International Journal of Research In Vocational Studies (IJRVOCAS)
VOL. 2, NO. 3, December 2022, PP. 37~43
Print ISSN 2777-0168| Online ISSN 2777-0141| DOI prefix: 10.53893
https://journal.gpp.or.id/index.php/ijrvocas/index

Seismic Response Analysis of 2-Storey Mosque Structure Using Diagonal Brace Damper and Toggle Brace Damper

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To cite this article:

Fikri, J. ., & Huang, L.-J. . (2022). Seismic Response Analysis of 2-Storey Mosque Structure Using Diagonal Brace Damper and Toggle Brace Damper. International Journal of Research in Vocational Studies (IJRVOCAS), 2(3), 37–43. https://doi.org/10.53893/ijrvocas.v2i3.150

Received: November 29, 2022; **Accepted**: December 12, 2022; **Published**: December 26, 2022

Abstract: Mosque structure are typical public building where Muslim follower doing their worship and social activities. These structures are common in Indonesia where the dangerous earthquake usually happens. This paper is aimed to study of passive control of a typical 2-storey Mosque structure using diagonal and toggle brace damper. At the first, we build a simplified structure model of 2 degree of freedom (2DOF) for controlled and uncontrolled system. In this study, we create 5 cases where case 1 as uncontrolled system. Then we compared the dynamic responses of the structure cases subjected to 1940 El Centro earthquake record using time history analysis (THA). The effect of the geometric configuration of the damper attached to the structure which influenced by the magnification factor will be studied.

Keywords: Passive Vibration Control, Toggle Brace Damper (TBD), Magnification Factor, Time History Analysis (THA)

1. Introduction

Mosque is public place for Muslim follower doing their religion activities. Moreover, this place has another function as the center of social and cultural activities in abroad sense [1]. The shape of the building is very familiar with rectangle or square. In general, the roof use dome or plate structural type. This typical structure is demanded to have large free area in the center to accommodate the worshiper doing their activities.

Indonesia is located in Pacific Ring of Fire where a confluence of three-world tectonic plates (Indo-Australian Plate, the Eurasian Plate, and Pacific Plate). This result in the frequently happen of earthquake and about 80% of biggest earthquake over the world happen in this Pacific Ring of Fire [5].

The Mosques structures are very common public building in Indonesia. During the earthquake, these structures are very venerable and can lead to catastrophic failure in Mosque structure such as shown in Figure 1 [12].

Figure 1. *The failure of Mosque structure [12].*

The theory of vibration analysis of structure and dynamic responses due to earthquake has been clearly explained in the textbooks [13]. Some passive [3][11] and active control system have been developed by researcher to control the structure response due to earthquake. The experimental study on the passive control have been carried out by some researchers [6][13]. On previous study [8], the diagonal brace and toggle brace damper which attach to the 1-storey Mosque building have given a significant value of reduction of structural response due to earthquake excitation.

This paper aimed to study the passive control of a typical 2-storey Mosque structure using diagonal and toggle brace damper. Assumed, Steel pipe are used as a member of bracing and linear viscous fluid damper are considered as a damper device. In the first approach, we build a simplified structure model of 2 degree of freedom (2DOF) for controlled and uncontrolled system. Then we figure out the most effective geometric design of the energy dissipation system. Finally, we use time history analysis (THA) in order to get dynamic response of structure due to earthquake ground acceleration. The analysis was conducted using Matlab software which commonly practised by some researchers to perform analytical and numerical analysis [9][10].

2. Toggle Brace Damper System

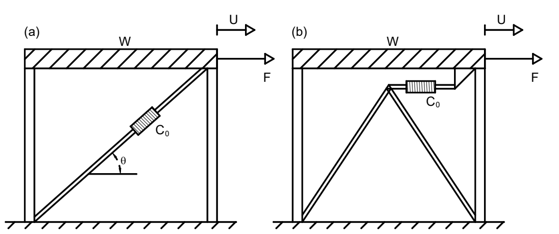
Constantinou et all [3] have described the general configuration of toggle brace damper shown in figure 2. In diagonal and chevron braced configurations, the damper displacement is less (diagonal) or equal (chevron) than the drift of the floor where the devices installed [3].

The following formula representing the configuration:

$$u_D = fu \tag{1}$$

$$F = fF_D \tag{2}$$

Where $u_D =$ relative displacement at the axis of damper; $u =$ the story drift; $F_D =$ the damper force; $F =$ the horizontal force exerted by damper on the frame and $f =$ is magnification factor ($\cos\theta$ for diagonal and 1.0 for chevron).



(a) (b)

Figure 2.(a) diagonal configuration; and (b) chevron configuration.

Assumed we utilized the linear viscous damper, then the damper force expressed by:

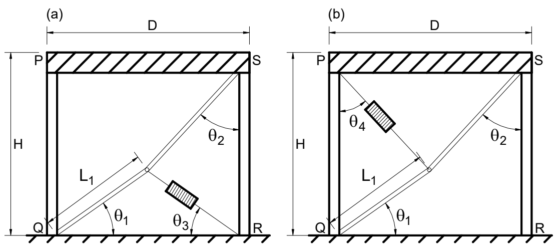
$$F_D = C\dot{u}_D = Cf\dot{u} \tag{3}$$

Then Eq. 2 can be rewritten as

$$F = C_0 f^2 \dot{u} \tag{4}$$

2.1.Geometric Parameter and Constraints of Toggle Brace Damper System.

In diagonal brace damper, the magnification factor is depended on the bracing slope. on the contrary, J. Hwang et all [6] proposed the procedure for determining the geometric of the toggle brace damper (TBD) (the upper and lower configuration) based on three dimensionless geometric parameter $\theta_1, L_1/D$ and H/D shown in Figure 3.

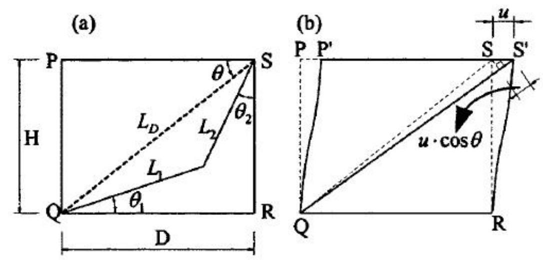


(a) (b)

Figure 3. (a) Lower TBD system; and (b) Upper TBD system.

To acquire the optimum value of magnification factor, we should refer to these constraints [6]. Regarding to the constraint, the equation can be derived considering the two braces (L1 and L2) not form a straight line or even snapping through;

$$u/H \le \left[L_1/D + \left(\frac{(H/D) - (L_1/D)\sin\theta_1}{\cos\theta_2} \right) - \sqrt{(H/D)^2 + 1} \right] \sqrt{1 + (D/H)^2} \tag{5}$$



(a) (b)

Figure 3. (a) undeform shape; and (b) deform shape.

2.2.Magnification Factors of Toggle Brace Damper System

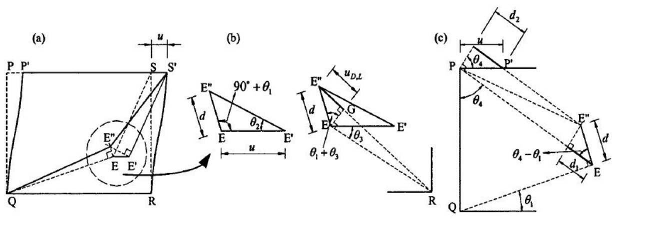
Assuming the small deformation in the frame and ignore the axial flexibility of the brace, we can derived the magnification factor of toggle brace damper based on the relationship between the deformed and undeformed frame [6]. The following equations explain the relationship.

$$f_L = \frac{u_{D,L}}{u} = \frac{\sin\theta_2 \sin(\theta_1+\theta_3)}{\cos(\theta_1+\theta_2)} \tag{6}$$

$$f_U = \frac{u_{D,U}}{u} = \frac{\sin\theta_2}{\cos(\theta_1+\theta_2)}\cos(\theta_4-\theta_1)+\sin\theta_4 \tag{7}$$

$$F = F_2\sin\theta_2 = \frac{\sin\theta_2\cos(\theta_1-\theta_3)}{\cos(\theta_1+\theta_2)}F_D = f_L F_D \tag{8}$$

$$F = F_4\sin\theta_2 + F_D\sin\theta_4 = \left(\frac{\cos(\theta_4-\theta_1)}{\cos(\theta_1+\theta_2)}\sin\theta_2+\sin\theta_4\right)F_D = f_U F_D \tag{9}$$



(a) (b) (c)

***Figure 5**. (a) deformed frame; (b) lower toggle system; and (c) upper toggle system.*

2.3. Parametric study of Magnification Factors in Toggle Brace Damper System

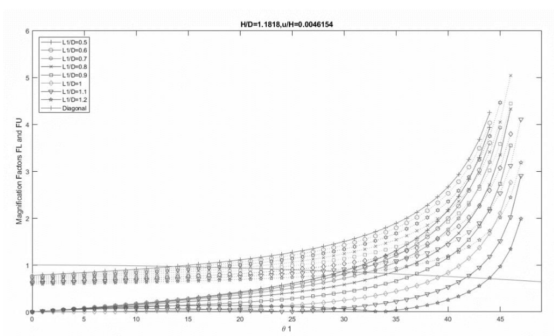


***Figure 6**. the relationship of f - θ1 1st floor of 2-story Mosque Structure*

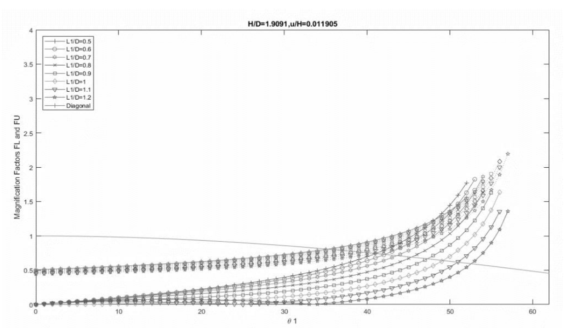


***Figure 7**. the relationship of f - θ1 2nd floor of 2-story Mosque Structure.*

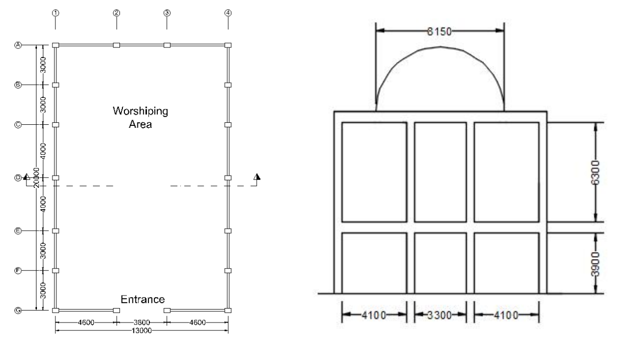
The figure 6 and 7 shows that the upper toggle brace is the best choice and the data shown in table 1.

***Table 1**. Summary of magnification Factor*

Structure	Brace Configuration				
	Diagonal	Upper Toggle			
	θ	θ1	H/D	L1/D	*f*U
1-Story	62.35	59	1.91	1.2	3.34
2-story					
1st floor	49.76	46	1.18	0.8	5.04
2nd floor	62.35	57	1.91	1.2	2.15

3. The Mosque Structure Model

The Mosque structure has a rectangle plan shape with a dome roof shown in figure 8.



(a) (b)

***Figure 8**. (a) top view; and (b) front view*

The Equation for motion for 2DOF uncontrolled system of a Mosque structure (case 1) can be expressed as

$$\begin{bmatrix} m_{s1} & 0 \\ 0 & m_{s2} \end{bmatrix}\begin{bmatrix} \ddot{u}_1 \\ \ddot{u}_2 \end{bmatrix} + \begin{bmatrix} c_{s1}+c_{s2} & -c_{s2} \\ -c_{s2} & c_{s2} \end{bmatrix}\begin{bmatrix} \dot{u}_1 \\ \dot{u}_2 \end{bmatrix} + \begin{bmatrix} k_{s1}+k_{s2} & -k_{s2} \\ -k_{s2} & k_{s2} \end{bmatrix}\begin{bmatrix} u_1 \\ u_2 \end{bmatrix} = -\begin{bmatrix} m_{s1} & 0 \\ 0 & m_{s2} \end{bmatrix}\begin{bmatrix} 1 \\ 1 \end{bmatrix}[\ddot{u}_g] \tag{10}$$

Where M_{S1}, C_{S1}, K_{S1} and M_{S2}, C_{S2}, K_{S2} denotes the mass, damping and stiffness of first and second storey of the Mosque structure, respectively. While $u(t)$ and $\ddot{u}_g(t)$ denotes the story drift and ground acceleration due to earthquake excitation.

We assumed the mass of the structure as a lumped mass, the total stiffness of the structure is estimated by the theory of structure and the structure inherent a small damping ratio

ς_0 =0.01=1% with the total controlled system has a total damping ratio ς_{tot} = 0.05=5%.

Using the Equation 4 we can form the damper force equation of the diagonal braced damper attached in 1st and 2nd floor.

$$F = n_c C_0 . \cos\theta^2 . \dot{u} \quad (11)$$

Then the damper force of upper toggle brace damper for 1st and 2nd floor can be expressed:

$$F = n_c C_0 . f_u^{\ 2} . \dot{u} \quad (12)$$

Where n_c is simply total number of damper devices each floor and for the 2-storey Mosque structure, the damping coefficient c_0 of 1st floor and 2nd floor are c_{01} and c_{02}, respectively.

Based on the equation 11 and 12, we can develop 4 cases for controlled system. For the case 2, we use both diagonal configuration for 1st floor and 2nd floor, then the matrix of equation of motion will be,

$$\begin{bmatrix} m_{s1} & 0 \\ 0 & m_{s2} \end{bmatrix}\begin{bmatrix} \ddot{u}_1 \\ \ddot{u}_2 \end{bmatrix} + \begin{bmatrix} c_{s1}+c_{s2}+n_c c_{01}\cos^2\theta^{1st}+n_c c_{02}\cos^2\theta^{2nd} & -(c_{s2}+n_c c_{02}\cos^2\theta^{2nd}) \\ -(c_{s2}+n_c c_{02}\cos^2\theta^{2nd}) & c_{s2}+n_c c_{02}\cos^2\theta^{2nd} \end{bmatrix}\begin{bmatrix} \dot{u}_1 \\ \dot{u}_2 \end{bmatrix} + \begin{bmatrix} k_{s1}+k_{s2} & -k_{s2} \\ -k_{s2} & k_{s2} \end{bmatrix}\begin{bmatrix} u_1 \\ u_2 \end{bmatrix} = -\begin{bmatrix} m_{s1} & 0 \\ 0 & m_{s2} \end{bmatrix}\begin{bmatrix} 1 \\ 1 \end{bmatrix}[\ddot{u}_g] \quad (13)$$

In the case 3, we use both upper toggle configuration for 1st and 2nd floor, the matrix of equation of motions expresses as,

$$\begin{bmatrix} m_{s1} & 0 \\ 0 & m_{s2} \end{bmatrix}\begin{bmatrix} \ddot{u}_1 \\ \ddot{u}_2 \end{bmatrix} + \begin{bmatrix} c_{s1}+c_{s2}+n_c c_{01} f_U^{\ 2}+n_c c_{02} f_U^{\ 2} & -(c_{s2}+n_c c_{02} f_U^{\ 2}) \\ -(c_{s2}+n_c c_{02} f_U^{\ 2}) & c_{s2}+n_c c_{02} f_U^{\ 2} \end{bmatrix}\begin{bmatrix} \dot{u}_1 \\ \dot{u}_2 \end{bmatrix} + \begin{bmatrix} k_{s1}+k_{s2} & -k_{s2} \\ -k_{s2} & k_{s2} \end{bmatrix}\begin{bmatrix} u_1 \\ u_2 \end{bmatrix} = -\begin{bmatrix} m_{s1} & 0 \\ 0 & m_{s2} \end{bmatrix}\begin{bmatrix} 1 \\ 1 \end{bmatrix}[\ddot{u}_g] \quad (14)$$

In the case 4, we utilize the diagonal bracing configuration at 1st floor and upper toggle brace at 2nd floor, so the matrix of equation of motions become,

$$\begin{bmatrix} m_{s1} & 0 \\ 0 & m_{s2} \end{bmatrix}\begin{bmatrix} \ddot{u}_1 \\ \ddot{u}_2 \end{bmatrix} + \begin{bmatrix} c_{s1}+c_{s2}+n_c c_{01}\cos^2\theta^{1st}+n_c c_{02} f_U^{\ 2} & -(c_{s2}+n_c c_{02} f_U^{\ 2}) \\ -(c_{s2}+n_c c_{02} f_U^{\ 2}) & c_{s2}+n_c c_{02} f_U^{\ 2} \end{bmatrix}\begin{bmatrix} \dot{u}_1 \\ \dot{u}_2 \end{bmatrix} + \begin{bmatrix} k_{s1}+k_{s2} & -k_{s2} \\ -k_{s2} & k_{s2} \end{bmatrix}\begin{bmatrix} u_1 \\ u_2 \end{bmatrix} = -\begin{bmatrix} m_{s1} & 0 \\ 0 & m_{s2} \end{bmatrix}\begin{bmatrix} 1 \\ 1 \end{bmatrix}[\ddot{u}_g] \quad (15)$$

In the case 5, we use upper toggle brace at 1st floor and diagonal brace configuration at 2nd floor, so the matrix of equation of motions will be,

$$\begin{bmatrix} m_{s1} & 0 \\ 0 & m_{s2} \end{bmatrix}\begin{bmatrix} \ddot{u}_1 \\ \ddot{u}_2 \end{bmatrix} + \begin{bmatrix} c_{s1}+c_{s2}+n_c c_{01} f_U^{\ 2}+n_c c_{02}\cos^2\theta^{2nd} & -(c_{s2}+n_c c_{02}\cos^2\theta^{2nd}) \\ -(c_{s2}+n_c c_{02}\cos^2\theta^{2nd}) & c_{s2}+n_c c_{02}\cos^2\theta^{2nd} \end{bmatrix}\begin{bmatrix} \dot{u}_1 \\ \dot{u}_2 \end{bmatrix} + \begin{bmatrix} k_{s1}+k_{s2} & -k_{s2} \\ -k_{s2} & k_{s2} \end{bmatrix}\begin{bmatrix} u_1 \\ u_2 \end{bmatrix} = -\begin{bmatrix} m_{s1} & 0 \\ 0 & m_{s2} \end{bmatrix}\begin{bmatrix} 1 \\ 1 \end{bmatrix}[\ddot{u}_g] \quad (16)$$

Where, C_s is damping coefficient of each damper; n_C is the total number of the damper member which is 2; $\cos\theta$ and f_U denotes the magnification factor of diagonal and upper toggle brace damper, respectively.

4. Free Vibration and Seismic Response Analysis of Uncontrolled and Controlled System

4.1. Free Vibration Analysis

In dynamic analysis, we can obtain the natural circular frequency, natural period and natural frequency of the system by using the Equation below:

$$[M]\{\ddot{u}\} + [K]\{u\} = 0 \quad (17)$$

$$-\omega^2[M]\{\varphi\}_i \sin(\omega t) + [K]\{\varphi\}_i \sin(\omega t) = 0 \quad (18)$$

Then, $\omega_{n1} = 54.8446$ rad/sec,

$$T_{n1} = \frac{2\pi}{\omega_{n1}} = \frac{2\pi}{54.8446} = 0.1145\text{second}, \quad (19)$$

$$f_{n1} = \frac{1}{T_{n1}} = \frac{1}{0.1145} = 8.7336\text{Hz}, \quad (20)$$

And, $\omega_{n2} = 19.6190$ rad/sec,

$$T_{n2} = \frac{2\pi}{\omega_{n2}} = \frac{2\pi}{19.6190} = 0.3202\text{second}, \quad (21)$$

$$f_{n2} = \frac{1}{T_{n2}} = \frac{1}{0.3202} = 3.1230\text{Hz}, \quad (22)$$

4.2. Seismic Response Analysis

The first-order state-space description of equation of motions are employed to investigate the seismic response,

$$[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} = [M]\{r\}[\ddot{u}_g] \quad (23)$$

Where,

M= $\begin{bmatrix} m_{s1} & 0 \\ 0 & m_{s2} \end{bmatrix}$, C= $\begin{bmatrix} c_{s1}+c_{s2} & -c_{s2} \\ -c_{s2} & c_{s2} \end{bmatrix}$,

K=$\begin{bmatrix} k_{s1}+k_{s2} & -k_{s2} \\ -k_{s2} & k_{s2} \end{bmatrix}$

u=$\begin{Bmatrix} u_1 \\ u_2 \end{Bmatrix}$, r=$\begin{Bmatrix} 1 \\ 1 \end{Bmatrix}$

State space models are conventionally written as,

$$\dot{x} = Ax + g(x) + Bu \qquad (24)$$

For 2DOF system, the equation becomes:

$$\frac{d}{dt}\begin{bmatrix} u \\ \dot{u} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -M^{-1}K & -M^{-1}C \end{bmatrix}\begin{bmatrix} u \\ \dot{u} \end{bmatrix} + \begin{bmatrix} 0 \\ -M^{-1} \end{bmatrix}\{\ddot{u}_g\} \quad (25)$$

Where,

A=$\begin{bmatrix} 0 & 1 \\ -M^{-1}K & -M^{-1}C \end{bmatrix}$ and B=$\begin{bmatrix} 0 \\ -M^{-1} \end{bmatrix}$

Dynamic responses can be solved numerically using Equation 13-16 and 18 with Wilson- θ method or Newmark- β method, and/or using Equation 25 and 4-th order Runge-Kutta Method [6] , in this equation we employ Equation 25.

5. Parameter of the Structure

The parameter of the structure are presented in the table 2,

Table 2. *Uncontrolled Mosque Structure*

Parameters	1st Floor	2nd Floor
Mass (M_S)	142255.40 (kg)	159962.63 (kg)
Stiffness (K_S)	33.317*10^7 (N/m)	7.904*10^7 (N/m)
Damping Coefficient (C_S)	137890.18 (N.s/m)	71115.44 (N.s/m)

6. Result and Discussion

6.1. Seismic Response Analysis

In seismic response analysis, we use the value of total damping ratio ς_{tot} = 5% for all controlled Mosque Structure. We employ the 1940 El Centro earthquake ground motions records for all cases. We Plot the maximum response of the displacement, velocity and acceleration shown in Figure 9 and 10.

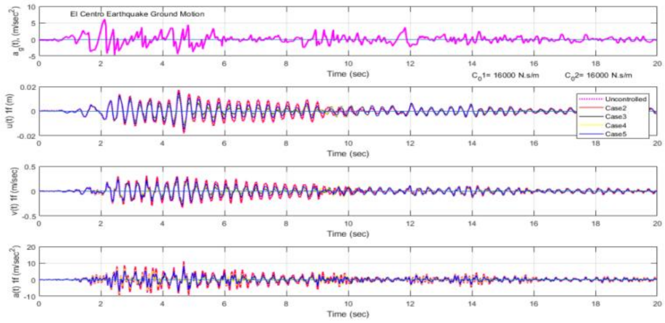


Figure 9. *Seismic responses of uncontrolled and controlled 2DOF model at 1st floor of typical Mosque structure under 1940 El Centro ground acceleration.*

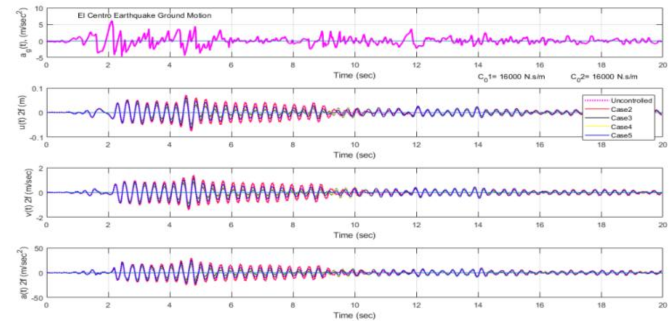


Figure 10. *Seismic responses of uncontrolled and controlled 2DOF model at 2nd floor of typical Mosque structure under 1940 El Centro ground acceleration*

6.2. Maximum Response of 2DOF System

Response of the 2 Story Mosque structure under 1940 El Centro ground acceleration are explained from table 3 to 6.

Table 3. *Maximal displacements response for uncontrolled and various controlled cases of 2DOF model of typical Mosque structure under 1940 El Centro ground acceleration*

Displacement $u_{\max}$	Case 1	Case 2	Case 3	Case 4	Case 5
1st Floor	0.0180	0.0177	0.0118	0.0134	0.0148
Reduction %		-1.77%	-34.62%	-25.87%	-17.62%
2nd Floor	0.0757	0.0742	0.0475	0.0533	0.0635
Reduction %		-2.04%	-37.27%	-29.56%	-16.20%

Table 4. *Maximal velocities response for uncontrolled and various controlled cases of 2DOF model of typical Mosque structure under 1940 El Centro ground acceleration*

Velocity $\dot{u}_{max}$	Case 1	Case 2	Case 3	Case 4	Case 5
1st Floor	0.332	0.327	0.211	0.252	0.277
Reduction %		-1.51%	-36.24%	-24.07%	-16.58%
2nd Floor	1.403	1.373	0.856	0.971	1.161
Reduction %		-2.11%	-38.98%	-30.78%	-17.23%

Table 5. *Maximal accelerations response for uncontrolled and various controlled cases of 2DOF model of typical Mosque structure under 1940 El Centro ground acceleration*

Acceleration $\ddot{u}_{max}$	Case 1	Case 2	Case 3	Case 4	Case 5
1st Floor	11.098	10.964	6.915	9.069	8.405
Reduction %		-1.21%	-37.69%	-18.29%	-24.26%
2nd Floor	29.463	28.879	19.568	20.898	24.782
Reduction %		-1.98%	-33.58%	-29.07%	-15.89%

Table 6. *Maximal absolute Accelerations response for uncontrolled and various controlled cases of 2DOF model of typical Mosque structure under 1940 El Centro ground acceleration*

Acceleration $\ddot{u}_{max}$	Case 1	Case 2	Case 3	Case 4	Case 5
1st Floor	11.098	10.964	6.915	9.069	8.405
Reduction %		-1.21%	-37.69%	-18.29%	-24.26%
2nd Floor	29.463	28.879	19.568	20.898	24.782
Reduction %		-1.98%	-33.58%	-29.07%	-15.89%

The reduction rates are shown at figure 11 and 12.

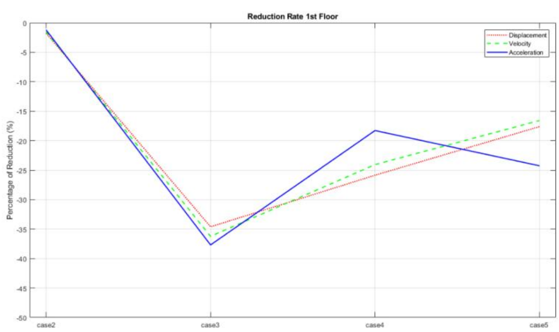


Figure 11.*Reduction rate of uncontrolled and controlled 2DOF model at 1st floor of typical Mosque structure under 1940 El Centro ground acceleration.*

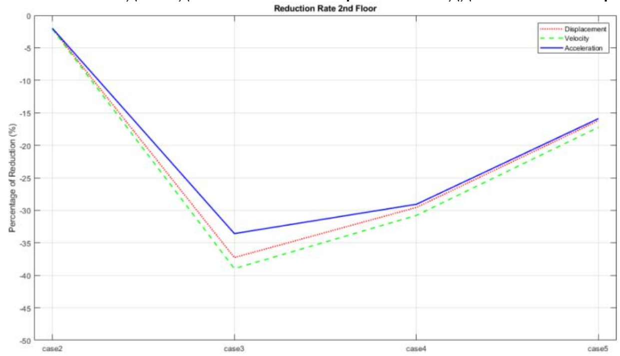


Figure 12. *Reduction rate of uncontrolled and controlled 2DOF model at 2nd floor of typical Mosque structure under 1940 El Centro ground acceleration*

It can be clearly seen that the structure which utilizing the upper toggle brace damper for both 1st and 2nd floor gives the best performance in reducing the dynamic response (displacement, velocity and acceleration).

The magnification factor is the main factor which leads to the reducing value of seismic response. The magnification factor of upper toggle brace damper configuration has amplified the damping force from the damping devices (viscous fluid damper) and it has greater amplification value then diagonal brace damper configuration.

7. Conclusion

A simplified structure model of 2 degree of freedom (2DOF) for both controlled and uncontrolled system is utilized, respectively on the comparative study of passive vibration control of typical Mosque structure using diagonal brace damper and toggle brace damper.

In seismic response analysis, by using the same damping coefficient obtained from the total damping ratio of ς_{tot} = 5% for all controlled system, it shows that the case 3 gives the best value of reduction of structural response due to earthquake excitation. So it can be concluded that the case 3 > case 4 > case 5 > case 2 > case 1 for the structure response reduction.

References

[1] Chopra, A. K., Dynamic of Structures: Theory and Application to Earthquake Engineering, 3rd edition, 2007.

[2] Constantinou, M. C., Soong, T. T., Dargush. G. F., Passive Energy Dissipation System for Structural Design and Retrofit. Multidiciplinary Center for Earthquake Engineering Research, University of New York at Buffalo, Buffalo, New York. 1998.

[3] Constantinou, M. C., Tsopelas, P., Hammel, W., and Sigaher, A. N. Toggle-brace-damper seismic energy dissipation systems. J. Struct. Eng., 127 (2), pp.105-112. 2001.

[4] Dalmeri, D. (2014). Revitalisasi Fungsi Masjid Sebagai Pusat Ekonomi Dan Dakwah Multikultural. Walisongo: Jurnal Penelitian Sosial Keagamaan, 22(2), 321-350. doi:https://doi.org/10.21580/ws.22.2.269

[5] Finaka, A. W. (n.d.). Indonesia di Lingkaran api pasifik:

Indonesia baik. indonesiabaik. Retrieved 2022, from https://indonesiabaik.id/infografis/indonesia-di-lingkaran-api-pasifik

[6] H. Gavin, "Numerical integration for structural dynamics," Department of Civil and Environmental Engineering, Duke University, Durham, NC, 2001.

[7] Hwang, J.-S., Huang, Y.-N., Hung. Y.-N., Analytical and experimental study of toggle-brace-damper systems. J. Struct. Eng., 131(7). pp.1035-1043. 2005.

[8] J. Fikri and L. -J. Huang, "Passive vibration control analysis of a mosque structure using diagonal bracing damper and toggle bracing damper," 2018 IEEE International Conference on Applied System Invention (ICASI), 2018, pp. 331-334, doi: 10.1109/ICASI.2018.8394601.

[9] Lindfield, G., & Penny, J. (2018). Numerical methods: using MATLAB. Academic Press.

[10] Nguyen, N. D., Le, T. L., & Thoi Le, N. (2022). Design and simulation of the controller proportional - integral - differential (PID) for unmanned surface vessels. International Journal of Research in Vocational Studies (IJRVOCAS), 1(4), 01–10. https://doi.org/10.53893/ijrvocas.v1i4.61

[11] Sleemah, A. A., and Constantinou, M. C., Investigation of seismic response of buildings with linear and nonlinear fluid viscous dampers. Rep. No. NCEER-97-0004, National Center for Earthquake Engineering Research, State University of New York at Buffalo, Buffalo, New York. 1997.

[12] Wirawan, J. (n.d.). Gempa Aceh ingatkan pentingnya bangunan tahan GEMPA. BBC News Indonesia. Retrieved , 2022, from https://www.bbc.com/indonesia/majalah-38441281

[13] Zhang. R., He. H., Weng. D., Zhou. H., Ding. S., Theoretical analysis and experimental research on toggle-brace-damper system considering different installation modes. Scientia Iranica., 19(6), pp. 1379-1390. 2012.