EFFECTIVE PLACEMENT OF MULTIPLE TUNED MASS DAMPERS IN IRREGULAR SHAPED REINFORCED CONCRETE BUILDING

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ABSTRACT

Using passive control devices to minimize the effect of lateral forces is a new door to make earthquake-resistant structures. Dampers absorb lateral forces induced by wind and earthquakes. There are several types of dampers in use such as Viscous dampers, Viscoelastic dampers and Friction dampers etc. Tuned Mass Damper is used for this study, it's a type of mass damper that utilizes the inertia property of a big mass to dissipate the lateral forces. For the evaluation of the response of re-entrant corner reinforced concrete buildings TMD is used in this study. TMDs have been successfully dissipating energy produced from lateral forces and ultimately lowering the vibration in the building. To address the complexities of irregularly shaped buildings, the study introduces a re-entrant corner building into the analysis. Then the single TMD was divided into 8 TMDs. The effective placement of the MTMD is obtained through a trial-and-error procedure. First, the 8 TMDs are placed symmetrically as close to center as possible. Subsequently, for following models, the distance is increased uniformly to understand the structure reaction with respect to the center of the structure. The maximum distance from center concluded the trial and error as the 8 TMDs are placed in the exterior corner of the structure. The process is done by using ETABS 18. For the analysis, Time History and Response spectrum functions are used to determine the reaction of the structure. A declination of base shear and vibration of the structure is noticed after TMDs and MTMD are introduced to the structure. The obtained result showed the maximum reduction in displacement was found in using 8 TMDs at the exterior corner which is about 41.24% in the top floor. The findings show that the rate of reduction of displacement gradually decreases when the MTMDs are placed far from the center of the model. The trial and error data conclude that the MTMDs work more efficiently with the distance from the center of a re-entrant corner building.

Keywords: *ETABS; MTMD; BNBC2020; TMD; Dampers.*

1. INTRODUCTION

With the rapid growth of urbanization, the cities are seeing massive migration of people from rural areas. “68% of the world population is projected to live in urban areas by 2050”, says the UN. With the huge wave of people coming to cities and urban areas, the problem arises to accommodate them in the limited space on the ground. So, the buildings and structures need to rise higher towards the sky. Doing so also increases the possibility of structures getting damaged by seismic forces. The same thing can be said for Bangladesh too. As Bangladesh is progressing towards becoming a developing country, it is also facing such problems of urbanization. (Islam et al., 2021). In order to accommodate the growing population, residential buildings are increasing in size. This new development resulting in more high-rise buildings. High-rise buildings are more susceptible to horizontal movements induced from wind and earthquake.

As Bangladesh lies on top of three active tectonic plates, which are the Indian plate, the Eurasian plate, the Burmese plate there lies a great potentiality of a massive earthquake in the region (Al zaman & Jahan Monira, 2017). Sylhet region, in particular, lies very close to the Dauki fault line, where a massive earthquake happened in 1897, which caused the Shillong plateau to rise violently almost 11 meters high (Bilham & England, 2001). Ram Krishna Mazumder and Abdullahi M. Salman conducted a study that shows the vulnerability of urban side of Sylhet under magnitude 8 and magnitude 7.6 (Mazumder & Salman, 2019).

After considering all the issues, taking measures against earthquakes is not only necessary, but it should be a basic consideration of structural design in this region. To minimize the effects of earthquakes, many passive control devices are used in buildings (Towashiraporn, 2008) A passive control device does not need an additional power source to mitigate the effects of dynamic loadings on structures. Ahsan Kareem, Tracey Kijewski and Yukio Tamura discussed recent technologies used for minimizing the structural responses of high-rise buildings and how axillary damping devices are used in developed countries (Kareem et al., 1999). These devices can be divided into three categories in term of techniques. These are mainly Energy Dissipating devices, Base isolation and Dynamic Oscillators.

Energy dissipating devices are mechanical devices that use the yield stress of solids and the incompressible property of fluid and phase transformation of materials to reduce the effects of earthquake forces. Some examples are Fluid viscous damper, Metallic yielding damper, Friction damper etc. These passive control devices are greatly effective to minimize the structural responses during earthquakes. For example: adding 56 fluid viscous dampers gave notable performances in reducing the seismic effects on building providing supplemental damping of 5.3% on 21 storied buildings (Guo et al., 2015). Friction dampers present a feasible and effective alternative to reduce earthquake effects on new and existing structures (Nielsen et al., 2022).

Dynamic Oscillators use a pendulum system with a mass and spring attached to it to counteract the dynamic response of structures against seismic vibration (Connor & Laflamme, 2014). An example of such a system is the tuned mass damper. The Tuned Mass Damper is used widely among the dampers because of its simplicity in implementation and low initial and maintenance cost (Pozos-Estrada et al., 2016). The Tuned mass damper can easily be retrofitted on old structures (Nakai et al., 2019). A tuned mass damper can easily be hidden out of sight to keep the building aesthetically pleasing. The TMD used in Taipei 101 is also an attraction to many visitors (Kourakis & Gy, 2007).

Frahm presented the first known use of TMD, a German physicist in 1909 on ship hulls to reduce its back and forth motion (Wagg, 2021). Then the main theory of Tuned mass damper was published and improved by Den Hartog in 1940, which was applied in a single degree of freedom (SDOF) system (Ozer & Royston, 2005). C.C. Chang and Henry T.Y. Yang proposed a closed loop feedback control algorithm using Active Tuned Mass Damper (ATMD). The ATMD with optimized passive properties was useful to reduce structural responses (Yang et al., 2022).

This study aims to analyze the implementation of TMD under the Bangladesh National Building Code 2020. A 20 storied irregular re-entrant corner building is taken as the vessel to conduct the study. The plus-shaped building, considered irregular shaped by BNBC 2020 (re-entrant corner-2.5.5.4), is chosen. Mohsen Khazaei, Reza Vahdani and Ali Kheyroddin conducted a study on irregular shaped buildings like L-shaped and U-shaped using near and far field records and also applied time history analysis to evaluate multiple tuned mass damper performances under seismic loading (Khazaei et al., 2020). The seismic properties of the study are similar to that of the Sylhet region’s property as described in the BNBC 2020. Here a single Tuned Mass Damper (TMD) and 8 Multiple Tuned Mass Damper (MTMD) are used to analyze the structure’s performance under seismic loading. The El Centro earthquake’s data has been considered for the time history analysis. The Time History curve of this

earthquake has been matched with the response spectrum curve of the BNBC 2020 and then used for analysis. The MTMD's are used in various structures to find the optimal location and compare the results.
The Objective of this study is to find out.

- The optimum parameters needed to set up TMD for an irregular-shaped building designed with BNBC guidelines.
- Effectiveness of single and MTMD in irregular shaped building
- Optimum location of MTMD's in structure with the trial-and-error method

2. MATERIALS AND METHODS

2.1 TMD Modelling

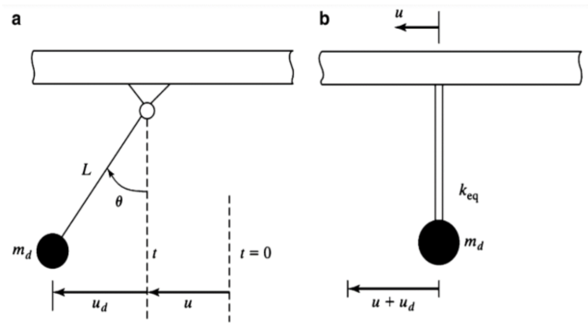
The modeling of the TMD is done by following Den Hartog TMD design for SDOF structures. Den Hartog used the concept of Frahm and worked it in an SDOF system by using TMD as a simple pendulum (J. P. Den Hartog, 1957). The relative motion of the pendulum produces a horizontal inertia force that opposes the floor motion. The following equation of motion represents the whole action as an equivalent SDOF system.

$$Tsin\theta + \left(\frac{w_d}{g}\right)(\ddot{u} + \ddot{u_d}) = 0 \quad (1)$$

Here, the tension in the cable is represented by T, w_d represents the relative horizontal displacement of the pendulum mass in the TMD, θ represents the angular displacement of the pendulum, $\ddot{u}$ is the horizontal displacement of the structure and $\ddot{u_d}$ is the relative displacement between the structure and the TMD . When θ is negligible, the following considerations apply.

$$u_d = L\,sin\theta \approx L\theta \quad (2)$$

$$T = W_d \quad (3)$$



[Fig. 1]: A simple pendulum TMD and Equivalent system (Connor & Laflamme, 2014)

The approximation transforms the original equation of motion into,

$$m_d\ddot{u}_d + \left(\frac{W_d}{L}\right)u_{\,d} = -m_d\ddot{u} \quad (4)$$

The shear spring stiffness stands

$$k_{eq} = \frac{W_d}{L} \quad (5)$$

The natural frequency of the pendulum is related to k_{eq} by,

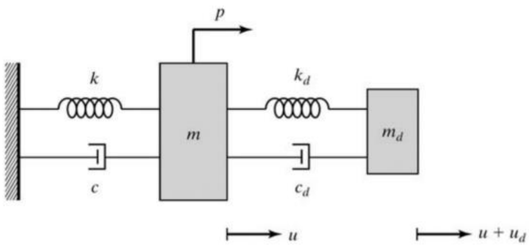
$$\omega_d^2 = \frac{k_{eq}}{m_d} = \frac{g}{L} \quad (6)$$

We know that the natural frequency of the pendulum is

$$T = 2\pi\sqrt{\frac{L}{g}} \tag{7}$$

Equation [7] is used to determine the length of the TMDs.

The other parameters are determined by Den Hartog's formula for TMDs with an SDOF system.



[Fig. 2]: Single Degree of Freedom - TMD system

The excitation of the main structure is represented by

$$\omega^2 = \frac{K}{M} \tag{8}$$

Where K and M are the primary system's stiffness and mass. Eq. (8) also refers to the eigenvalue found in the ETABS analysis. The formula works for damper's excitation too.

$$\omega_d^2 = \frac{m_d}{k_d} \tag{9}$$

The k_d represents the stiffness of the cable attached with the mass of the damper m_d. The link also acquires a certain damping coefficient to tune the whole system properly.

$$C_d = 2\zeta_d \omega_d m_d \tag{10}$$

The mass of the damper is obtained from the following simple equation,

$$\mu = \frac{m_d}{M} \tag{11}$$

μ is the mass ratio between the primary system and the mass of the damper.

Damping ratio and coefficient are the parameters that define how rapidly the Amplitude of a vibrating system decreases with respect to time. The value of the damping ratio decides whether the system is underdamped or overdamped.

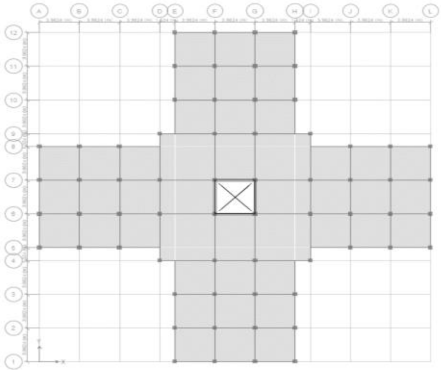
$$\zeta_d = \sqrt{\frac{3\mu}{8(1+\mu)}}\sqrt{\frac{2}{2-\mu}} \tag{12}$$

$$\zeta_{opt} = \sqrt{\frac{3}{8(1+\mu)(1-.5\mu)}} + (0.151\zeta_d - 0.17{\zeta_d}^2) + (0.163\zeta_d + 4.980{\zeta_d}^2)\mu \tag{13}$$

$$C_{opt} = 2\zeta_{opt}\omega_d m_d \tag{14}$$

2.2 Building Plan

For this study, a re-entrant cornered irregular building was selected, shown in [Fig. 3].



[Fig. 3]: Plan view of the building

The mass of the damper for $\mu = 0.05$ is given below
For a single TMD, the following value of **Table 1 and Table 2** was obtained from Eq. (1) to Eq. (8)

Table 1: Dampers properties for a single TMD

Mass (Ton)	Stiffness K_d (kN/m)	Damping coefficient C_{opt} (kN-s/m)
1345.47	17659.6144	1542.03

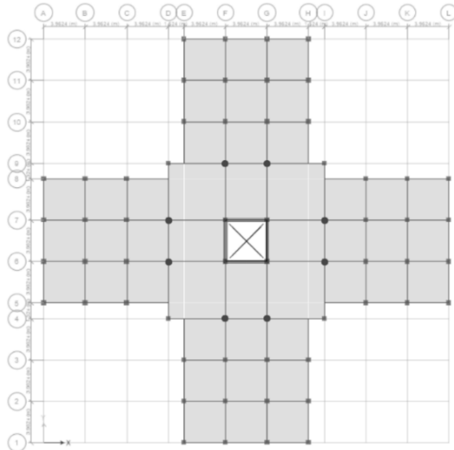
For 8 TMD's the following values are obtained:

Table 2: Damper properties for 8 TMDs

Mass (Ton)	Stiffness K_d (kN/m)	Damping coefficient C_{opt} (kN-s/m)
168.18 (X 8)	1801.15	174.11
	1924.75	179.97
	2066.02	186.36
	2180.8	191.68
	2313.23	197.01
	2454.49	203.4
	2622.24	209.7
	2848.28	218.84
$\sum$ = 1345.47	18210.92	1562.04

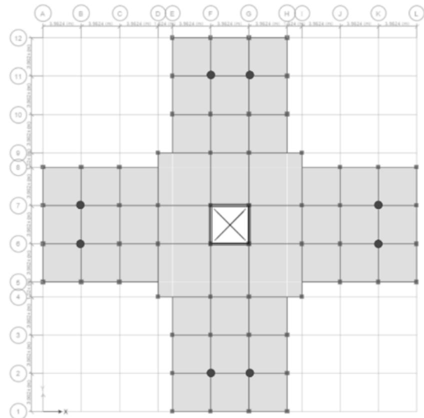
2.3 TMDs Positions

The first run of analysis to find the optimum location of MTMD in the building was done by setting the dampers in the interior section of the building (i.e. F4, G4, F9, G9, D6, D7, I6, I7 coordinates of the plan) as shown in [Fig. 4]



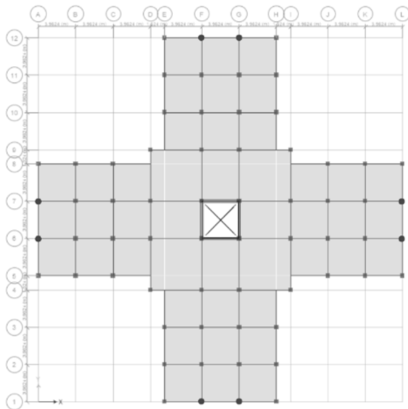
[Fig. 4]: Plan and Elevation view of TMD in the interior portion (1st trial)

Another interior simulation was done in the interior portion (i.e. F2, F11, G2, G11, B6, B7, K6, K7). The 2nd interior placement can be seen in the [Fig. 5]



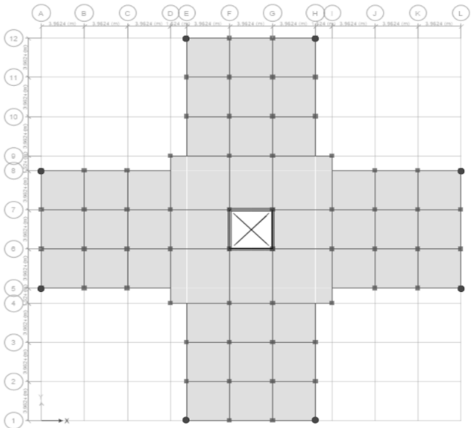
[Fig. 5]: Plan and Elevation view of TMD in the interior portion (2nd trial)

The second run of the analysis consisted of TMDs in the exterior portion of the building (i.e. A6, A7, F12, G12, L6, L7, F1, G1 coordinates of the plan) as shown in [Fig. 6]



[Fig. 6]: Plan and elevation view of TMD in the exterior portion

The third run of the analysis was performed with TMDs in the exterior corners of the structure (i.e. E12, H12, L8, L5, A8, A5, E1, H1 coordinates of the plan) shown in **[**Fig. 7]



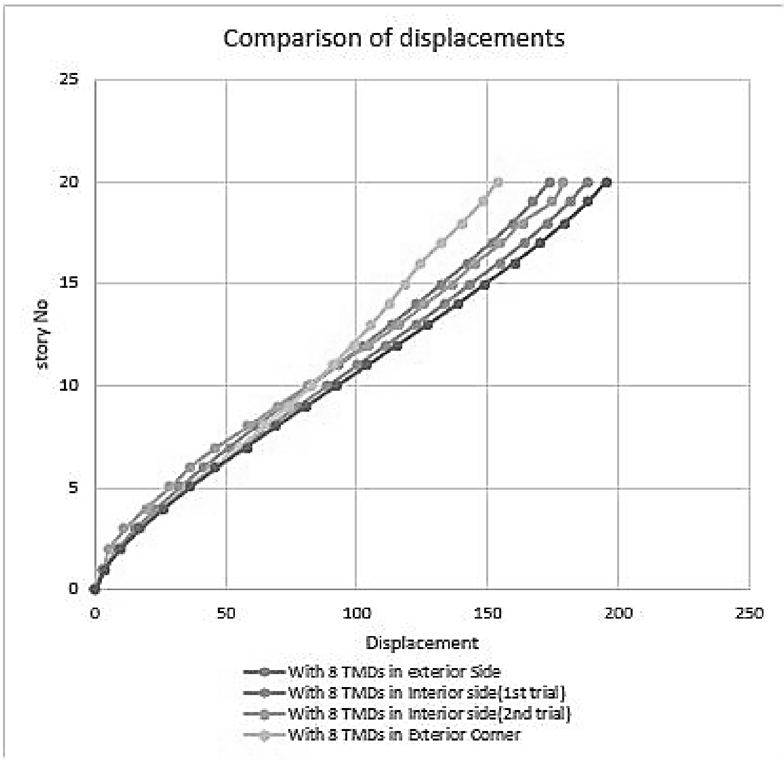
[Fig. 7]: Plan and elevation view of TMD in exterior corner

3. RESULTS AND DISCUSSIONS

The findings of this study majorly comprised with comparison of the structure subjected to the use of TMDs. There're two particular parameters are considered during the comparison; Story Displacement and Base Reactions. While the "L"-shaped and "U"-shaped is already been analyzed (Khazaei et al., 2020). These results will fill the gap for "Plus"-shaped building or axially symmetrical structures.

3.1 Story Displacement

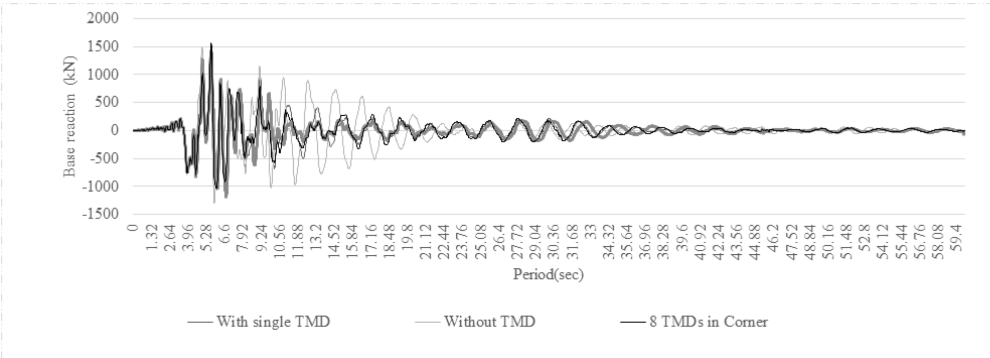
The analysis result from the ETABS shows the impact of a TMD in [Fig. 8]. It can be seen that 8 TMDs at the exterior corner of the building reduces about 41.24% of displacement than a building with no TMD and it reduces about 20% of displacement than a single TMD.



[Fig. 8]: Comparison between MTMD in different places of the building

3.2 Base Reaction

The base reaction vs. time curve shows the major control over base reaction in terms of base reactions. Under the minute-long NEWHALL earthquake, it is seen how the TMD makes the difference.
The effectiveness of the MTMDs in different placements can be seen in [Fig. 9] The figure shows the peak base reactions in time history analysis. However, the one with the best effectiveness falls behind the trend. The corner placement trend has the lowest values in its journey through the analysis which shows its effectiveness in mitigating shocks and vibration more.



[Fig. 9]: Summary comparison of Base reaction between different TMD placements

4. CONCLUSIONS

Drawing conclusions from the results and analyses presented in the preceding chapters, the following observations are made. The distribution of a single Tuned Mass Damper (TMD) into Multiple Tuned Mass Dampers (MTMD) leads to a notable 41.24% increase in decrement concerning displacement. Time history analysis indicates a consistent reduction in base reaction amplitude over time. When MTMDs are placed throughout the interior points of the structure, a 4.75% reduction is observed in the second trial compared to the first, demonstrating an 8% improvement over external MTMD placement. The trial-and-error approach highlights the efficacy of MTMDs at the exterior corners, showing a 14.1% greater displacement reduction than the second trial's interior MTMD placement.

Several limitations were considered during the formulation of these conclusions:

- Any alterations in structural member dimensions could significantly impact results, given the direct proportionality between TMD mass and structural mass.
- Due to the substantial influence of stiffness in the study, the results may not be generalizable to outputs in other irregular buildings, as both results and placement are likely to vary significantly.

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