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Wind Excitation Control In Skyscraper

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Abstract: In a skyscraper, structure vibration produces because of wind intensity. This wind intensity transferred into a dynamic load which causes the structure and along its connected portion structure create a problem. The type of high rise structure mass create a huge problem in the height increases, but the modified shape as well as some passive energy control system reducing lateral load on the structure. The effect modified the shape of the structure with great height analyses for a long, across direction and twisting of structure in Etab. Base on the analysis results, it has been concluded that effect of tune mass damper intermediate stories play a significant role to decreases the natural frequency and lateral displacement in a skyscraper.

Keyword: Chamfered Building, Tuned Mass Damper, MTMD, Skyscraper, Natural Time Period, Coefficient of Drag.

1. INTRODUCTION

The word skyscraper has been often used for high rise building that is generally 150m or taller, however, the terms such as tall, super tall and mega tall have been classified by the council on a tall building and urban habitat[CTBUH] for the building which is 200m, 300m, and 600m respectively. The Wind is air in motion relative to the surface of the earth. It varies with time and space due to unpredictable nature of wind, it is necessary to design the structure by considering the critical effect of the wind on the structure. The wind forces depend upon terrain and topography of location well as the nature of the wind, size, and shape of the structure and dynamic properties of the structure. As the wind encounters a structure, it exerts positive pressure on the windward face. The wind is then deflected around the structure and accelerated such that the velocity passing the upwind corners is greater than the velocity approaching the structure. The cost of wind tunnel test is comparatively high and conducting wind tunnel test at the preliminary design stage is uneconomical. The rapid growth of computational fluid dynamics in the virtual wind tunnel for analyzing the effect of drag and lift of the structure.

2. LITERATURE REVIEW

Huang and Li et al. [1] experimented with building height and the natural vibration frequencies to the predominant frequencies of the strong dynamic loads. The general inflow turbulence generator for large eddy simulation was based on the discretizing and synthesizing of random flow generation techniques. The author used method which was able to generate a fluctuating turbulent flow field satisfying desired spectra and spatial correlations including in homogeneity and anisotropy. It was found that combined methods fluid dynamics and solid structure dynamics computing help to resolve detailed wind-induced responses on high rise building.

Torino and Corso [2] analyzed high rise structure for horizontal forces distribution. Wake shapes were investigated by means of computational fluid dynamics [CFD] analysis. It was observed that due to the vortex created when the wind interacts with the façade corners in this point a separate air flow occurs creating air vortex. Also in twisting tower, it was found that positive and negative coefficient values were varying along lateral sides of the tower.

Said and Matsagar [3] investigated on the 76-storey building was modeled as shear type structure with a lateral degree of freedom at each floor, and tuned mass damper was installed at top story of the building. They were used Newmark's method to solve governing equation of motion of the structure. They concluded that MTMD were effectively performed vibration control under the wind load than the STMD.

2.1 Objectives-1

1. To check the drag coefficient of the modified skyscrapers.
2. To analyze the effect of the wind on a skyscraper.
3. To reduce wind excitation by MTMD on intermediate level in the structure.

3. METHODOLOGY

A. Design wind speed

The basic wind speed (V_z) any site shall be obtained from fig.1 IS 875 part 3-1987 and shall be modified to include the following wind velocity at height (V_z) for chosen structure.

a) Risk level.
b) Terrain roughness height and size of the structure.
c) Local structure.

$V_z = V_b.K_1.K_2.K_3$

V_z= Hourly mean wind speed in m/s at height Z.

V_b= Regional basic wind speed in m/s.

K_1= Probability factor (risk coefficient)(clause 5.31 of IS 875 part3-1987))

K_2=terrain and height factor (clause 5.3.2 of IS 875 part 3-1987)

K_3=Topography factor (Clause 5.3.3 of IS 875 Part 3-1987)

B. Design and pressure.

The design wind pressure at any height above mean level shall be obtained by following relationship between wind pressure and wind velocity

$$P_z = 0.6V_z^2$$

P_z=Design wind pressure in N/m^2 at height Z.

C. Gust factor method.

A gust factor, defined as the ratio between peak wind gust and mean wind speed over a period of time can be used along with other statistics to examine the structure of the wind. Gust factor is heavily dependent on upstream terrain condition (roughness)

Constant and parameters used for gust factor analysis are

i. T= Time period (pg.48, IS 875 part 3,1987)
ii. g_f= Peak factor and roughness factor(fig 8 of IS 875 part3,1987)
iii. B= Background factor(fig 9 of IS 875 part3,1987)
iv. S=Size reduction factor(fig 10 of IS 875 part3,1987)
v. E=Gust energy factor(fig 11 of IS 875 part3,1987)
vi. β=Damping coefficient(table34 of IS 875 part3,1987)
vii. G=Gust factor

$$G = 1 + g_f.r\sqrt{[B(1+\phi)^2 + \frac{SE}{\beta}}$$

viii. F_x= Along wind load on structure on strip area at height

$$F_x = C_f.A_e.P_z.G$$

D. The coefficient of drag and lift.

ρ =Density of the aerodynamic model.

v =Velocity of wind.

F_D =Drag force acting of the structure.

F_L =Lift force acting on the structure.

$$F_D = \frac{1}{2}.\rho.v^2.C_d$$

$$F_L = \frac{1}{2}.\rho.v^2.C_L$$

E. Design of tune mass damper.

1. Determine the mass and stiffness parameters, M and k of the primary system.
2. Specify the required modal damping ζ of the considered mode of the primary system.
3. Calculate the damping ratio of the secondary system.

$$\zeta_d = 2\zeta$$

4. Calculate the mass ratio.

$$\mu = \frac{2\zeta_d^2}{1-2\zeta_d^2}$$

5. Calculate the angular frequency of secondary system

$$\omega_d = \frac{1}{1+\mu}.\omega_o$$

6. Calculate M_d,C_d and k_d

$$M_d = \mu.M$$

$$k_d = \omega_d^2.M_d$$

$$k_d = \omega_d^2.M_d$$

$$C_d = 2.\sqrt{k_d.M_d}.\zeta_d$$

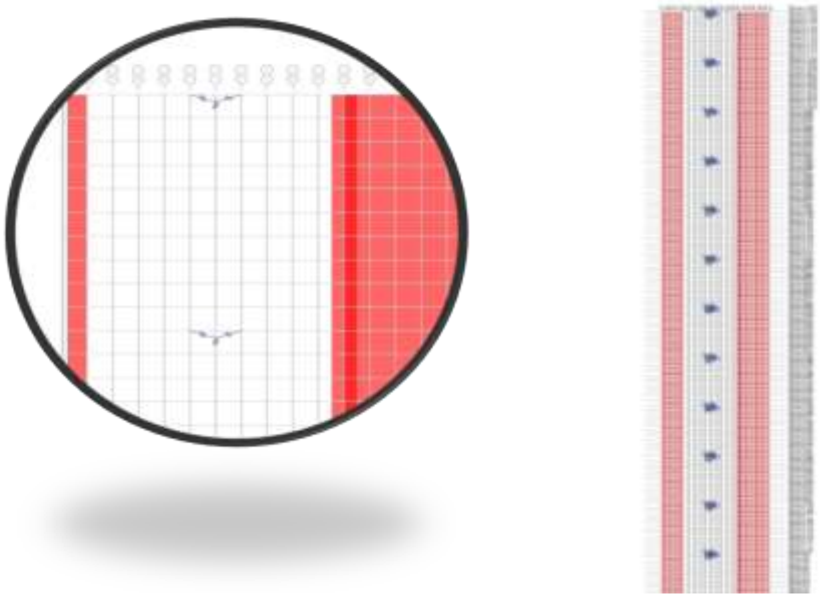


Fig.31.position of MTMD with enlarging view

3.3 Structural building detail

In the present study, wind response components at the building as per IS 875 part 3-1987 are calculated and analyzed with help of ETAB's 15V2.2

Table 3.1 Preliminary Data

No. of Storey	132
Bottom story ht.	3m
Storey ht.	3.2m
Soil type	medium
Wind speed	44 m/s
Terrain category	III
Building type	Class C
Grid size	6mX6m
Thickness of shear wall	0.6m
Material properties	
Grade of concrete	M80
	M40
Grade of steel	Fe500

	Fe415
Dead load intensities	
F.F. on floor	1.75KN/m^2
F.F. on roof	2 KN/m^2
Live load intensities	
L.L. on floors	2 KN/m^2
L.L. on roof	1 KN/m^2

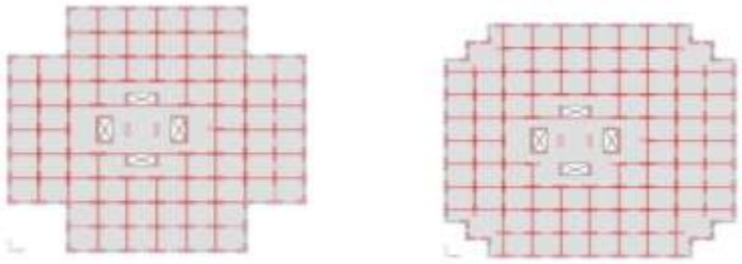


Fig.3.2. Single and Double Chamfered Model Plan

4. RESULTS

4.1 Effect along and across force, torsion

The skyscrapers are more susceptible to these three fundaments because of providing chamfered corner shape wind effect on corner reduce and these forces minimize the effect of the wind on a skyscraper.

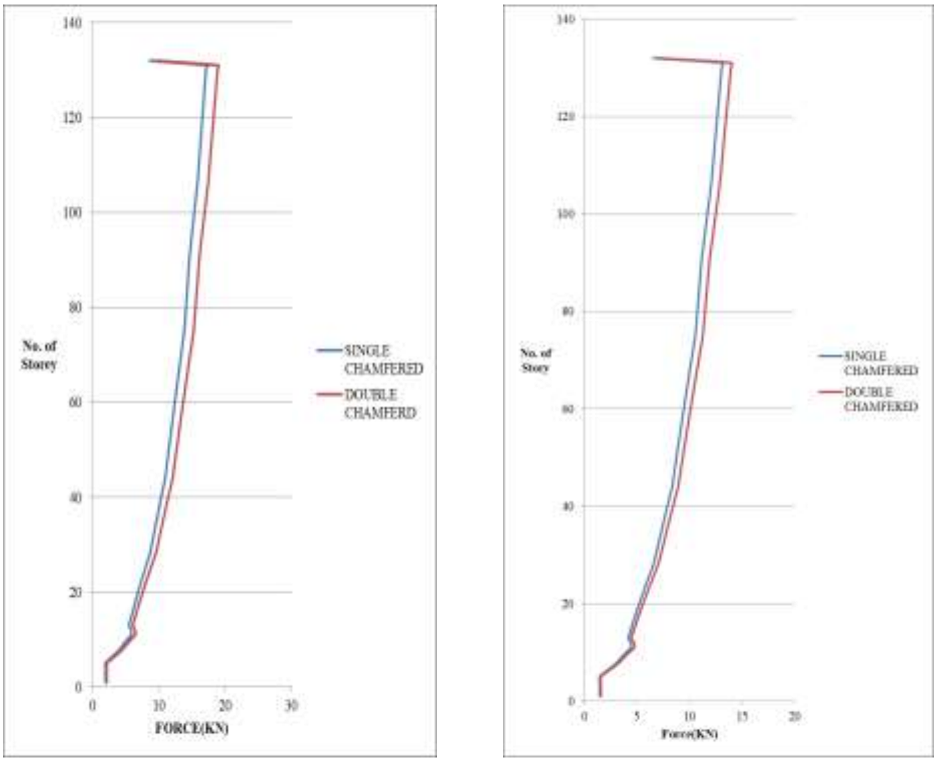


Fig. 4.1Along direction and across direction force

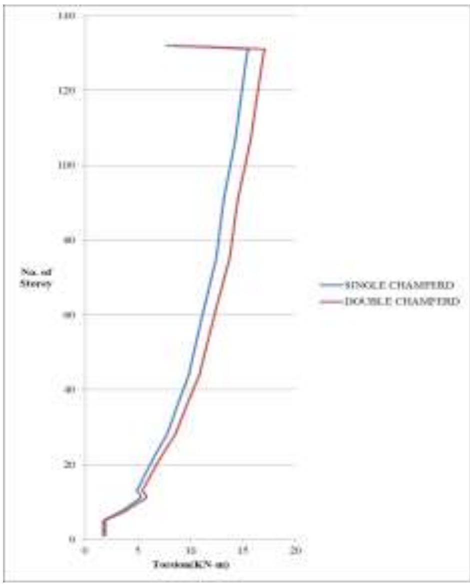


Fig. 4.2 Torsion

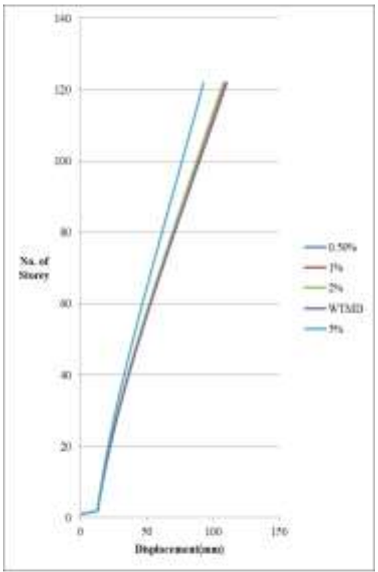
Table 4.1 Twisting angle effect of increased external damping

Single Chamfered(Radian)			Double Chamfered(Radian)		
Increased damping	static analysis	Dynamic analysis	Increased damping	static analysis	Dynamic analysis
0%	0.0036	0.0025	0%	0.0028	0.0026
0.50%	0.0036	0.0025	0.50%	0.0028	0.0026
1%	0.0035	0.00242	1%	0.0027	0.00251
2%	0.00321	0.0023	2%	0.00255	0.0024
5%	0.003	0.00219	5%	0.00232	0.00221

The along and across direction force will be reduced by amount 9.17% and 6.28% due to 5% increase damping of the tuned mass damper. The rotational angle of skyscraper reduced in the single chamfered structure is 16.67% in static analysis and dynamic analysis 12.4%. The rotational angle of skyscraper reduced in a double chamfered skyscraper is 17.14% in static analysis and 15% in dynamic analysis.

4.2 Effect of lateral Displacement

After applying tuned mass damper intermediate level to the structure the deflection reduces in both x and y direction in a skyscraper. The deflection if we compare the static condition it should be more sometime. After applying tuned mass damper intermediate level to the structure the deflection reduces in both x and y direction in a skyscraper. The lateral displacement in Direction and Y direction are reduced in a double chamfered skyscraper.



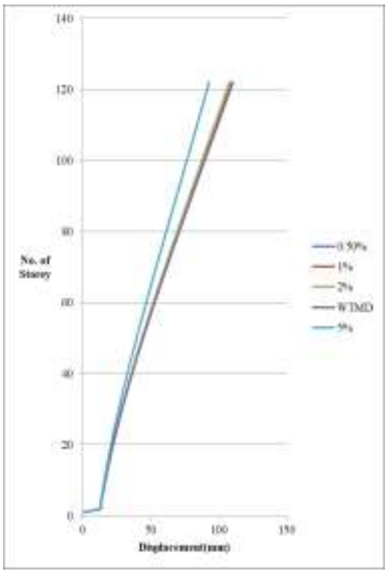
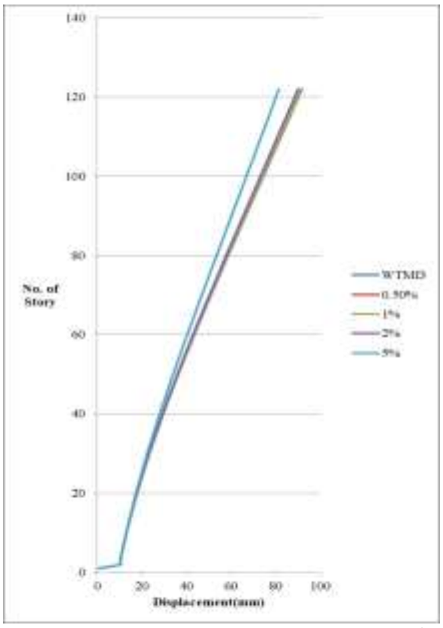


Fig. 4.3 single chamfered skyscraper Lateral displacement in Static and dynamic analysis X direction



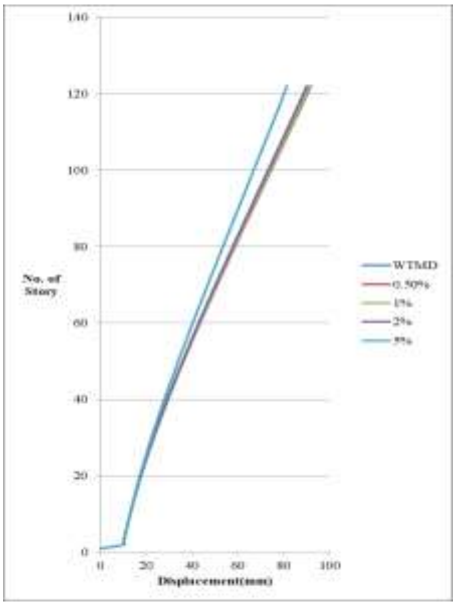


Fig. 4.4 Double chamfered skyscraper lateral displacement in Static and Dynamic analysis X direction

The lateral displacement is in the X direction in the single chamfered model in static condition reduced by 15.75% and dynamic 13.19%. The lateral displacement in the X direction in the double chamfered model in load static conditions 11.21% and dynamic 12.51%.

Table 4.2 Lateral Displacement in Y Direction

Lateral displacement in top of storey in Y direction (mm)		WTMD	0.5%	1%	2%	5%
	Single chamfered	82.5	82.0	81	80.8	72.2
	Double chamfered	69.5	69.3	69.0	67.6	57.6
	Reduction	15.7	15.4	14.8	16.3	20.2

The lateral displacement in X direction and Y direction are reduced in a double chamfered skyscraper. The lateral displacement is reduced as above table 5.9 in a skyscraper at increased damping percentage 5%.

4.3 Storey drift

As per clause no 7.11.1 of IS-1893 (Part-1):2002 the storey drift in any storey due to specified design lateral force with a partial load factor of 1 shall not exceed 0.004 times the storey height. Maximum storey drifts for building= 0.004 X h, for 3m storey height it is 0.0128.

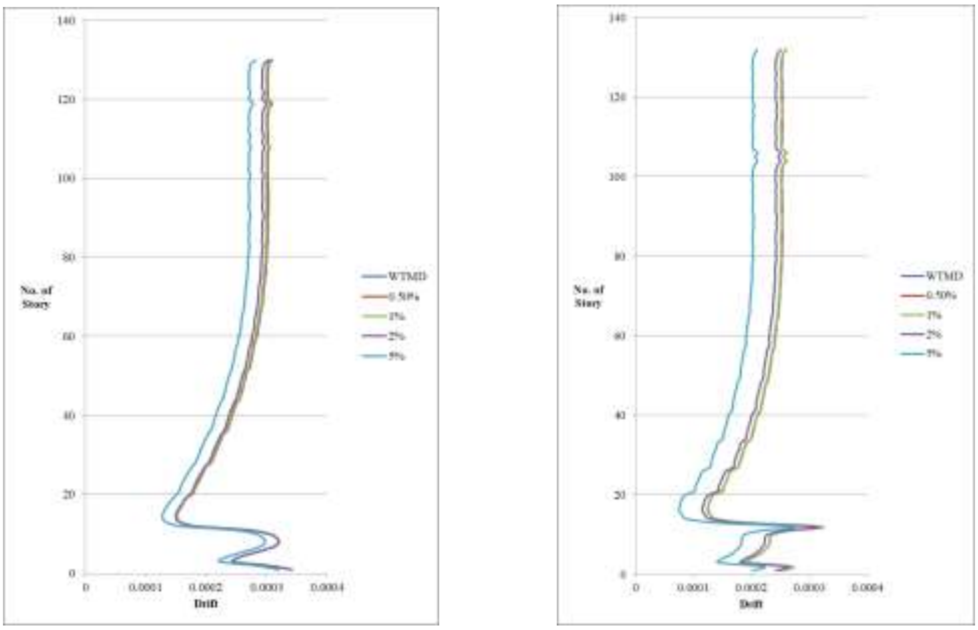


Fig. 4.5 Single and double chamfered storey drift in X direction

The story drifts in the X direction for 5% damping ratio for single chamfered model reduced by 8.737% and double chamfered model 19.23%.

4.4 Wind shear

The wind shear is acting on the structure which reduces by providing multiple dampers in the structure. The wind shear is less in comparison to the single chamfered skyscraper less double chamfered building.

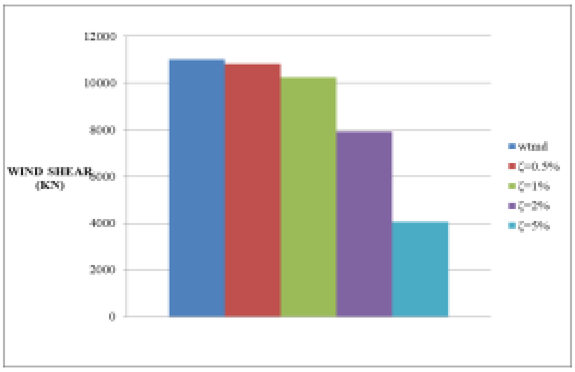


Fig. 4.6 Wind shear in single chamfered

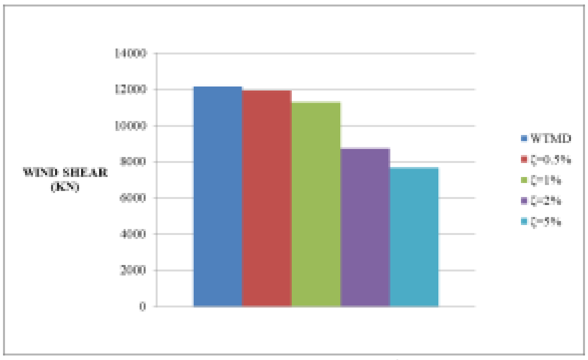


Fig. 4.7 Wind shear in double chamfered building

The wind shear in X direction reduced due to MTMD by single chamfered model 62.47% and double chamfered model 36.76%. The wind shear is acting on the structure which reduces by providing multiple dampers in the structure. The wind shear is less in comparison to the single chamfered building less double chamfered building.

4.5 Damped time period

We are increasing MTMD percentage in a skyscraper at a certain amount. For a benchmark structure whose natural time period is 2.307 seconds.

Table 4.3 Tuning ratio for single and double chamfered

Single chamfered	Damped frequency(Hz)	Tuning ratio	Double chamfered	Damped frequency (Hz)	Tuning ratio
0.5%	0.367	0.847	0.5%	0.404	0.933
1%	0.366	0.845	1%	0.404	0.933
2%	0.323	0.745	2%	0.405	0.935
5%	0.359	0.829	5%	0.396	0.914

The tuning ratio limit is 0.8-1.25. The single chamfered skyscraper the 2% increased damping is gives less tuning ratio. The double chamfered skyscraper the 5% increased damping is gives less tuning ratio.

4.6 Effective drag coefficient

The drag coefficient of a single chamfered skyscraper is 0.1 ratios (chamfered width/base width). For double chamfered skyscraper are 0.15 ratios (chamfered width/base width). The twisting skyscraper structure at 270° is less drag coefficient.

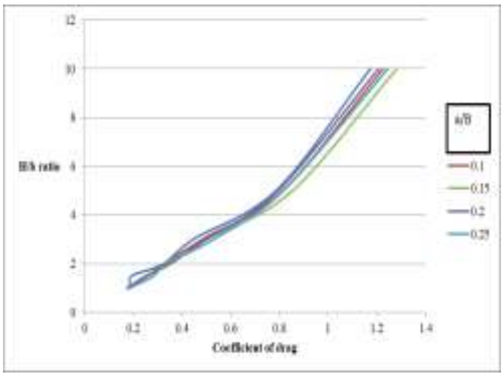


Fig.4.8 Single chamfered skyscraper coefficient of drag

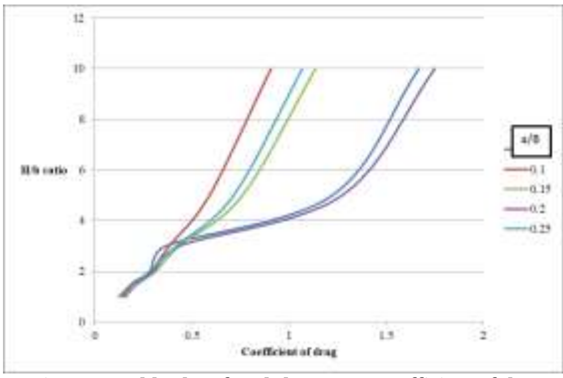


Fig. 4.9 Double chamfered skyscraper coefficient of drag

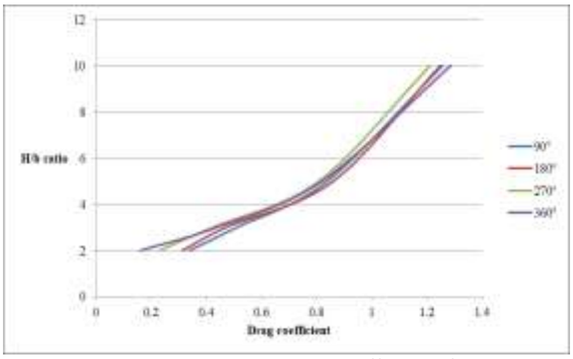


Fig.5.20 Twisting skyscraper coefficient of drag

CONCLUSIONS

1. The along and across direction force will be reduced by amount 9.17% and 6.28% due to 5% increase damping of the tuned mass damper. The rotational angle of skyscraper reduced in the single chamfered structure is 16.67% in static analysis and dynamic analysis 12.4%. The rotational angle of skyscraper reduced in a double chamfered skyscraper is 17.14% in static analysis and 15% in dynamic analysis.
2. The lateral displacement in the skyscraper in the X direction is reduced by providing MTMD of ζ-5% the lateral displacement in the X direction in the single chamfered model in static condition reduced by 15.75% and dynamic 13.19%.The lateral displacement in the X direction in the double chamfered model in load static conditions 11.21% and dynamic 12.51%.
3. The single chamfered building story drift is also considerably are reduces due to high damping ratio. For 5% damping ratio, the storey drifts in X direction for 5% damping ratio single chamfered model reduced by 8.737% and double chamfered model 19.23%.
4. The wind shear is reduced due to MTMD in the skyscraper. For 5% damping ratio, the wind shear in X direction reduced due to MTMD by single chamfered model 62.47% and double chamfered model 36.76%.
5. The tuning ratio limit is 0.5-1.25. The single chamfered skyscraper the 2% increased damping is gives less tuning ratio. The double chamfered skyscraper the 5% increased damping is gives less tuning ratio.

6 The drag coefficient of a single chamfered skyscraper is 0.1 ratios (chamfered width/base width). For double chamfered skyscraper is 0.15ratios (chamfered width/base width). The twisting skyscraper structure at 270° is less drag coefficient.

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