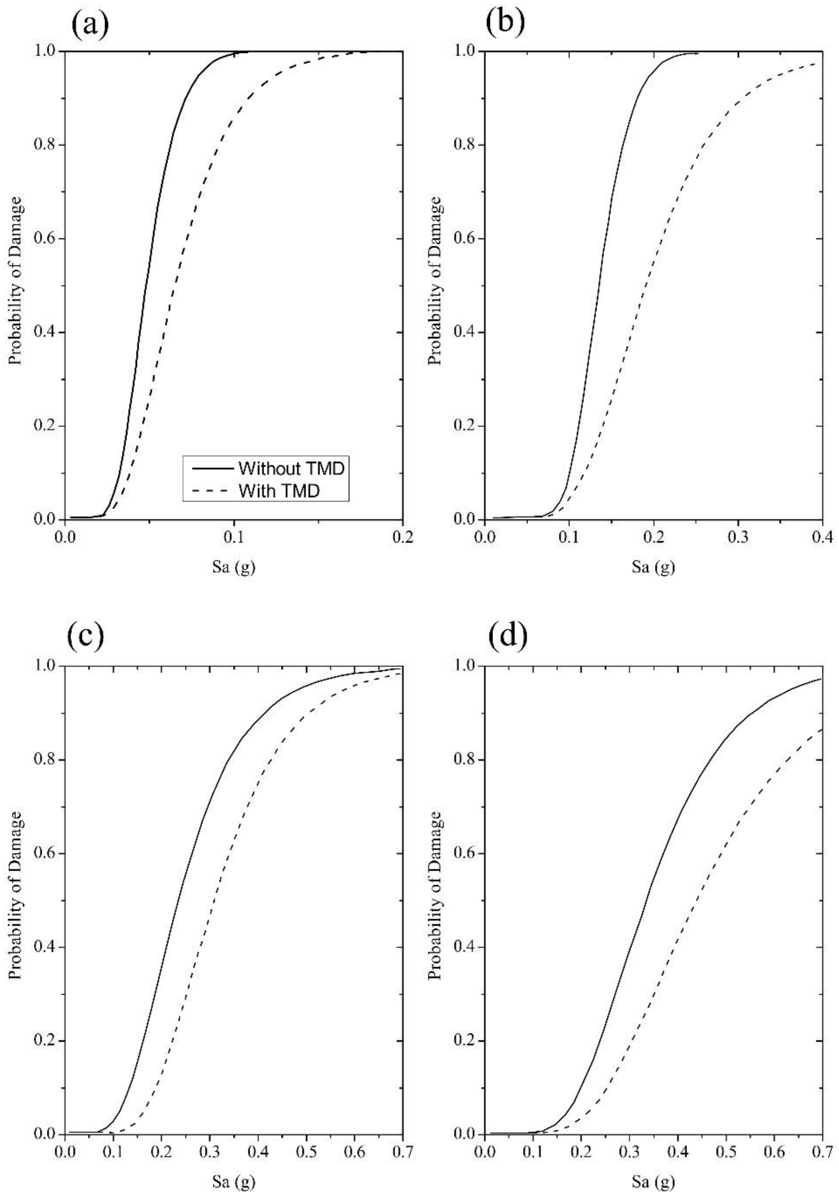


Fig. 9 Fragility curves of rectangle shape building with and without TMD for (a) slight damage, (b) moderate damage, (c) major damage, and (d) collapse damage state in terms of spectral acceleration ($S_a$)

## CONCLUSIONS

The top weak storey as a tuned mass damper has a remarkable effect on reducing the inelastic response of the elements of buildings. The effects of added TMD are studied through incremental dynamic analysis. Tuned mass damper in the form of weak storey at the top is found to be effective in reducing seismic forces in both the structures (square shape and rectangle shape).

For determining the potential losses resulting from earthquakes and to assess the effectiveness of TMD, fragility curves can be used. The analysis of the results indicates that tuned mass damper is effective in reducing structural deformations and hence improving the fragility curves.

## REFERENCES

1. Housner, G.W., Bergman, L.A., Caughey, T.K., Chassiakao, A.G., Claus, R.O., Masri, S.F., Skelton, R.E., Soong, T.T., Spencer, B.F. and Yao, J.T.P. (1997). “Structural Control: Past, Present, and Future”, *Journal of Engineering Mechanics, Vol.* 123, *No.* 9, *pp.* 897-971.

2. Sladek, J.R. and Klingner, R.E. (1983). "Effect of Tuned Mass Dampers on Seismic Response", *Journal of Structural Engineering, Vol.* 109, *No.* 8, *pp.* 2004-2009.
3. Sadek, F., Mohraz, B., Taylor, A.W. and Chung, R.M. (1997). "A Method of Estimating the Parameters of Tuned Mass Dampers for Seismic Applications", *Earthquake Engineering and Structural Dynamics, Vol.* 26, *pp.* 617-635.
4. Palazzo, B. and Petti, L. (1999). "Combined Control Strategy: Base Isolation and Tuned Mass Damping", *ISET Journal of Earthquake Technology, Vol.* 36, *No.* 2-4, *pp.* 121-137.
5. Wang, A.P., Fung, R.F. and Huang, S.C. (2001). "Dynamic Analysis of a Tall Building with a Tuned-Mass-Damper Device Subjected to Earthquake Excitations", *Journal of Sound and Vibration, Vol.* 244, *No.* 1, *pp.* 123-136.
6. Bakre, S.V. and Jangid, R.S. (2007). "Optimum Parameters of Tuned Mass Damper for Damped Main System", *Structural Control and Health Monitoring, Vol.* 14, *pp.* 448-470.
7. Taniguchi, T., Kiureghian, A.D. and Melkumyan, M. (2008). "Effect of Tuned Mass Damper on Displacement Demand of Base-Isolated Structures", *Engineering Structures, Vol.* 30, *pp.* 3478-3488.
8. Chey, M.H., Carr, A.J., Chase, J.G. and Mander, J.B. (2008). "Resetable Tuned Mass Damper and Its Application to Isolated Stories Building System", *Proceedings of the* 14$^{th}$ *World Conference on Earthquake Engineering, Beijing, China*.
9. Hoang, N., Fujino, Y. and Warnitchai, P. (2008). "Optimal Tuned Mass Damper for Seismic Applications and Practical Design Formulas", *Engineering Structures, Vol.* 30, *pp.* 707-715.
10. Matta, E. (2013). "Effectiveness of Tuned Mass Dampers against Ground Motion Pulses", *Journal of Structural Engineering, Vol.* 139, *No.* 2, *pp.* 188-198.
11. Shariatmadara, H. and Razavi, H.M. (2014). "Seismic Control Response of Structures Using an ATMD with Fuzzy Logic Controller and PSO Method", *Structural Engineering and Mechanics, Vol.* 51, *No.* 4, *pp.* 547-564.
12. Aly, A.M. (2014). "Vibration Control of High-Rise Buildings for Wind: a Robust Passive and Active Tuned Mass Damper", *Smart Structures and Systems. Vol.* 13, *No.* 3, *pp.* 473-500.
13. Nigdeli, S.M. and Bekdas, G. (2014). "Optimum Tuned Mass Damper Approaches for Adjacent Structures", *Earthquakes and Structures, Vol.* 7, *No.* 6, *pp.* 1071-1091.
14. Sun, C., Nagarajaiah, S. and Dick, A.J. (2014). "Family of Smart Tuned Mass Dampers with Variable Frequency under Harmonic Excitations and Ground Motions: Closed-Form Evaluation", *Smart Structures and Systems, Vol.* 13, *No.* 2, *pp.* 319-341.
15. Wen, Y., Chen, Z. and Hua, X. (2016). "Design and Evaluation of Tuned Inerter-Based Dampers for the Seismic Control of MDOF Structures", *Journal of Structural Engineering, Vol.* 143, *No.* 4, *pp.* 1-11.
16. Vamvatsikos, D. and Cornell, C.A. (2002). "Incremental Dynamic Analysis", *Earthquake Engineering and Structural Dynamics, Vol.* 31, *pp.* 491-514.
17. Vamvatsikos, D. and Cornell, C.A. (2005). "Direct Estimation of Seismic Demand and Capacity of Multidegree-of-Freedom Systems through Incremental Dynamic Analysis of Single Degree of Freedom Approximation", *Journal of Structural Engineering, Vol.* 131, *No.* 4, *pp.* 589-599.
18. Azarbakht, A. and Dolšek, M. (2011). "Progressive Incremental Dynamic Analysis for First-Mode Dominated Structures", *Journal of Structural Engineering, Vol.* 137, *No.* 3, *pp.* 445-455.
19. Tirca, L., Serban, O., Wang, M.Z. and Modica, D.D. (2013). "Incremental Dynamic Analysis of Existing Steel Braced Frame Buildings in Moderate Seismic Zones", *Structures Congress, ASCE, pp.* 2298-2309.
20. Brunesi, E., Nascimbene, R., Parisi, F. and Augenti, N. (2015). "Progressive Collapse Fragility of Reinforced Concrete Framed Structures through Incremental Dynamic Analysis", *Engineering Structures, Vol.* 104, *pp.* 65-79.
21. Santos, K.R.M., Kougioumtzoglou, I.A. and Beck, A.T. (2016). "Incremental Dynamic Analysis: A Nonlinear Stochastic Dynamics Perspective", *Journal of Engineering Mechanics, Vol.* 142, *No.* 10, *pp.* 1-7.
22. Elias, S. and Matsagar, V. (2017). "Research Developments in Vibration Control of Structures Using Passive Tuned Mass Dampers", *Annual Reviews in Control, Vol.* 44, *pp.* 129-156.

23. Elias, S. (2018). "Seismic Energy Assessment of Buildings with Tuned Vibration Absorbers", *Shock and Vibration, Vol.* 2018, *pp.* 1-10.
24. Taha, A.E., Elias, S., Matsagar, V. and Jain, A.K. (2019). "Seismic Response Control of Asymmetric Buildings Using Tuned Mass Dampers", *The Structural Design of Tall and Special Buildings, Vol.* 28, *No.* 18, *pp.* 1-16.
25. Elias, S. and Matsagar, V. (2020). "Seismic Response Control of Steel Benchmark Building with a Tuned Mass Damper", *Asian Journal of Civil Engineering, Vol.* 21, *No.* 2, *pp.* 267-280.
26. IS 1893 (Part 1) (2016). "Criteria for Earthquake Resistant Design of Structures, Part 1 General Provision and Buildings (Fifth Revision)", *BIS; New Delhi, India*.
27. IS 456 (2000). "Plain and Reinforced Concrete-Code of Practice (Fourth Revision)", *BIS, New Delhi, India*.
28. IS 13920 (2016). "Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces-Code of Practice", *BIS, New Delhi, India*.
29. IS 875 (Part 1) (1987). "Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures (Second Revision)", *BIS, New Delhi, India*.
30. IS 875 (Part 2) (1987). "Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures (Second Revision)", *BIS, New Delhi, India*.
31. SAP 2000. "Integrated Software for Structural Analysis and Design", *Technical Reference Manual, Computers and Structures, Inc*.
32. FEMA 356 (2000). "Pre-Standard and Commentary for the Seismic Rehabilitation of Buildings", *FEMA* (2000), *(Federal Emergency Management Agency)*.
33. Guneyisi, E.M. and Altay, G. (2008). "Seismic Fragility Assessment of Effectiveness of Viscous Dampers in R/C Buildings under Scenario Earthquakes", *Structural Safety, Vol.* 30, *pp.* 461-480.