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Self-control of high rise building L-shape in plan considering soil structure interaction

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Abstract. A new technique to mitigate irregular buildings with soil structure interaction (SSI) effect subjected to critical seismic waves is presented. The L-shape in plan irregular building for various reasons was selected, subjected to seismic a load which is a big problem for structural design especially without separation gap. The L-shape in plan building with different dimensions was chosen to study, with different rectangularity ratios and various soil kinds, to show the effect of the irregular building on the seismic response. A 3D building subjected to critical earthquake was analyzed by structural analysis program (SAP2000) fixed and with SSI (three types of soils were analyzed, soft, medium and hard soils) to find their effect on top displacement, base shear, and base torsion. The straining actions were appointed and the treatment of the effect of irregular shape under critical earthquake was made by using tuned mass damper (TMD) with different configurations with SSI and without. The study improve the success of using TMDs to mitigate the effect of critical earthquake on irregular building for both cases of study as fixed base and raft foundation (SSI) with different TMDs parameters and configurations. Torsion occurs when the L-shape in plan building subjected to earthquake which may be caused harmful damage. TMDs parameters which give the most effective efficiency in the earthquake duration must be defined, that will mitigate these effects. The parameters of TMDs were studied with structure for different rectangularity ratios and soil types, with different TMD configurations. Nonlinear time history analysis is carried out by SAP2000 with El Centro earthquake wave. The numerical results of the parametric study help in understanding the seismic behavior of L-shape in plan building with TMDs mitigation system.

Keywords: TMD; SSI; building control; irregular buildings; FEM; optimum TMD parameters; non-linear time history analysis

1. Introduction

The TMDs improve a good performance in buildings subjected to earthquake loads to mitigate its effect. The parameters of TMDs can be found by iterations to give the minimum values of top displacements and low values of base shear in both directions and torsion for multiple degrees of freedom. The torsional effects and the floor rotate along a vertical axis (with increase of lateral displacements of some points at the same level), this effect is due to non-synchronic activity of

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basement of the building. The parameters of TMD affected its response during earthquake excitation are spring stiffness, damping and mass of the TMD (which is a ratio of the building mass), these parameters are the keys of tuning, the building subjected to earthquake. The place of TMD installed in the building have a great effect in mitigates the earthquake effect on the irregularly building under seismic loads. The numerical results were found for TMDs installed on top of the structure, and through the vertical elevation of the building.

Self-control is an expression denotes that the building can resist the earthquake effect at any angle of earthquake exposure the building with any plan configurations without the need of redistributing the control devices on the building.

Expansion and structural joints are solution for slender and irregular in plan building to escape of the harmful effect of these building under seismic loads, in high rise building the effect of these joints when the building subjected to earthquake is pounding between these parts which can be occurred especially if these gaps are not sufficient in distances which allow pounding between these parts. Rectangular high rise buildings with irregular in plan floors suffer from torsional effects when subjected to earthquake. An unequal displacement of points per floor in the same level was an evidence of irregular movement at the same level. Some retrofit methods are effective in limiting cases for seismic loads, but it cannot be used for other types of building and requires special design of these buildings and among these methods TMD to mitigate irregular in plan floor buildings (torsional response on buildings).

Gilani*et al.* (2012) proved that the addition of TMD will alter the fundamental mode of the concrete core by introducing two modes, so that the most of seismic response reduced by TMD with mass ratio 20% to the concrete core, whenever increase to 25% the response decreased by 30 to 40%.

Lu *et al.* (2010) used twelve pairs of TMD weighing 115 tons total in the Expo Culture Centre in Shanghai, China to mitigate the vibration response of it, which were tuned to the vertical vibration frequency of the structure, and proved that the TMD reduce the floor vibration acceleration by nearly 15%.

Lu *et al.* (2016) proposed a TMD system for a high rise building subjected to wind with details of wind tunnel experiment to investigate performance of the proposed system configuration. The theoretical analysis shows agreement with the experimental results, and proves the effectiveness of the damping performance of the particle TMD system under wind excitation.

Salvi and Rizzi (2016) studied optimum tuning formulas for a passive TMD; to achieve optimum TMD parameters two fitting models presented and the optimum TMD parameters which reduced the structural dynamic response carried out on SDOF and MDOF buildings systems.

Rezaee and Mousaad (2016) studied different damping enhancement technologies used in offshore wind turbines and they concluded that: accomplishments of the tested system are similar and improve both the performance and the resilience of the wind turbine. VDs are the most robust; one of the advantages of TSDs is their capability to suppress a wide range of frequencies.

Wang and Lin (2015) developed an analysis procedure for extracting the parameters of TMD combined building and this procedure validated by shaking-table tests which proved that procedure can be applied to health monitoring of buildings.

Domizio*et al.* (2015) studied the TMD-building system performance subject earthquakes with two analyses and different TMD parameters; they showed that the value of mass ratio 1% is the best value using for optimization methods.

Aly (2015) studied hybrid TM/MR dampers system for a high rise building under wind loads and summarized that, increasing the stiffness of the building did not comfort and serviceability, the distribution of TMD can be oriented in the direction of the straining actions produced from the lateral force rise buildings.

Bortoluzzi*et al.* (2015) studied the using of TMD on an existing timber footbridge.

Makihara*et al.* (2015) summarized that the TMD generator can be used as an activating power supplier for electrically self-reliant SHM systems.

Aly (2014) proposed to design robust and efficient TMD for the uncertain natural frequency, the optimization objective and the input excitation (it different from the optimal parameters) which its robustness and effectiveness in reducing the responses of high-rise buildings under multidirectional wind and improved TMD in one direction by active TMD.

Sun *et al.* (2014) studied a semi-active independently variable stiffness device and a pendulum with an adjustable length and concluded that the small damping ratio and an appropriate mass ratio can produce significant reduction when compared to the case with no tuned mass damper.

Sadhu *et al.* (2014) proposed an algorithm for modal identification of structures equipped with TMD and proved that it is able to separate and identify closely-spaced modes with a frequency of separation as close as 7% and showed that the performance of algorithm decomposition is significantly affected by the presence of measurement noise while using the partial measurements.

Quaranta*et al.* (2016) used a linear TMD on the roof of linear elastic structural systems subjected to pulse-like ground motions, they found closed-form design formulations proposed to optimize the device.

Nigdeli and Bekdas (2013) used TMD to prevent the brittle fracture of the RC structures by use optimum TMD parameters which do not exceeding the compressive strength of concrete under seismic loads by random search method, and they concluded that the optimized TMD can be used for the retrofit of weak structures in mean of insufficient shear force safety.

Matta (2015) evaluated a method for cost effectiveness of TMD implemented in building and summarized that TMDs in middle-rise steel in high seismic areas may be considerably larger than traditional performance criteria.

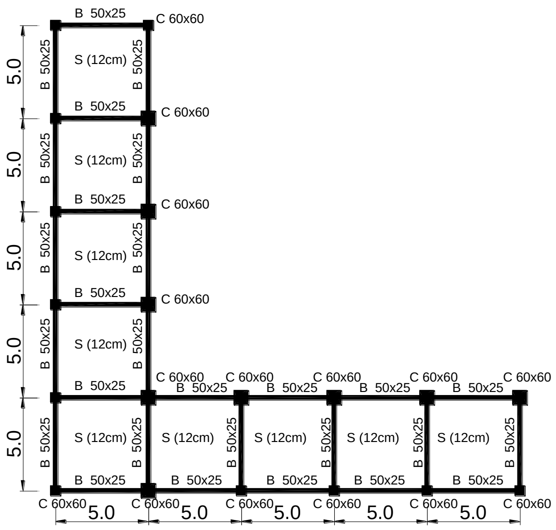
Danial and Lavan (2015) studied the using of MTMDs in building subjected to earthquake and how it control its seismic response and found that adding of mass at various locations and tuning the TMDs was effective in seismic building response control.

Nigdeli and Bekdaş (2014) used TMD to mitigate the pounding between adjacent buildings subjected to earthquake and they concluded that the use TMDs were effective on rigid and flexural buildings.

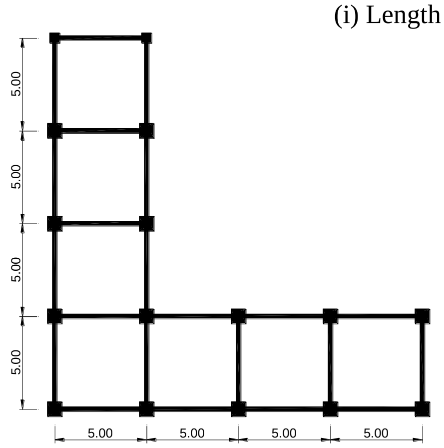
Farshidianfar and Soheili (2013) investigated the optimized parameters of TMD in high-rise buildings for different types of soils with optimization method to mitigate the earthquake effect on structures.

Bekdaş and Nigdeli (2017), discussed the problems with L in plan shape buildings for the all directions vibrations earthquake, each rectangular jointed together has different movements and vibrations which can destroy the building subjected to earthquake.

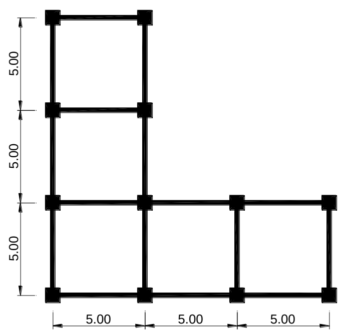
This paper explains how is the possibility of using passive TMD to reduce the seismic response of RC asymmetric buildings (high rise building, 12 storeys L-shape in plan) to choice the best location and the best numbers of TMDs. The system made of bidirectional TMDs, arranged to minimize the structural response. Different high rise structures with various dimensions are considered to prove the validation of the system. A trial and error procedure was adopted in this work the first control system is made of bidirectional TMDs located over the top floor at corners of the building, and the second system is made of corners bidirectional TMDs arranged all over the height of the building. Top displacement, base shear in both directions (x, y) and base torsion are



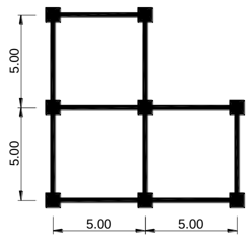
(i) Length 25 m (rectangularity ratio ¼)



(ii) Length 20 m (ratio ⅓)



(iii) Length 15 m (ratio½)



(iv) Length 10 m (ratio1)

Fig. 1 L-shape in plan HRB with different ratios (rectangularity ratios)

Table 1 Numerical data for building

Storey	12 storey
Beam size	250×500 mm
Column size	600×600 mm
Slab thickness	120 mm
Live load on the floor	2 kN/m^2

used in comparisons of different TMD arrangements in the building. The parameters were changed for TMD: (1) *m* (*mass*), *c* (*damping*), and *k* (*stiffness*), (2) placement of TMD, with respect to floor and height of the building, and (3) Types of soil like soft, medium, and hard soils, then monitor changes in the values of base shear, base torsion and top displacements for each change in these parameters.

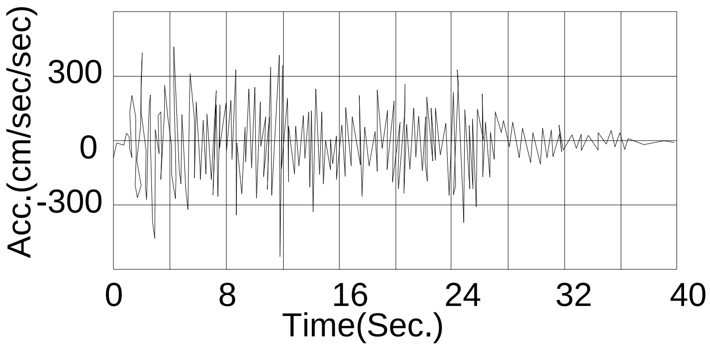
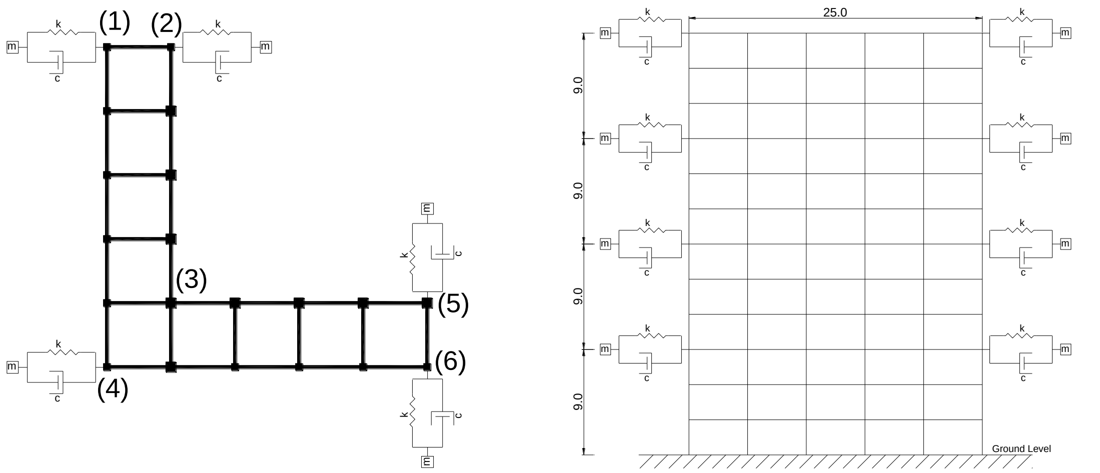


Fig. 2 Accelerograms used for the analyses El Centro



(i) TMDs and points locations in the plan of the building

(ii) TMDs locations in the elevation of the building

Fig. 3 Distributions of bidirectional TMDs in plan and elevation of the building

2. Model descriptions

Fig. 1 shows the plans with 12 floors (total height 36 m-High Rise Building (HRB)) each 3 m height all beams dimensions 250×600 mm and columns are square with dimensions 600×600 mm (as shown in Table 1), and spacing in x, and y directions are 5 m, all floors had uniformly distributed as shown in Table 1. The beams and columns are represented as frame elements in SAP2000, the slabs was represented as shell elements (The slabs were modeled with a mesh of shell elements with in-plan stiffness) and whole buildings were represent as 3D and the earthquake excitation in one direction (X-direction). The foundation of all buildings models were represented as raft foundation with projection 1500 mm from the exterior columns of the model the thickness of the plate foundation was 1200 mm. the TMDs were represented so that service in both direction (x and y directions). Fig. 1 represents 4 models of different rectangularity ratios of L-shape in plan legs, the rectangularity ratio (ratio of length to width) ¼, ⅓, ½, and 1 with height equals to 36 m (12 floors) from the foundation level. Non-linear time history analysis is carried out with SAP2000 software using El Centro Earthquake records.

Table 2 Stiffness and damping values for soils under raft foundation

Direction	Stiffness	Damping	Mass
Vertical	$k=\dfrac{4Gr}{1-\nu}$	$1.79\sqrt{k\rho r^3}$	$1.50\rho r^3$
Horizontal	$18.2Gr\dfrac{(1-\nu^2)}{(2-\nu^2)}$	$1.08\sqrt{k\rho r^3}$	$0.28\rho r^3$

G=Shear modulus, ρ=Mass density, ν=Poisson ratio, r=Plate radius. (Newmark and Rosenblueth, prentice hall (1971))

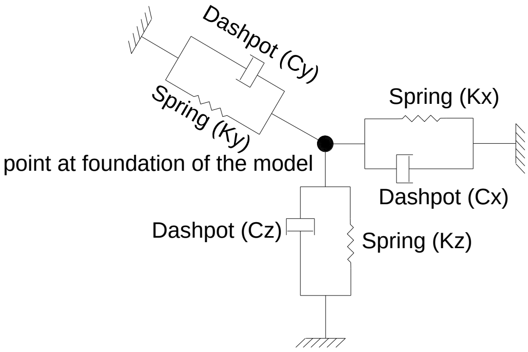


Fig. 4 3D SSI element connected to raft foundation (damper and spring in x, y and z directions)

2.1 Characteristics of ground response analyses

Fig. 2 shows the El Centro time history has pick ground acceleration (PGA) of 0.318 g. all earthquake excitation were unidirectional earthquake to show the worst case of models subjected to earthquake.

Fig. 3 shows the distribution of TMDs on the plan of models and through the elevation of the models. The TMDs on the plan of the models were distributed at the corners and service bidirectional this option used for fixed base models and hard soil cases (which reached to acceptable values of straining actions), but for the cases of medium and soft soils these TMDs distributions in plan also distributed through the elevation of the models (each 9 m heights group at corners of the model) (each TMD was bidirectional service under unidirectional earthquake).

2.2 Soil model

Three types of soils which were tested, hard, medium and soft soils. All cases of soil were represented by spring-dashpot element in 3D (Farghaly and Abdelrahim 2013), the dynamic behavior of the raft foundation resting soil is represented by spring and viscous damper system, and the values of the spring stiffness and damping coefficients were calculated using the recommended expressions by Newmark and Rosenblueth (1971) in Table 2, by equating the area of a circular plate to the square plate and solving for r. It can be seen the springs and dashpots in the three directions (X, Y, and Z directions) as shown in Fig. 4.

2.3 TMD parameters

Table 3 Equations describe the parameters values of using TMD

Author	Frequency ratio γ_{opt}	Damping ratio $\xi_{d\ opt}$	Comments
Den Hartog (1956)	$\frac{1}{1+\mu}$	$\sqrt{\frac{3\mu}{8(1+\mu)^3}}$	first equations for optimum tuning parameters of a TMD and an undamped SDOF system based on a harmonic excitation
Warburton (1982)	$\frac{\sqrt{1-\mu/2}}{1+\mu}$	$\sqrt{\frac{\mu(1-\mu/4)}{4(1+\mu)(1-\mu/2)}}$	based on random white noise acceleration excitation and an undamped SDOF system
Fujino and Abe (1993)	$\frac{\sqrt{1-\mu/2}}{1+\mu}$	$\frac{1}{2}\sqrt{\frac{\mu(1+3\mu/4)}{(1+\mu)(1+\mu/2)}}$	Based on random excitation for undamped 2DOF systems
Feng and Mita (1995)	$\frac{\sqrt{1-\mu/2}}{1+\mu}$	(i) $\frac{1}{2}\sqrt{(1+\mu)\gamma^4+\gamma^2+\frac{1-3(1+\mu)^2\gamma^2}{(1+\mu)^2}}$ (ii) $\frac{\gamma}{2}\sqrt{(1+\mu)\gamma^2+1-\frac{1}{1+\mu}}$	Based on white noise excitation of 2DOF system for displacement and acceleration
Sadek *et al.* (1997)	(i) $\frac{1}{1+\mu}$ (ii) $\frac{1}{1+\mu}\left[1-\xi_s\sqrt{\frac{\mu}{1+\mu}}\right]$	(i) $\sqrt{\frac{\mu}{1+\mu}}$ (ii) $\frac{\xi_s}{1+\mu}+\sqrt{\frac{\mu}{1+\mu}}$	Based on earthquake excitation for both undamped (i) and damped (ii) 30 SDOF systems
Rudinger (2006)	$\sqrt{\frac{(2+\mu)}{2(1+\mu)^2}}$	$\sqrt{\frac{\mu(4+3\mu)}{4(1+\mu)^3}}$	Based on white noise excitation on undamped and damped linear and nonlinear SDOF systems with linear damping = 1
Krenk and Hogsberg (2008)	$\frac{1}{1+\mu}$	$\frac{1}{2}\sqrt{\frac{\mu}{(1+\mu)}}$	based on force and white noise acceleration excitation on undamped and damped 2Dof systems
Hoang *et al.* (2008)	(i) $\frac{\sqrt{(1-6\mu)(1+\mu^2)}}{1+\mu}-0.7\xi_s$ (ii) $\frac{\sqrt{(1-\frac{8\mu}{6})}}{1+\mu}-\frac{0.7\xi_s}{1-\frac{\mu}{2}}$ (iii) $\frac{\sqrt{(1-\mu/2)}}{1+\mu}-\frac{0.7\xi_s}{1-\mu/2}$	(i) $\frac{\sqrt{\mu(1+2.5\mu+2\mu^2)}}{2(1+2.7\mu)}$ (ii) $\sqrt{\frac{\mu(1-\frac{\mu}{4})}{4(1+\mu)(1-\frac{\mu}{2})}}+0.25\mu\xi_s$ (iii) $\sqrt{\frac{\mu(1-\mu/4)}{4(1+\mu)(1-\mu/2)}}+0.25\mu\xi_s$	based on seismic excitation of damped SDOF for ranges of ground frequency ratio of $\delta=\omega_g/\omega_s$ (i) $\delta = 1$ (ii) $1 < \delta < 3$ (iii) $\delta \geq 3$

A 3D SAP2000 model developed with TMD connected to structure form components of the model. NLTMD elements were explicitly connected into the model with properties using relationship of $F=CV^{\alpha}$ where C=50 and α=0.3. Table 3 shows the equations used over the past years in this field.

Fig. 5 shows a SDF system with TMD, to deduce the equations of TMD using in multistory buildings.

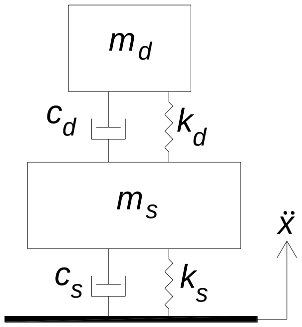


Fig. 5 SDOF system with TMD

The equations of representing a SDOF system with a TMD are:
$\mu = m_d / m_s$ (mass ratio)
$\omega_s^2 = k_s / m_s$ (frequency of the structure)
$\omega_d^2 = k_d / m_d$ (frequency of TMD)
$\xi_s = c_s / 2\omega_s m_s$ (damping ratio of the structure)
$\xi_d = c_d / 2\omega_d m_d$ (damping ratio of TMD)
$\gamma = \omega_d / \omega_s$ (frequency ratio)

The values of γ_{opt} and ξ_{dopt} obtained through equations presented in Table 3 determine the TMD stiffness and damping parameters (Den Hartog 1956)

$$k_d = \gamma_{opt}^2 \omega_d^2 m_d \tag{7}$$

$$c_d = 2\, \xi_{d\,opt}\, \gamma_{opt} \omega_d\, m_d \tag{8}$$

By examining the displacement, acceleration and base shear results, it is observed the performance of the TMDs in reducing the vibration responses which affected by the rigidity of the model; for taller and flexible structures. Equations recommended by Hoang *et al.* (2008) used for irregular structures with a fundamental period of less than 1 sec. and Sadek *et al.* (1997) equations used for structures with a period greater than 1 sec.

Khante and Nirwan (2013) provided that TMD increases the rigidity to reduce lateral displacements, torsional response decreases and the peak displacement, peak bending moment peak base shear decrease with increasing mass ratio, ($\mu \geq 0.05$ peak displacement, peak bending moment show increasing trend).

2.4 Optimum Parameter of TMD

The optimum TMD parameters μ (mass ratio), k (spring stiffness) and c (damping damper) proposed to fix two parameters and change the third one, as given in Table 4 it had eight groups applied, the first four groups were 5 TMDs on the top corners of the model (with different parameters values), the second 4 groups were also 5 TMDs distributed on the corners of the model plan but, also through the elevation of the model. The iterations began with the values extracted from Eqs. (7), (8) and then the trial performed to give the minimum values of top displacements and straining actions when the model subjected to earthquake. Table 4 show the values changed to give the optimal parameters in TMDs for different models configurations.

Table 4 Optimum parameter of TMD

Group No.	Mass Ratio ($\mu=m_d/m_s$)%	Stiffness (k_d)	Damping (c_d)	Notes
(1)	10	70	20	5 TMDs distributed on top each corner of the model
(2)	6	50	15	5 TMDs distributed on top each corner of the model
(3)	4	40	10	5 TMDs distributed on top each corner of the model
(4)	2	20	5	5 TMDs distributed on top each corner of the model
(5)	3	15	5	4 TMD groups (each group 5 TMDs on each corner of the model) distributed on the elevation of the model (each 9 m height)
(6)	2	8	3	4 TMD groups (each group 5 TMDs on each corner of the model) distributed on the elevation of the model (each 9 m height)
(7)	1.5	4	2	4 TMD groups (each group 5 TMDs on each corner of the model) distributed on the elevation of the model (each 9 m height)
(8)	0.5	1.5	1	4 TMD groups (each group 5 TMDs on each corner of the model) distributed on the elevation of the model (each 9 m height)

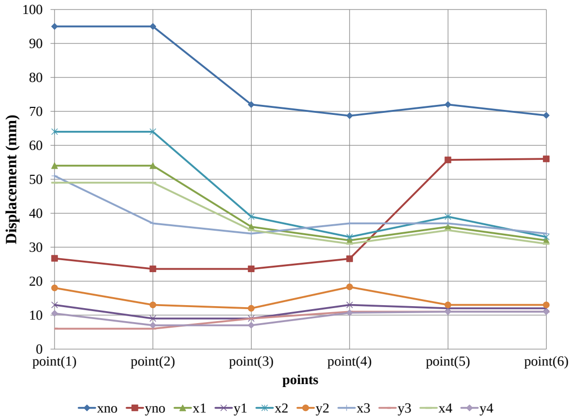
3. Parametric study

The responses of asymmetric building (L-shape in plan) using TMD subjected to unidirectional earthquake were investigated to find the optimum TMD parameters in the proposed groups. As shown in table 4 the selected TMD parameters (TMD groups parameters k=stiffness, C=damping and μ=mass ratio) were applied on the 4 models with the same height (different rectangularity ratios) and different kinds of soil beneath the raft foundation of each model and find the top displacements of the corners of each model, base shear in both directions (x, y) and base torsion, results with earthquake effect. All cases were compared with the results from the model without TMDs and fixed base cases to find the relation of these parameters of TMDs and soils with different kinds on such special buildings.

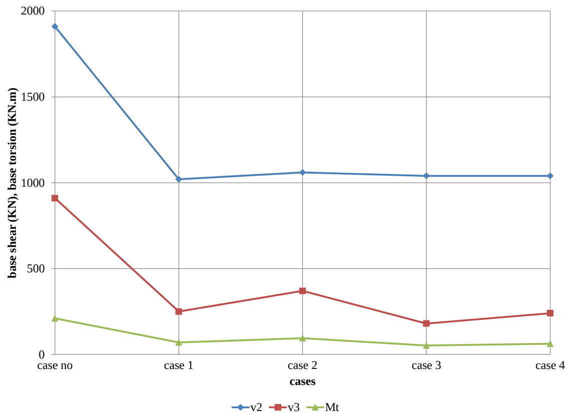
3.1 Result and discussions

The response of asymmetric building with TMD for El Centro ground motion is checked in terms of peak lateral top displacements, base shear in both directions (V1, V2), and total base torsion (M_t).

Fig. 6 shows the variation of top horizontal displacements of the corners of the models under unidirectional earthquake. Fig. 6(i) shows the horizontal displacements of the corners of 25×25 m model with rectangularity ratio equals to ¼ , Fig. 6(ai) shows the lateral displacement of top corners of the fixed model in x and y directions, the points in the earthquake direction have a large displacement in x direction than in y direction at the points 5, 6 the displacements in both directions x, y are close. The displacements in x or y direction is closed in all corners points and by using TMDs at the top of model fourth group the displacements in x direction reduced by nearly by 2.3 times than the model without TMDs and in y direction reduced by nearly 5.5 times. Fig. 6(aii) shows the base shear in both directions and base torsion in the model with and without

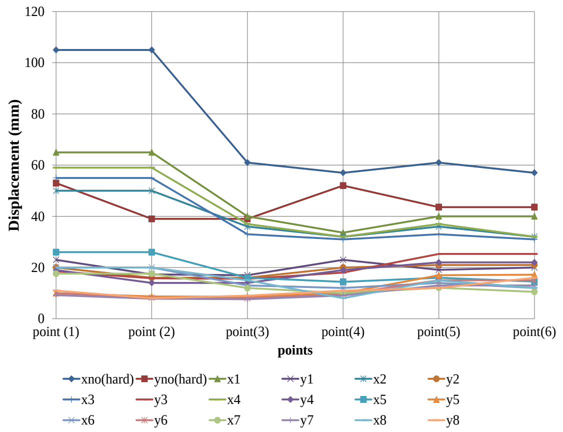


(i) Lateral top displacements of corners of the model

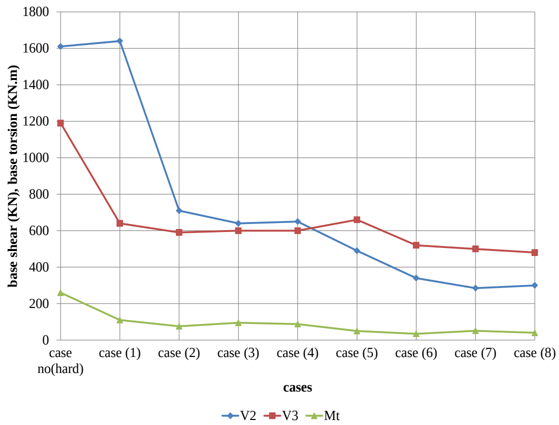


(ii) Straining actions of the model

(a) Fixed base model



(i) Lateral top displacements of corners of the model

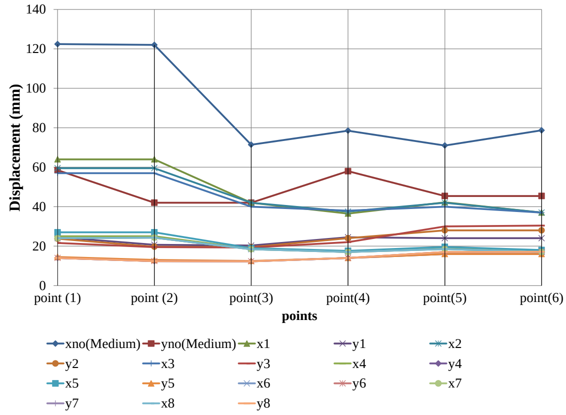


(ii) Straining actions of the model

(b) Hard soil model

TMDs, the shear in y direction generated because of the irregularity of the model (L-shape) even so the model subjected to x direction earthquake wave, base shear in x direction is bigger than y direction without TMDs by nearly 2 times, but using top model TMDs reduced base shear in x by 1.8 times and in y direction reduced by nearly 3.8 times and base torsion reduced by 3.4 times.

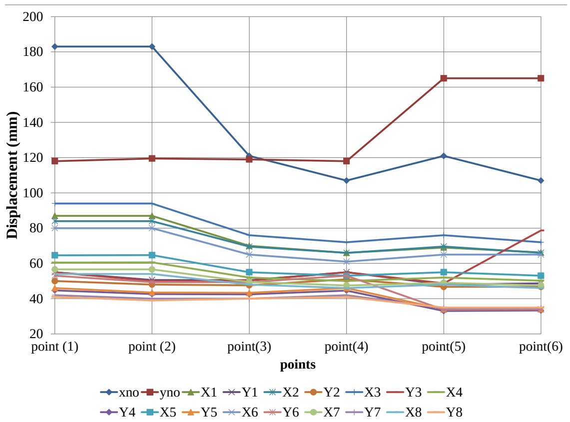
Fig. 6(bi) shows the lateral displacements of top model raft foundation founded on hard soil, using eight groups of TMDs (four at top corners and four in corners at top and through the model) the efficiency of using TMDs on the top and through the model reduced x and y lateral top displacements by nearly 5 and 4.5 times respectively than model without TMDs. Fig. 6(bii) shows the straining actions using TMDs in different configurations (top corner or corner through TMDs) after case (6) the straining actions are constant for all forces (x, y base shear and base torsion) the lowest values of base shear in x and y directions are is reduced by nearly 5.3 and 2.5 times respectively, the effect of distribution TMDs through the elevation of the model are shown as reducing straining actions by nearly 2.3 and 1.3 times than top corner TMDs and torsion nearly reduced by 6.5 times when use TMDs on corners through the model.



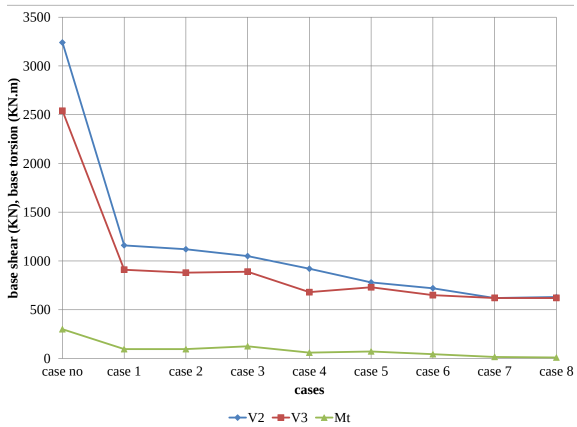
(i) Lateral top displacements of corners of the model

(ii) Straining actions of the model

(c) Medium soil model



(i) Lateral top displacements of corners of the model



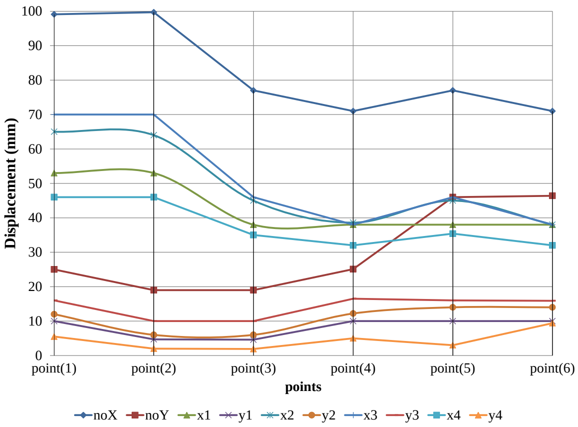
(ii) Straining actions of the model

(d) Soft soil model

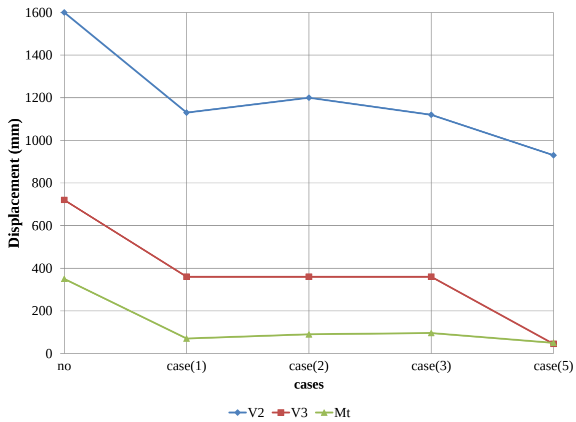
Fig. 6 Results of model rectangularity ratios ¼

Fig. 6(ci) shows top lateral displacements of the model founded on medium soil using TMDs with different configurations, there is dispersion in the values of the displacements in both directions and the using of TMDs on corners through the model reduced displacements in x and y directions by nearly 7 and 6 times respectively than the case without TMDs. Fig. 6(cii) shows the effect of using TMDs with different configurations on the straining actions of the model, the base shear in both directions are nearly equals until case (4) but base shear in x direction reduced by nearly 4 times than without case but it is reduced by 1.5 times than y direction, base shear reduced by 2.6 times than without case and base torsion nearly decreased by 5.5 times than without case.

Fig. 6(d) shows top displacements and straining actions of the model founded on soft soil. Fig. 6(di) shows the top lateral displacement of the model of the TMDs at corners through the model as four groups gives the minimum values of the lateral displacements in x and y directions and that the torsion effect increased in the change soil type to soft soil, as shown in increasing top displacements in points 5 and 6 of the model with respect to points 1 and 2, displacements

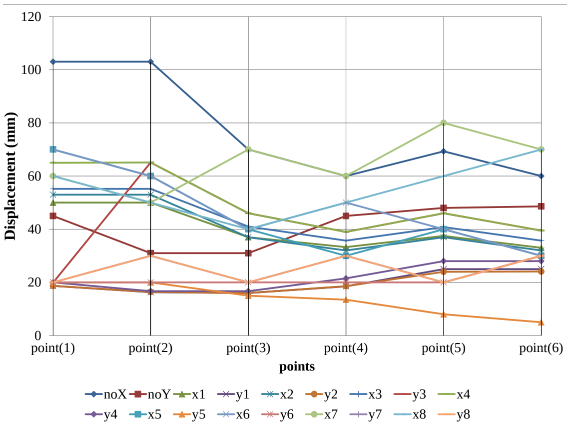


(i) Lateral top displacements of corners of the model

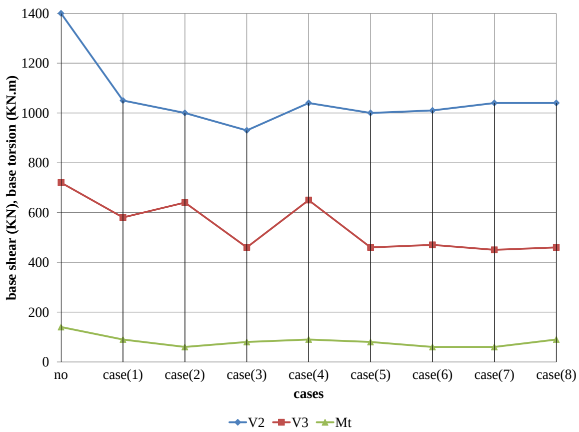


(ii) Straining actions of the model

(a) Fixed base model



(i) Lateral top displacements of corners of the model

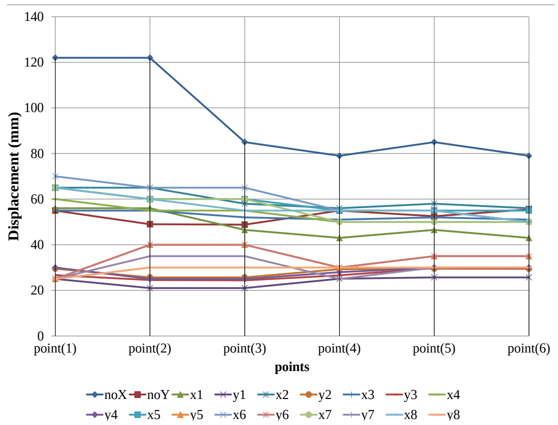


(ii) Straining actions of the model

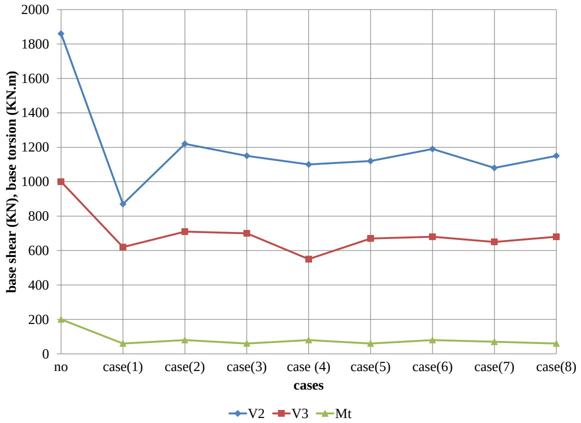
(b) Hard soil model

decreased by 3 and 4 times than the case of without and the effect of TMDs alike top or through the model and the big effect of torsion disappear even so the big value of the displacements. Fig. 6(dii) shows the straining actions of the model, base shear in both directions are nearly identical and the distribution of TMDs through the model give the most powerful effect in reducing base shear in both directions, reduced by nearly 5 times, and the base torsion almost vanished. The base shear decreased by 1.4 times when using TMDs through the model than TMDs on top of the model.

Fig. 7 shows the straining actions of the model of L-shape in plan model with rectangularity ratio ⅓. Fig. 7(a) illustrates the straining actions of the model with fixed base, Fig. 7(ai) shows the lateral top displacement of fixed base model under earthquake excitation, the TMDs used in this case was top corners placement only, the values of top lateral displacements in both direction were calculated and showed that the difference between displacement for one plan points were different so the torsion effect appear in such case in the case of decreasing mass ratio, stiffness and damping, the lateral displacement in x and y directions decreased by nearly 2.2 and 5 times

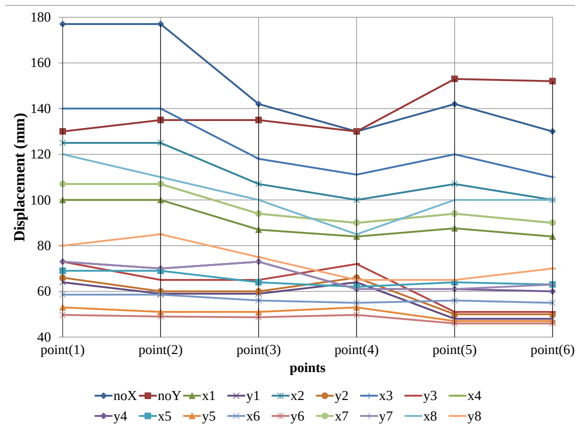


(i) Lateral top displacements of corners of the model

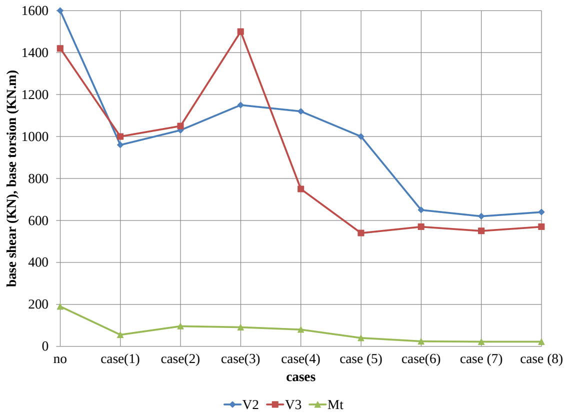


(ii) Straining actions of the model

(c) Medium soil model



(i) Lateral top displacements of corners of the model



(ii) Straining actions of the model

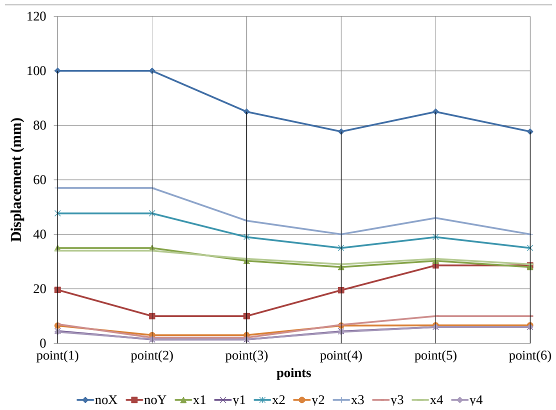
(d) Soft soil model

Fig. 7 Results of model rectangularity ratios ⅓

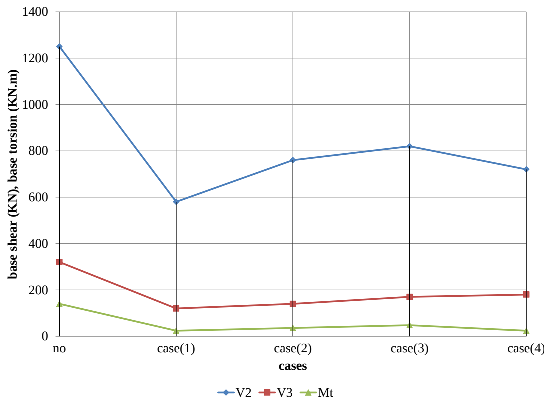
respectively than no TMDs case, the lateral displacement increased in the side exposed of earthquake and decreased in the opposite side of the model. Fig. 7(aii) shows the straining actions of the model, case 5 decreased the base shear in x and y directions and torsion by 1.7, 14 and 7 times respectively than no TMDs case.

Fig. 7(b) shows the straining actions of the model founded in hard soil; there is dispersion in the results of the lateral displacements for both TMDs configurations the use of top TMDs decrease top displacements in x and y direction by 2 and 2.1 times than no TMDs case respectively. Fig. 7(bii) represents the straining action of the model under earthquake excitation with different TMDs configurations, base shear in x and y directions and torsion decreased by 1.5, 1.56 and 1.75 times than no TMDs case respectively.

Fig. 7(c) illustrates the straining actions of the model founded in medium soil, Fig. 7(ci) shows the lateral displacements in both directions with more regularly, in case 3 (top TMDs only) lateral displacements decreased in both directions by 2 times than no TMDs case. Fig. 7(dii) shows the

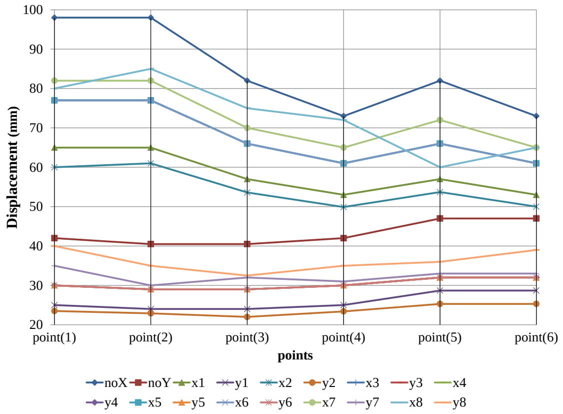


(i) Lateral top displacements of corners of the model

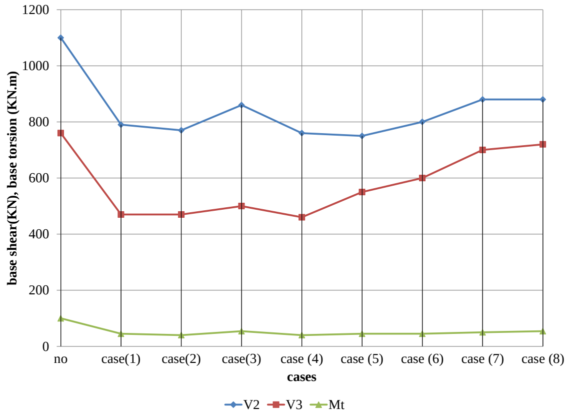


(ii) Straining actions of the model

(a) Fixed base model



(i) Lateral top displacements of corners of the model



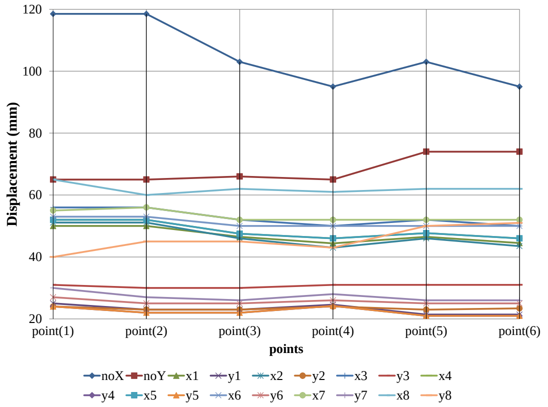
(ii) Straining actions of the model

(b) Hard soil model

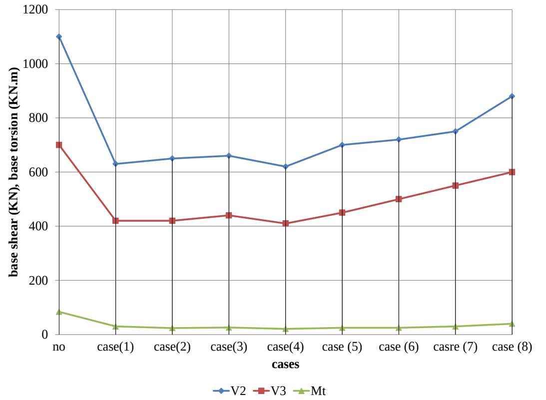
straining actions of the model and in case 4 decreased base shear in x and y directions and torsion by 2, 1.8 and 2.5 times respectively than no TMDs case.

Fig. 7(d) shows the straining actions of the model founded in soft soil, in case (6) lateral displacement in x, y directions decreased by nearly 2.7 and 2.6 times respectively than no TMDs case but this phenomenon is reversal in the values (the values of lateral displacement in y direction is bigger than the corresponding values in x direction at the other side of the model) between x and y directions. Fig. 7(dii) illustrates the straining actions of model under unidirectional earthquake, base shear in x and y directions and torsion decreased by 2.7, 2.4 and 7.9 times than no TMDs case respectively in case (5) TMDs distribution through and at top of the model.

Fig. 8 shows model with rectangularity ratio ½ , Fig. 8(a) shows the straining actions of the model with fixed base. Fig. 8(ai) represented the lateral displacements in x and y directions in which decreased by 2.75 and 5 times respectively than no TMDs case (the TMDs case only on top model). Fig. 8(aii) shows the straining actions of the model in which, base shear in x and y directions and torsion decreased by 2.1, 2.6 and 5.8 times respectively than no TMDs case, in case (1) top TMDs distribution. Fig. 8(b) shows the straining actions of the model founded on hard soil,

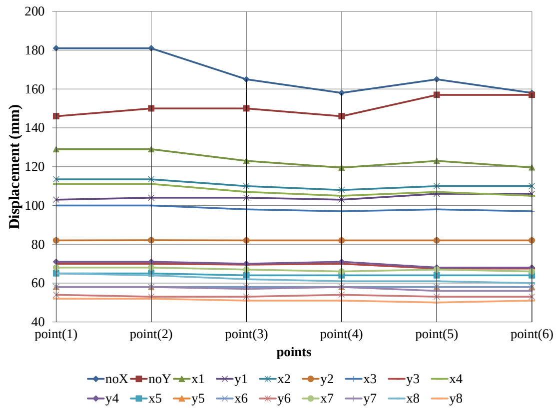


(i) Lateral top displacements of corners of the model

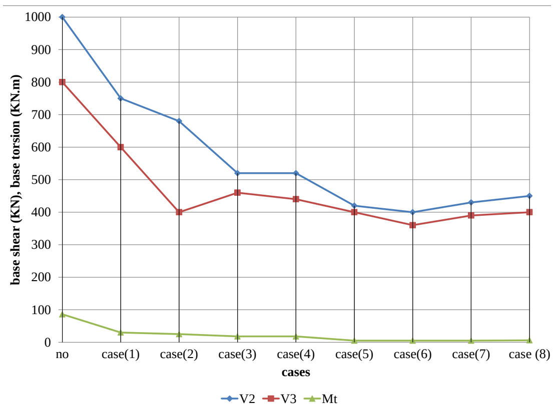


(ii) Straining actions of the model

(c) Medium soil model



(i) Lateral top displacements of corners of the model



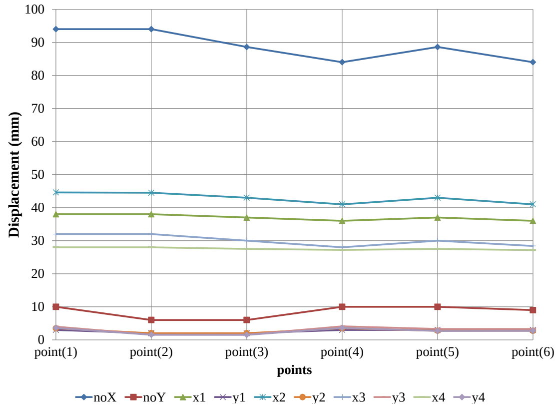
(ii) Straining actions of the model

(d) Soft soil model

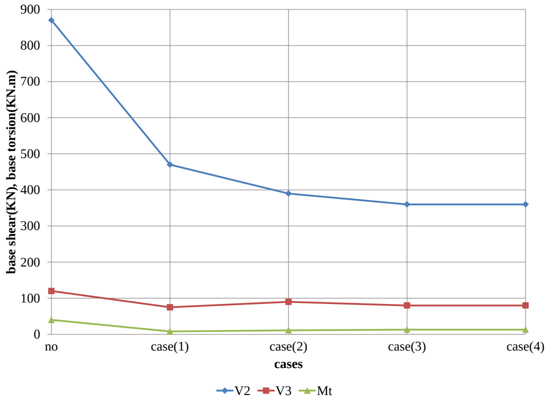
Fig. 8 Results of model rectangularity ratios ½

Fig. 8(bi) represents lateral displacement of the model in which decreased by 1.6 and 1.85 times respectively in x and y directions for case (2) of TMDs distribution. Fig. 8(bii) shows that the base shear in x and y directions and torsion decreased by 1.4, 1.6 and 2.5 times respectively in case (2) TMDs distribution.

Fig. 8(c) represents the model founded on medium soil, Fig. 8(ci) shows the lateral displacements, the displacements in x and y directions reduced by 2.2 and 3.5 times respectively in case (3). Fig. 8(cii) represents the straining actions and the reduction ratios in base shear in x and y directions and torsion are 1.7, 1.7 and 4 times respectively in case 4 of TMDs distribution. Fig. 8(d) represents the model founded on soft soil, Fig. 8(di) shows the displacements in x and y directions and the case of no TMDs shows a convergent value of x and y displacements, in case (4) TMDs distribution decreased the x and y displacements by nearly 1.6 and 2.8 times than the case of no TMDs. Fig. 8(dii) shows in case (l) of TMDs distribution which gives the minimum values of base shear in x and y directions and torsion in which decreased by 2.5, 2.2 and 17 times respectively than no TMDs.

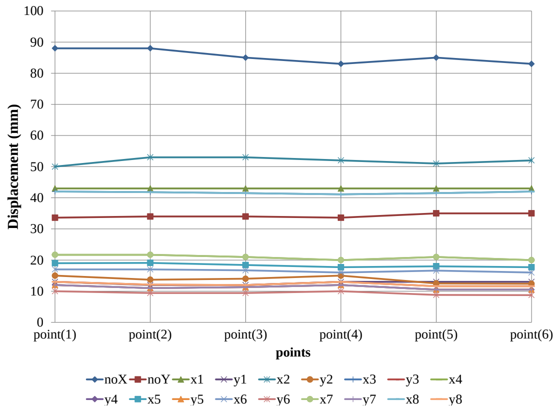


(i) Lateral top displacements of corners of the model

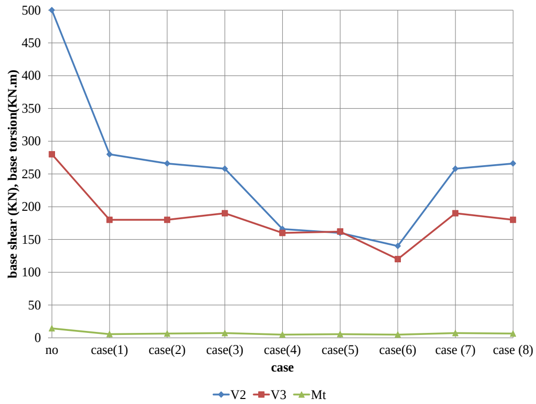


(ii) Straining actions of the model

(a) Fixed base model



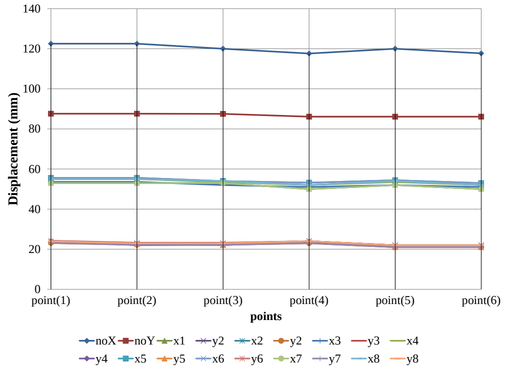
(i) Lateral top displacements of corners of the model



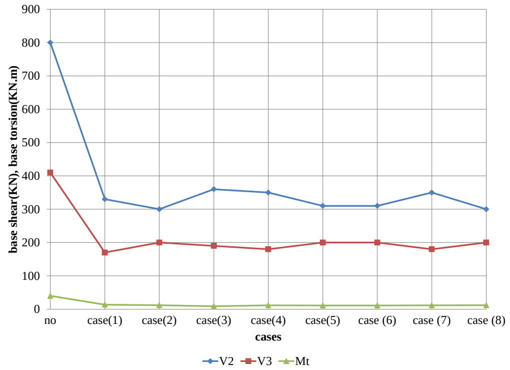
(ii) Straining actions of the model

(b) Hard soil model

Fig. 9 represents L shape in plan model with rectangularity ratio 1, Fig. 9(a) represents the straining actions of the model with fixed base. Fig. 9-ai shows the lateral displacements of the model, by using TMDs at top corners of the model, the displacements in x and y directions decreased by 3 times than no TMD case, but it is clear the torsion effect decreased because of the big rectangularity ratio (1), in Fig. 9(aii),base shear in x and y directions and torsion decreased in case (4) of TMDs distribution by 2.4, 1.5 and 3 times respectively than the no TMDs case, (it is obvious the low values of base shear in y direction and torsion). Fig. 9(b) represents the model founded in hard soil which it is suffice by using top TMDs on corners of the model, in Fig. 9(bi), x and y directions lateral displacements by nearly 5 and 4 times respectively than the no TMDs case, in case (6) of TMDs distribution, Fig. 9(bii) shows straining actions, base shear in x and y directions and torsion decreased by 3, 1.75 and 2.25 times respectively than no TMDs case but it is obvious the low values of torsion for all cases. Fig. 9(c) shows the model founded on medium soil, Fig. 9(ci) shows the lateral displacements in x and y directions which, decreased by 2.35 and 4 times respectively in case (8) TMDs distribution and the system is sufficient by using only top corner TMDs to get the efficiency of all cases. Fig. 9(d) represents the model founded on soft soil.

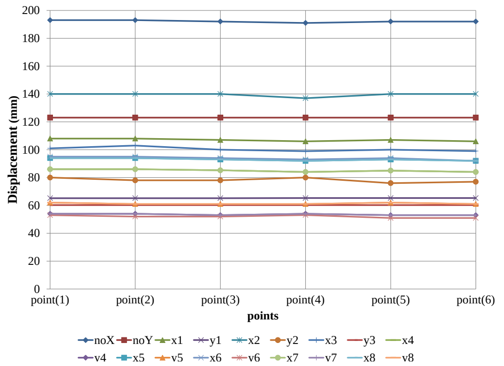


(i) Lateral top displacements of corners of the model

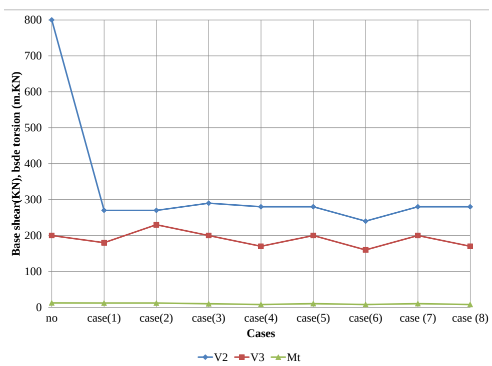


(ii) Straining actions of the model

(c) Medium soil model



(i) Lateral top displacements of corners of the model



(ii) Straining actions of the model

(d) Soft soil model

Fig. 9 Results of model rectangularity ratios $_1$

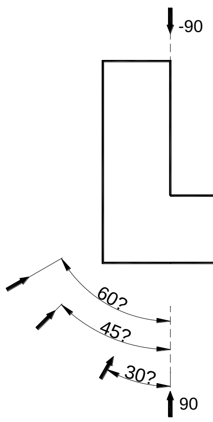


Fig. 10 direction of earthquake exposure the model

Fig. 9(di) lateral displacements in x and y directions decreased when using case (8) by 2 and 2.2 times respectively than no TMDs case. Fig. 9(dii) shows the straining actions of the model, base

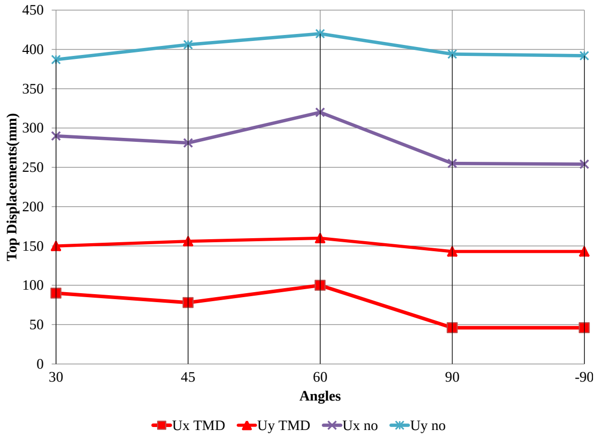


Fig. 11 Lateral displacements of the model with different earthquake exposure angles

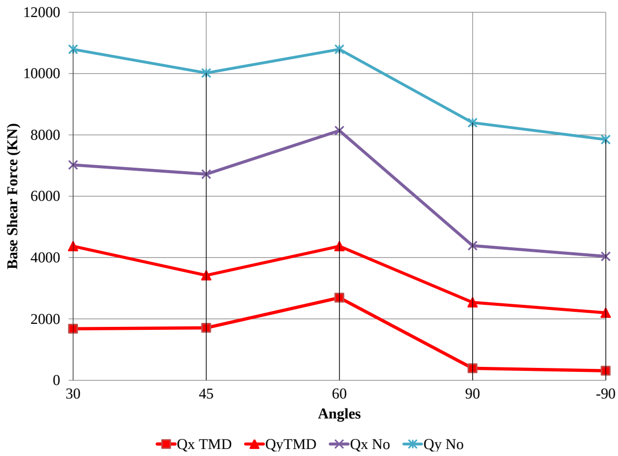


Fig. 12 Base shear in x and y directions of the model with different earthquake exposure angels

shear in x and y direction and torsion decreased by 3, 1.25 and nearly constant by 1.5 times respectively than no TMDs case.

Fig. 10 show the directions of earthquake exposure the model to show the response of the model when the earthquake direction changed. Four angles were checked 90, -90, 60, 45 and 30 which represents the most angles which will earthquake hit the model; these angles will cover all possible hit angles can the earthquake exposures the model.

Fig. 11 represents the lateral displacements in x and y directions for a fixed base model with different exposure earthquake angles to show the effective of the using control system in L-shape in plan model. Lateral displacement in y direction with TMD control system decreases by 2.67 times than the corresponding values without control system. Lateral displacement in x direction with TMD control system decreases by 6 to 3 times than the corresponding values without control system. From these results the control system (TMD at corners of the model with specific spring stiffness and damping coefficient of damper) is effective in such model case.

Fig. 12 illustrates the base shear forces in x and y directions for the ¼ rectangular ratio model under different earthquake exposure angles. Base shear in y direction with TMD control at corners

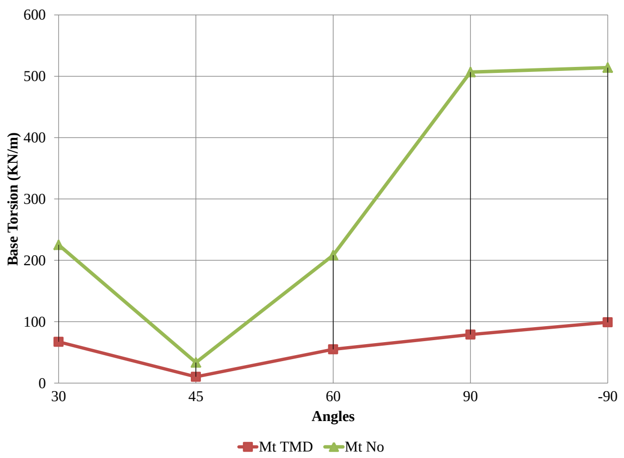


Fig. 13 Base torsion of the model under different earthquake exposure angles

of the model decreases by nearly 4 to 2.5 times than the corresponding values without TMD control system. Base shear in x direction with TMD control at corners of the model decreases by nearly 4 to 2 times than the corresponding values without TMD control system.

Fig. 13 shows torsion of the model under earthquake exposure angles. The torsion in the model decreased when the exposure angles is near to angle 45^{o} because of the symmetric of the exposure angle of the earthquake, but when the exposure angle increases until 90^{o} or decreases until angle zero because of the near of unidirectional earthquake effect, the values of torsion decrease sharply when use TMD control system than the corresponding values without TMD control system.

Angles 30 and 45^{o} show the minimum values of torsion than the biggest angels of the earthquake exposure, but TMS control system in each angles show significant reduction in the values of torsion than the corresponding values of torsion without TMD control system.

4. Conclusions

The performance of the bidirectional TMDs in reducing the vibration responses of irregular L-shape in plan model with different rectangularity ratios and different kinds of base conditions (fixed base or founded on hard, medium and soft soils) which is affected by the configurations of BTMDs and its parameters were presented. By calculating the values of the displacement, base shear in both directions and base torsion results. A parametric study was performed to get the optimum parameters of BTMDs and its distributions in the model for different kinds of soil and rectangularity ratios. These results show that, the TMDs configurations have a great effect on the response of the building, the top TMDs (distribution on each corners of the model) the most effective in fixed and hard soil and for big rectangularity ratio model, the mass variation is the effective parameter in the system than stiffness and damping values to give the smallest response of top displacements, base shear and torsion, the effect of irregular in plain shape of model increased with decrease the rectangularity ratios and so, the base shear is increased in the other direction (perpendicular to the earthquake direction) and torsion on the model. The placements of TMDs, in the top corners of the model or through the model affect the values of lateral displacements and straining actions of the model especially when the effect of soil is considering.

The following concluding remarks can be extended:

• The smallest rectangularity ratio of model the bigger top displacements and straining actions, whenever the rectangularity ratio decreases the base shear in perpendicular direction increase.

• Whenever the soil gets stronger (or fixed base), and the rectangularity ratio is smaller the best distribution TMDs are on the top of the model corners model with big mass, stiffness and damping parameters.

• Whenever the soil gets softer and the rectangularity ratio is smaller the best distribution TMDs are through the model with small mass, stiffness and damping parameters for each TMD.

• Torsion and base shear in perpendicular direction of the earthquake direction are bigger whenever the soil gets softer and the rectangularity ratio gets smaller.

• Whenever the rectangularity ratio gets bigger the model behave as irregular in plan shape model.

• The control system (TMD at the corners of the model) proved efficiency at different exposure angles of the earthquake hit the model.

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