CHAPTER 6

NUMERICAL EXAMPLES

To illustrate the usefulness of the various vibration controls (TLD, MTLD, TMD, MTMD, and ATMD) for example applications and also to quantity and assess their effectiveness, three examples of high- and very high-rise buildings namely 183-m, 317.5-m, 400-m, as shown in Fig. 6.1, are studied. Very high-rise buildings are selected because the tendency of the buildings is higher in the near future. The structural properties and wind exposures are shown in Table 6.1. The results, including roof pressure, maximum along-wind roof displacement, peak along- and across-wind accelerations at the top of buildings without vibration controls, are presented in Table 6.3.

6.1 Response of Building without Vibration Control

The EXCEL computer program is developed to calculate the along-wind and across-wind responses from the studied parameters. The calculated responses were compared with their limitation in NBC code. Three high- and ver high-rise buildings (183-m, 317.5-m, and 400-m high) have slenderness ratio, $\sqrt{WD}/H$, varied from 0.12 to, 0.16. The building density is varied from 153-200 kg/m^3. After investigated through NBC code in Table 6.3, it is discovered that

1. The response of every building is still higher than NBC allowance especially for the case of 317.5 m and 400 m high buildings.

From Boonyapinyo et al. [1997], mostly, the equivalent static pressures of the buildings presented by NBC code are clearly less than the wind pressures of Building Control Act code when the low-rise buildings is located in exposure C but higher when the high-rise buildings are located in exposure A. From this study, roof pressures on high and very high buildings (183-m, 317.5-m and 400-m high buildings) of NBC code are much higher (Such as 218.77 kg/m^2 for 183-m high buildings in exposure B as shown in Table 6.3) than the roof pressures of Building Control Act (160 kg/m^2 as shown in Table 1.1). It means that Building Control Act is not reliable especially for very high building. There are many parameters which are considered in NBC code such as shape of the building, material properties of buildings, exposure, gust effect on the building, air density and wind speed so that NBC is more preferable to calculate the responses of the high-rise building under wind loads. In NBC code the other advantage is including the consideration of real wind spectrum.

From investigating the high-rise building under wind load by NBC code, it can be discovered that the top displacement of the building, Δ, is highest in exposure A (Δ=1.98 for uncontrolled 317.5–m high building, Δ=1.876 for exposure B as shown in Table 6.3.1, and Δ=1.715 for exposure C). 0.265 m different for Δ for exposure A and C is clearly seen. It is why the very high-rise building in exposure A is much needed consideration and focused for mass ratio effect of TMD and gain coefficient effect of ATMD, which are shown in Fig. 6.5-6.8 and 6.13-6.19. However, in Thailand, all exposure has to be considered so that 400-m high building under wind load in all exposures is also shown in Table 6.3. After investigating the acceleration of these three high-rise buildings, Table 6.3 shows that

2. For high- and very high-rise building, the across-wind acceleration is much larger (About 1.7-3.5 times in this study) than the along-wind one.

Then the vibration control varied from 1% to 3% mass ratio is applied

6.2 Designs of Passive Vibration Controls (μ=0.01)

The mass ratio of each kind of dynamic damper is selected to be equal where natural frequencies and damping ratios are different to tune each kind of dynamic damper to be optimal. Designs of TMD, MTMD, TLD, and MTLD, for high-rise building with 183 m high can be summarized in Table 6.2. For 317.5 m and 400 m high building, TLD and MTLD with μ=0.01 is not applied because the low natural frequency and the high mass of building cause h/a less than 0.1. Designs of TMD, MTMD for high-rise building with 317.5 m and 400 m high are also summarized in Table 6.2. For example, calculating the equivalent damping ratio for TMD, MTMD on 400 m high building in along wind direction is given in Appendixes A and B.

6.3 Effects of Passive Vibration Controls on Reductions in Wind Load and Response (μ=0.01)

Normally, the parameter used to investigate the building with vibration control is damping ratio. And for more simplicity, the equivalent damping ratio is obtained to be used instead (shown in Appendix D). Where else, the NBC code is reliable forms for the design of the high-rise buildings under wind load. So, in the study, the equivalent damping method is used to investigate the response of the building with vibration control, which the responses are obtained, by applying on NBC code.

The computation of the equivalent static pressure, and response of 183-m high-rise building with and without vibration controls in exposure B, based-on NBC code, is shown in Appendix D.

Results of equivalent static pressure profile along buildings, the along wind displacement, along and across wind acceleration at the top of buildings are expressed in Fig. 6.2-Fig. 6.4, and Table 6.3. From Fig. 6.2-Fig. 6.4, and Table 6.3, the following results can be obtained.

1. High percentage reductions of the buildings attached with vibration controls are clearly shown

2. From the comparison between each kind of passive dynamic damper, it can be discovered that for the same total mass, MTMD in the sense of optimization is the most effective among passive dynamic dampers whereas the optimal TLD is the least effective.

3. When focusing on the difference between the effective of every kinds of passive dynamic dampers, it can be discovered that the effective is high for low damping ratio building (45% reduction for the peak along- and across-wind acceleration at the top of building and 28% reduction for Δ of 317.5-m high building with 1% mass ratio of TMD in exposure B) but low for high damping ratio building (38% reduction for the peak along- and across-wind acceleration at the top of building and 12% reduction for Δ of 183-m high building with 1% mass ratio of TMD in exposure B). It is why can be said that, the lower the damping ratio high-rise building, the more the effective of vibration controls on the lateral displacements of the buildings.

4. After focusing on the other passive dynamic dampers, it can be seen that although damping ratio of MTLD (ξ_{tatal}=0.08) is higher than TMD (ξ_{total}=0.05), TMD is still more effective in the sense of the reductions of the responses than MTLD.

5. From Fig. 3.2, the tendency of the behavior of the structure under wind load with optimal dynamic damper is nearly to the case of harmonic load so, in preliminary study, the behavior of the structure under wind load with the passive dynamic damper can expected from the behavior of the structure with the passive dynamic damper under harmonic load.

To determine the parameters, effecting on the reduction of the building, three high-rise buildings in different exposure with dynamic dampers are investigated based on NBC code (Seeing from Appendix D). It is also clearly found that vibration controllers mainly reduce the gust effect C_g of high-rise building (14% reduction of C_g for TMD case), which is over than the mean static response of the building.

Table 6.3 also shows that the percentage reductions of the across and along wind acceleration building for the equal mass ration vibration controllers are almost the same (About 37% for 183-m high building with TMD in exposure B). In additions, the percentage reductions of along wind displacement and equivalent static pressure are nearly the same (About 12.1% for 183-m high building with TMD in exposure B).

When focusing on the difference between the effective of MTMD and TMD, it can be discovered that the effective of MTMD and TMD is high different (0.022 m) for the low damping ratio building (317.5-m high building in exposure B) but low different (0.001 m) for the high damping ratio building (183-m high building in exposure B) as shown in Table 6.3. It is why in order to select the dynamic dampers; the dynamic properties have to be considered.

Table 6.3 is focused on the relations between the optimal equivalent damping ratios and the responses of high-rise buildings under wind load. The peak along- and across-wind acceleration at the top can be reduced by about 45% for 317.5 m high building attached with 1% mass ratio of TMD in exposure B. However, the maximum lateral deflection at the top building can be reduced by only 28% for the same building and TMD in exposure B. So that the reductions of the peak accelerations in both direction at the top of 317.5 m high building are about 1.6 times of lateral deflection at the top of the same building. It is because the maximum lateral deflection consists of mean (static) and dynamic response, and the dynamic damper can effect mainly on the dynamic one.

6.4 Designs of TMD and TLD (μ=0.03 for 317.5 m and 400 m High Buildings)

In the case of TLD, it is necessary that h/a should stay about within 0.1-0.4. So the mass ratio of TLD have to increase to be 3% from 1% of the first modal mass of 317.5-m and 400-m high buildings. Other reason is to increase the effectiveness of TLD itself. Designs of TLD for three buildings are shown in Table 6.4.

Design of TMD for three buildings are shown as follows

1. 183-m high building

$$m_1 = 0.01 m_s = 113 \text{ ton}$$
$$\omega_1 = 0.99\omega_s = 0.26 \text{ Hz}$$
$$\xi_1 = \sqrt{\mu}/2 = 0.05$$
$$\xi_e^{opt} = \left(\sqrt{\mu}/4\right) + 0.8\xi_s = 0.037$$

2. 317.5-m high building

$$m_1 = 0.03 m_s = 885 \text{ ton}$$
$$\omega_1 = 0.971\omega_s = 0.0971 \text{ Hz}$$
$$\xi_1 = \sqrt{\mu}/2 = 0.0866$$
$$\xi_e^{opt} = \left(\sqrt{\mu}/4\right) + 0.8\xi_s = 0.051$$

3. 400-m high building

Along-wind direction

$$m_1 = 0.03 m_s = 1817.7 \text{ ton}$$
$$\omega_1 = 0.971\omega_s = 0.0874 \text{ Hz}$$
$$\xi_1 = \sqrt{\mu}/2 = 0.0866$$
$$\xi_e^{opt} = \left(\sqrt{\mu}/4\right) + 0.8\xi_s = 0.051$$

Across-wind direction

$$m_1 = 0.03 m_s = 1817.7 \text{ ton}$$
$$\omega_1 = 0.971\omega_s = 0.0971 \text{ Hz}$$
$$\xi_1 = \sqrt{\mu}/2 = 0.0866$$
$$\xi_e^{opt} = \left(\sqrt{\mu}/4\right) + 0.8\xi_s = 0.051$$

Results include equivalent static pressure profile along buildings, the along wind displacement, along and across wind acceleration at the top of buildings are expressed in Table 6.5.

6.5 Effects of TMD and TLD on Reductions in Wind Load and Response (μ=0.03 for 317.5 and 400 m High Buildings)

From Table 6.4, it is found that the moving mass of TLD is about 60-80% of TMD for these three high-rise buildings. And from Table 6.5, the equivalent damping ratio of TMD case is higher about 0.005 than the case of TLD. It results that the percentage reductions of the roof pressures for the both cases are different about 1-1.5% for the more effective of TMD. Not so far from the roof pressures, the percentage reductions of Δ of high-rise buildings have the gap about 1%. And further more, the percentage reductions of peak along and across wind accelerations at the top of buildings are about 2-5% apart. So the reason to select between TMD and TLD should not be the effectiveness but the installation and maintenance costs.

When the response of the high-rise buildings with every kinds of passive vibration controls are compared with the allowance of NBC code, Table 6.3 shows that the responses of 183-m high building, in exposure B which is the normal case the exposure in Bangkok are stay within the allowance. However, mostly, the reduction responses of the high-rise buildings with the passive dynamic dampers can not stay within, especially, the high-rise buildings in exposure A. So, the high-rise buildings are suggested to be constructed with higher damping ratio, or the mass of dynamic dampers is added, or the active one instead applies.

6.6 Effects of TMD Mass Ration

The effects of mass ratio on maximum roof displacements in along-wind and across-wind directions in exposure A of the three high-rise buildings are shown in Fig. 6.5 and Fig. 6.6, respectively.. The results in Fig. 6.5 show that, as expected, the damper inertial increase with higher mass ratio causing reduction in along- and across-wind displacements. This effect is more pronounced for very high-rise building (317.5 m and 400 m high). The mass ratio of about 1% can significantly reduce the along- and across-wind displacements for 317.5 m and 400 m high buildings. Increase in mass ratio to 3% can slightly further reduce the displacement and it approaches to mean (static) displacement. It is should be noted that the peak across-wind displacement for 317.5 m high building in Fig. 6.6 is grater than that for 400 m high building because of the large width of the 400 m high building.

Figs. 6.7 and 6.8 show the effects of mass ratio of TMD on the peak stroke of TMD in along- and across-wind direction, respectively. Because the damper mass absorbs most of the energy of the excitation, its displacement is much large than that of the displacement of the rooftop. Therefore the peak stroke is dominated by the damper mass. As results, the mass ratio of TMD may increase up to 2-3% for 317.5 m and 400 m high building to reduce the peak stroke of TMD.

6.7 Design of Active Vibration Control (μ=0.03 for 317.5 m and 400 m High Buildings)

Design of TMD and ATMD for 183-m, 317.5-m, and 400-m high buildings are summarized in Table 6.6. For 183-m building, mass ratio is equal to 1%. For taller and more flexible building (317.5 m, and 400 m high), the mass ratio of 3% is used. μ_0 = -0.0075 for 183 m high building and μ_0 = -0.02 for 317.5 m and 400 m high buildings is applied. For example, calculating of the equivalent damping ratio for ATMD on 400 m high building in along wind direction is expressed in Appendix C. Table 6.7 shows the comparison of vibration response for three buildings without and with TMD and ATMD in various wind exposures.

6.8 Effects of Active Tuned-Mass Damper on Reductions in Wind Load and Response (μ=0.03 for 317.5 m and 400 m High Buildings)

Firstly ATMD is selected to be investigated. It is demonstrated that ATMD is much higher effective than TMD especially when μ_o is almost $\mu/(1+\mu)$. Figures 6.9 – 6.11 show comparison of equivalent wind loads in exposure B for 183 m and 317.5 high buildings with and without TMD and ATMD. From these results, the followings can be noted.

1. Buildings with passive and active dynamic dampers lead to increase in equivalent damping ratio and then result in significant reduction in gust effect factors, equivalent wind loads, deflections and accelerations of the buildings.

2. For 183 m high building attached with 1% mass ration of TMD, the peak accelerations (both along- and across-wind directions) and the maximum deflection can be reduced about 38% and 12%, respectively, in exposure B. When 1% mass ration of ATMD with μ_0 = -0.0075 for the same building, the peak accelerations in both directions and maximum lateral roof deflection can be reduced by about 52% and 16%, respectively in exposure B. The effective of ATMD is about 1.35 times of TMD for this case.

3. For 317.5 m high building attached with 3% mass ration of TMD, the peak accelerations (both along- and across-wind directions) and the maximum deflection can be reduced about 55% and 34%, respectively, in exposure B. When 3% mass ration of ATMD with μ_0 = -0.02 for the same building, the peak accelerations in both directions and maximum lateral roof deflection can be reduced by about 65% and 40%, respectively in exposure B. The effective of ATMD is about 1.18 times of TMD for this case. Finally, it means that the approximately expectation of percent reduction of ATMD from TMD can be done passing acceleration gain factor and it is found that the proper value of μ_0 is about –60% to –80% of μ.

6.9 Effects of Feedback Control

The effects of feedback control is examined by varying μ_0 as shown in Fig. 6.12, determining the optimal controller gains ε_{opt} and ψ_{opt} for each μ_0, and then determine the equivalent damping ratio, equivalent wind load, deflection and acceleration of building using the method described earlier. The 400 m high building in wind exposure A is investigated with μ = 0.007, 0.01, 0.012, and 0.03. Fig. 6.13 shows that the equivalent damping ratio increase with ($-\mu_0$) for four different mass ratios. Fig. 6.14 and Fig. 6.17 show that the maximum displacement in the case of ATMD is always lower than that in case of the optimal passive damper. When the active force is absent, the both cases give the same data. This is the mechanism by which the response of the main structure is decreased by the controller. In the active damper, the controller (through the action of the control force) diverts further energy to the damper mass causing the damper mass to have ever-larger displacement than in the passively damped case. Therefore, the roof displacement reduces further. Figs. 6.15, 6.16, 6.18 and 6.19 show that the stroke and active force increase with ($-\mu_0$). It is noted that the required control force for 400 m high building with mass ratio of at least 1% in ATMD is well within the operational range of some practical hydraulic actuator. However the mass ratio (μ) should be increased up to 2-3 % for 317.5 m and 400 m high building to reduce the peak stroke of ATMD and the peak active force.

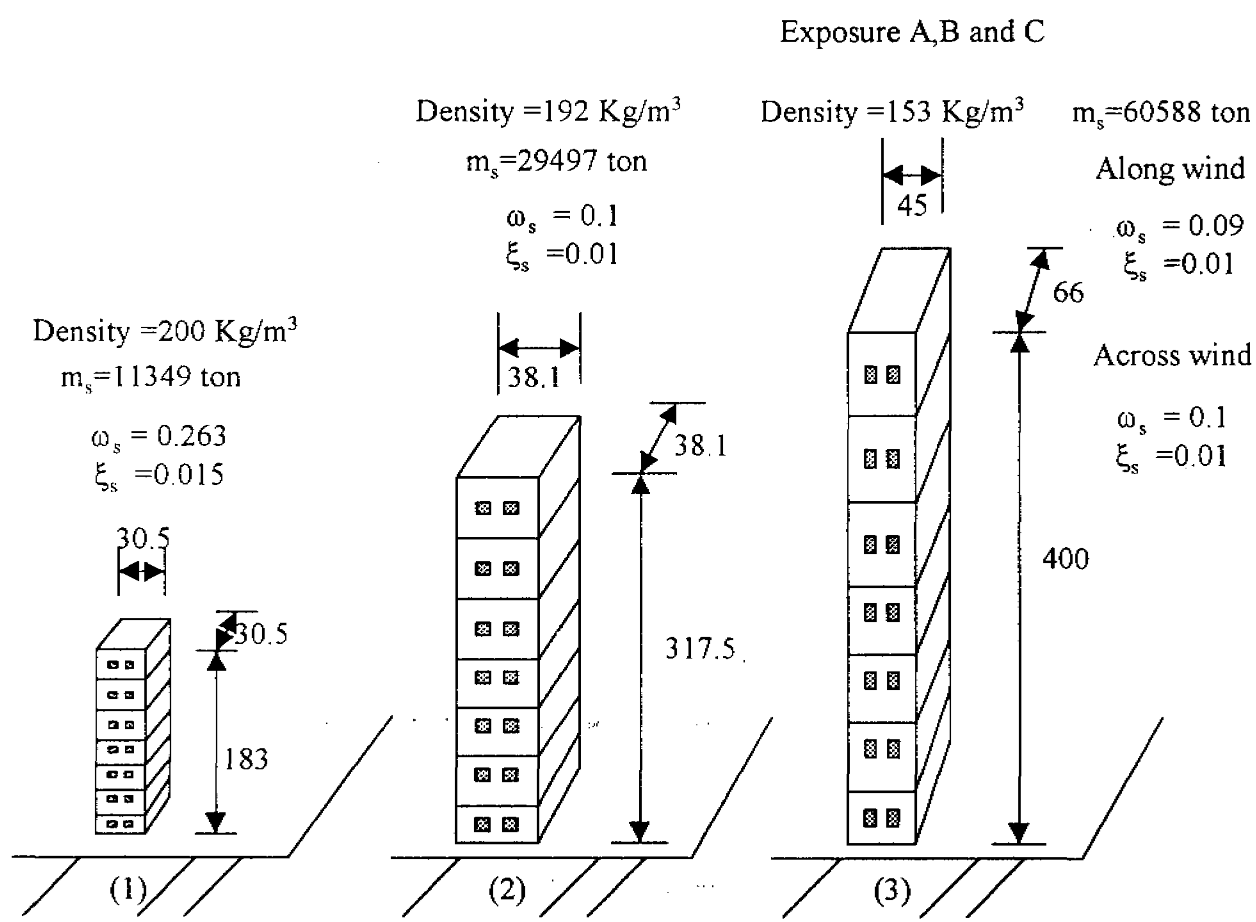

Fig. 6.1 Building examples

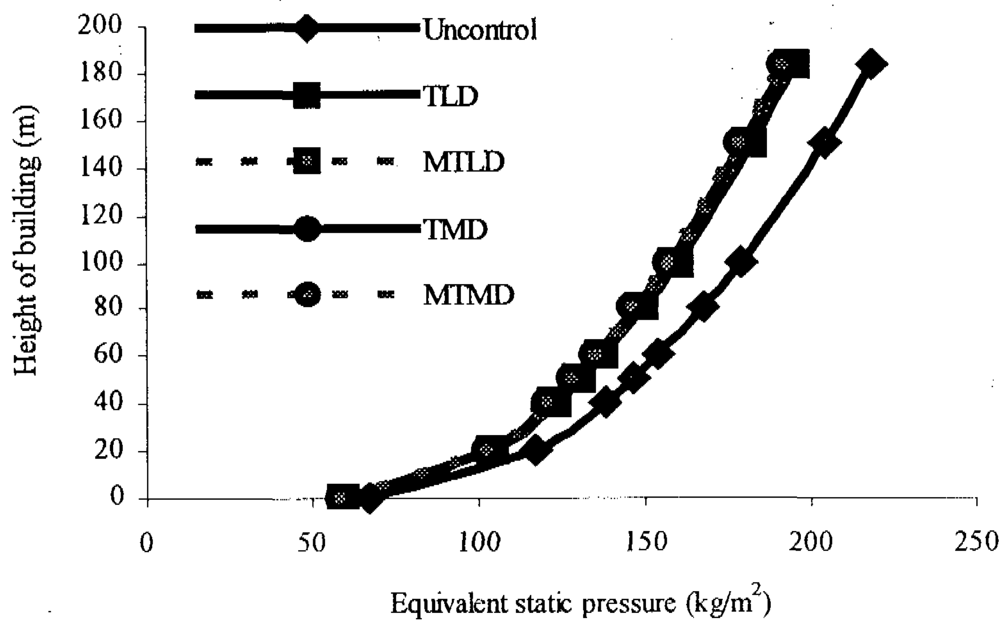

Fig. 6.2 Equivalent static pressure for 183-m high building (Exposure B)

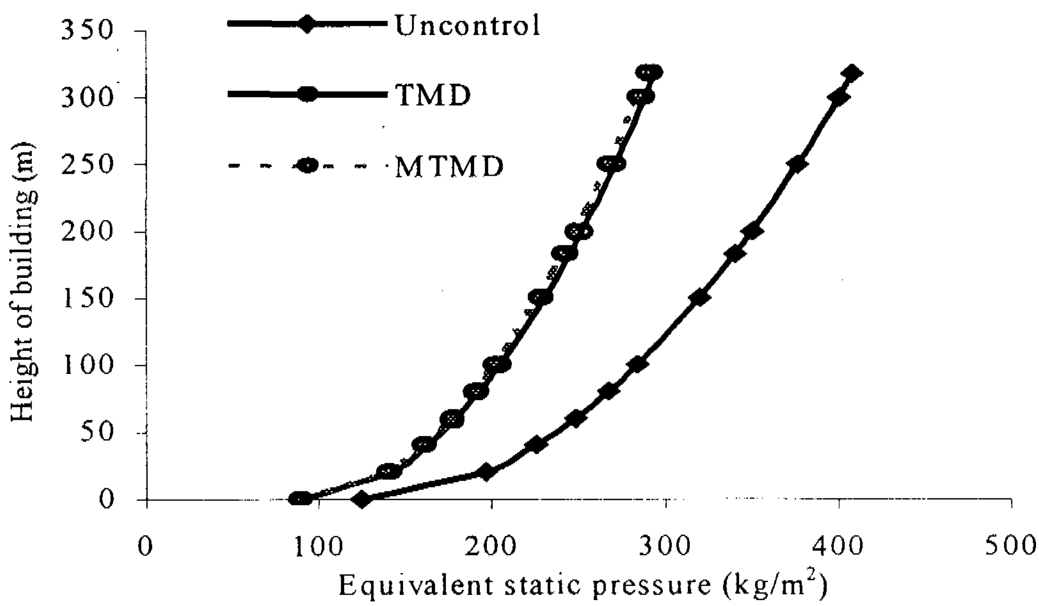

Fig. 6.3 Equivalent static pressure for 317.5-m high building (Exposure B)

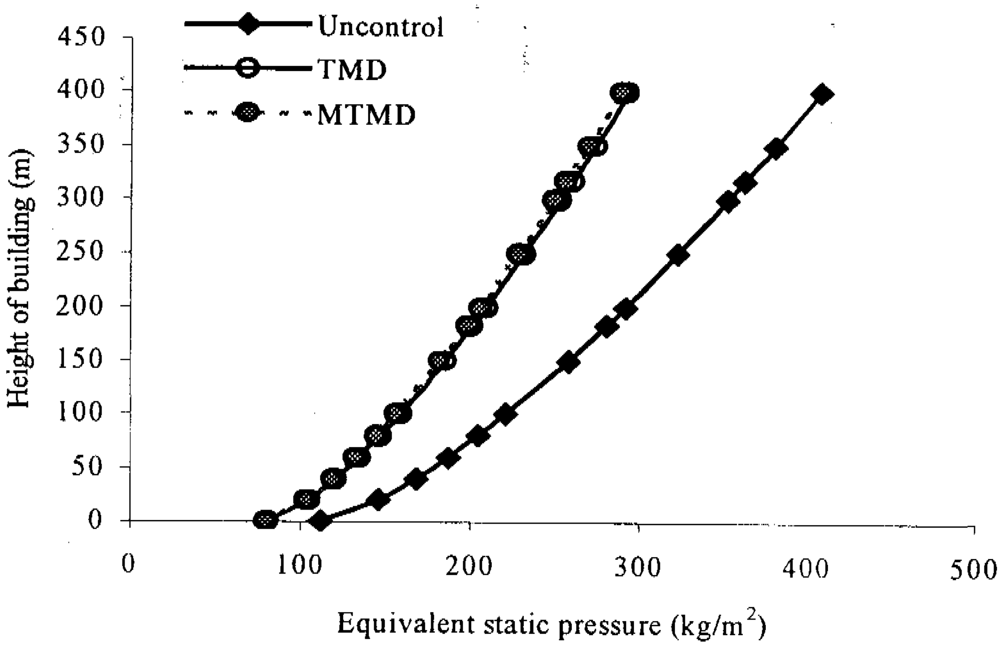

Fig. 6.4 Equivalent static pressure for 400-m high building (Exposure C)

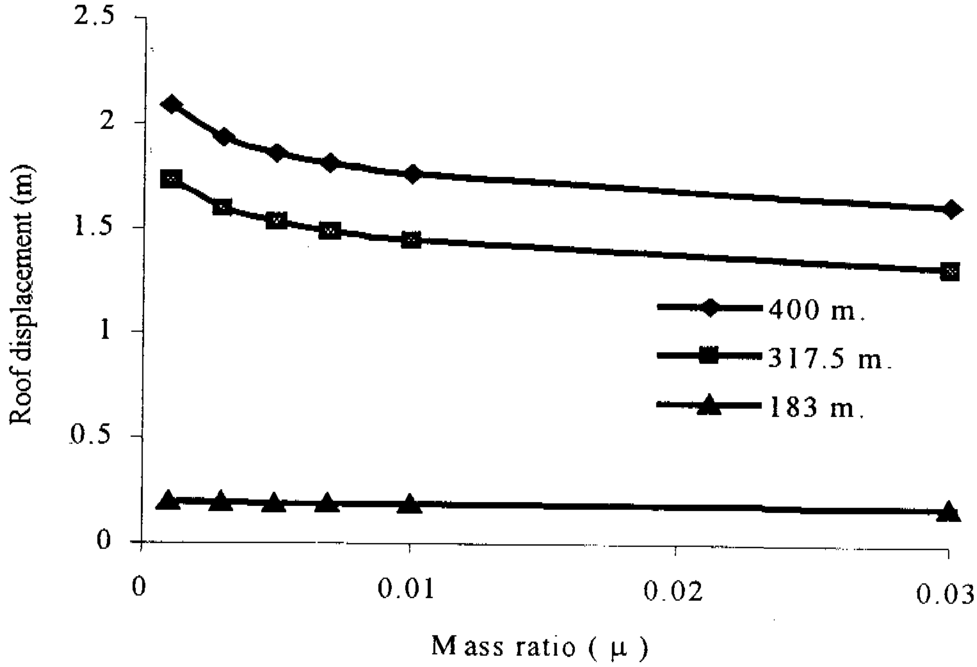

Fig. 6.5 Effect of mass ratio on maximum roof displacement in along-wind direction of three high-rise buildings in exposure A

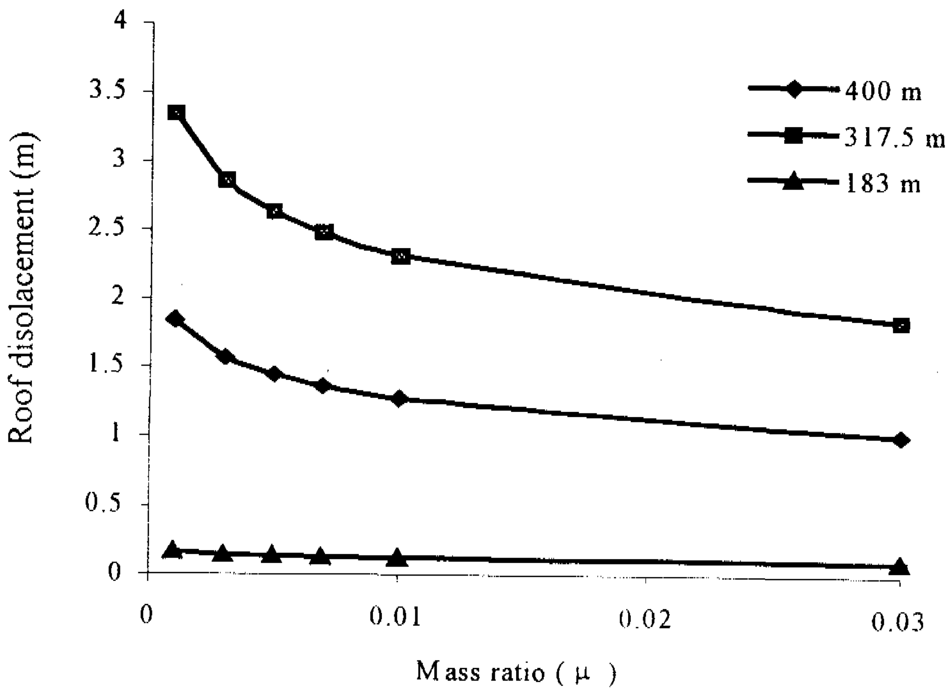

Fig. 6.6 Effect of mass ratio on maximum roof displacement in across-wind direction of three high-rise buildings in exposure A

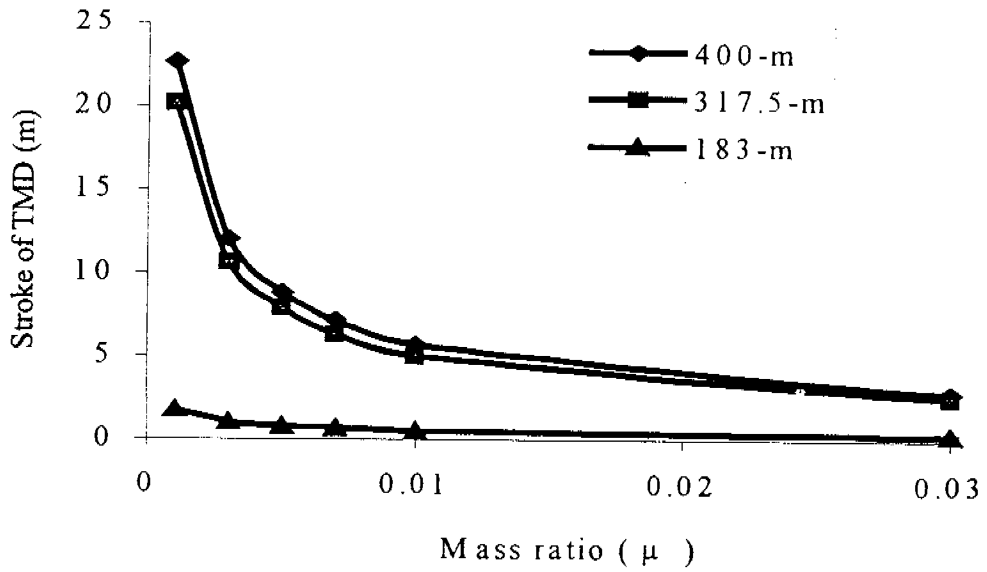

Fig. 6.7 Effect of mass ratio on peak stroke of TMD in along-wind direction of three high-rise buildings in exposure A

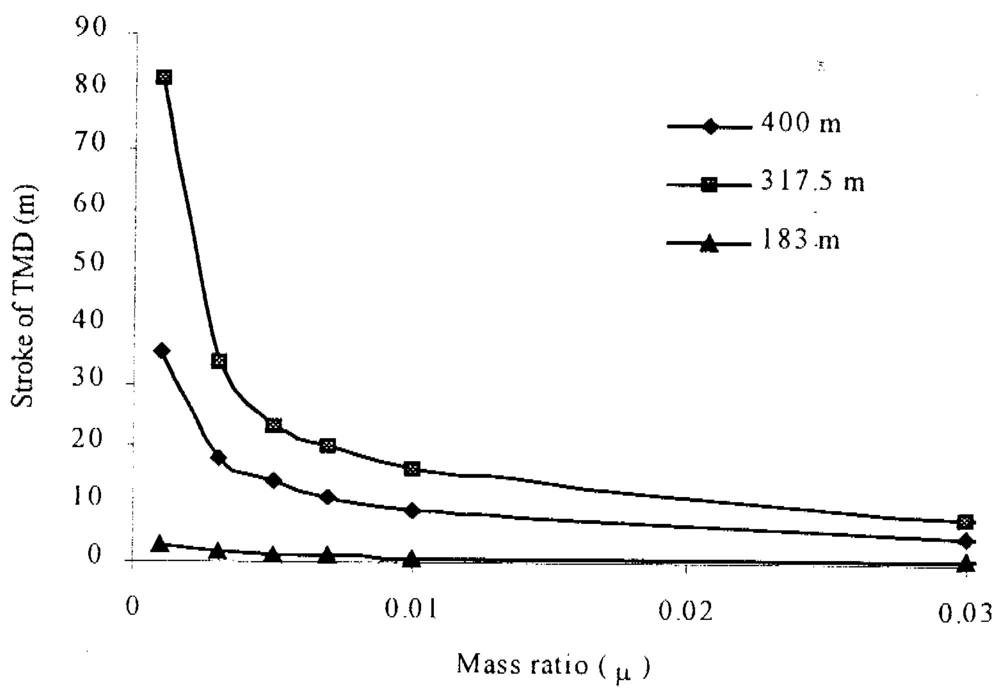

Fig. 6.8 Effect of mass ratio on peak stroke of TMD in across-wind direction of three high-rise buildings in exposure A

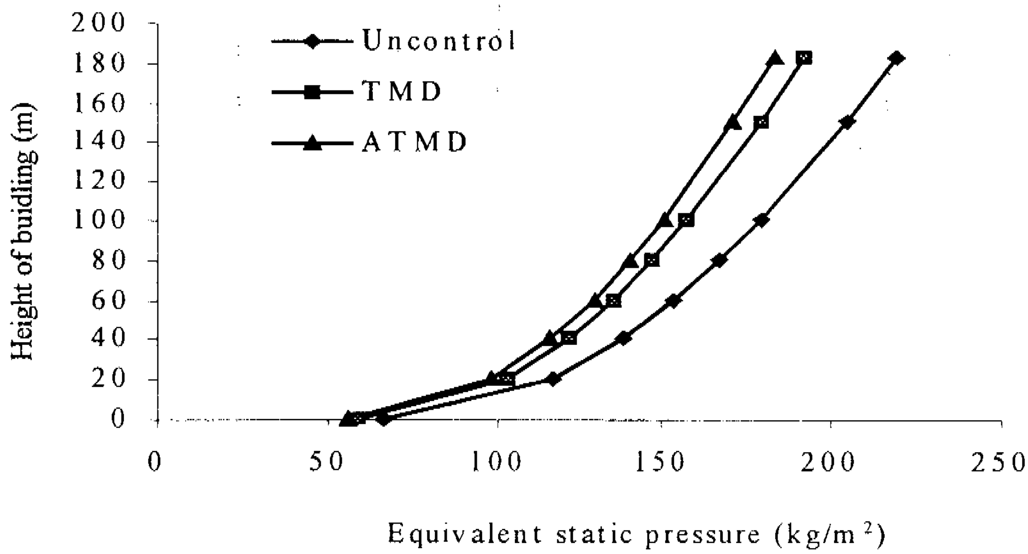

Fig. 6.9 Equivalent static pressure on 183-m high building in exposure B

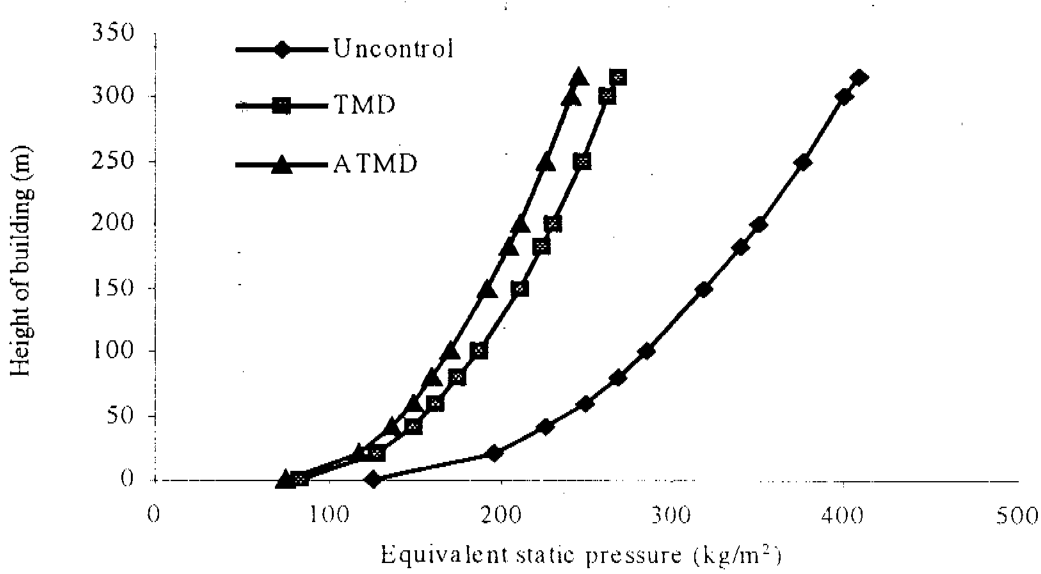

Fig. 6.10 Equivalent static pressure on 317.5-m high building in exposure B

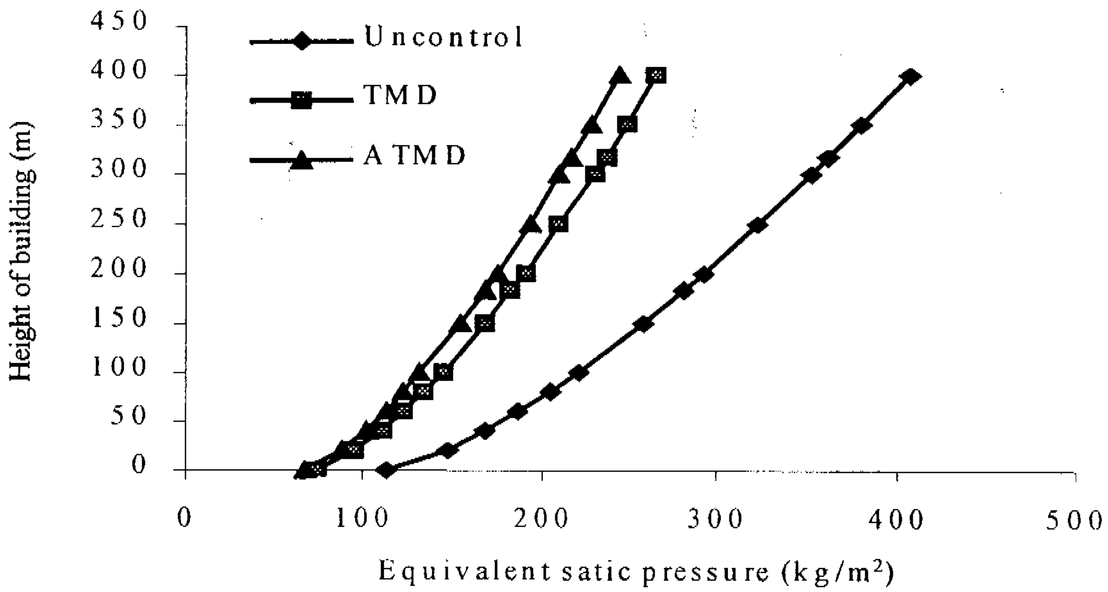

Fig. 6.11 Equivalent static pressure on 400-m high building in exposure C

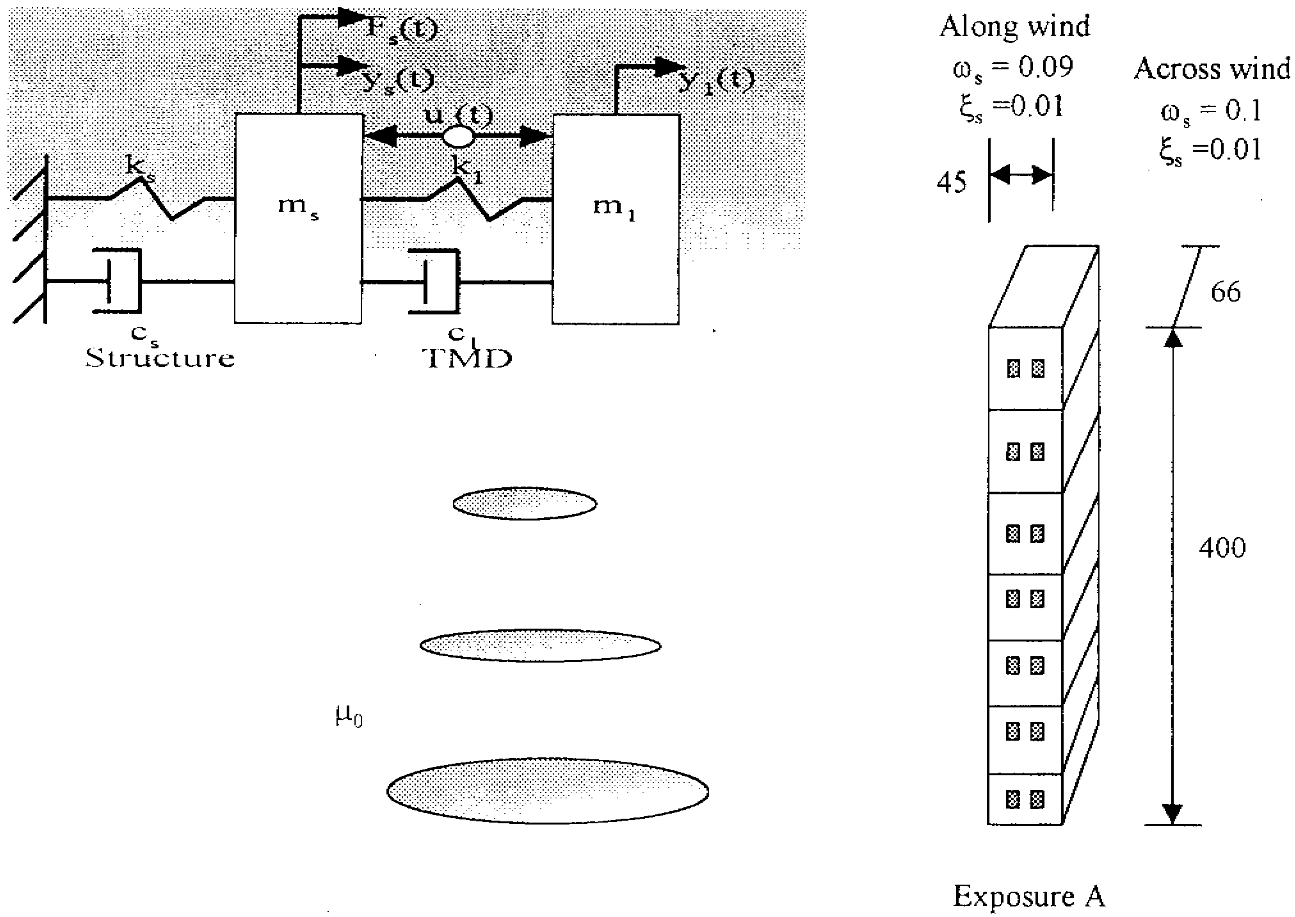

Fig. 6.12 Varying the acceleration gain (by mean of active force) of ATMD

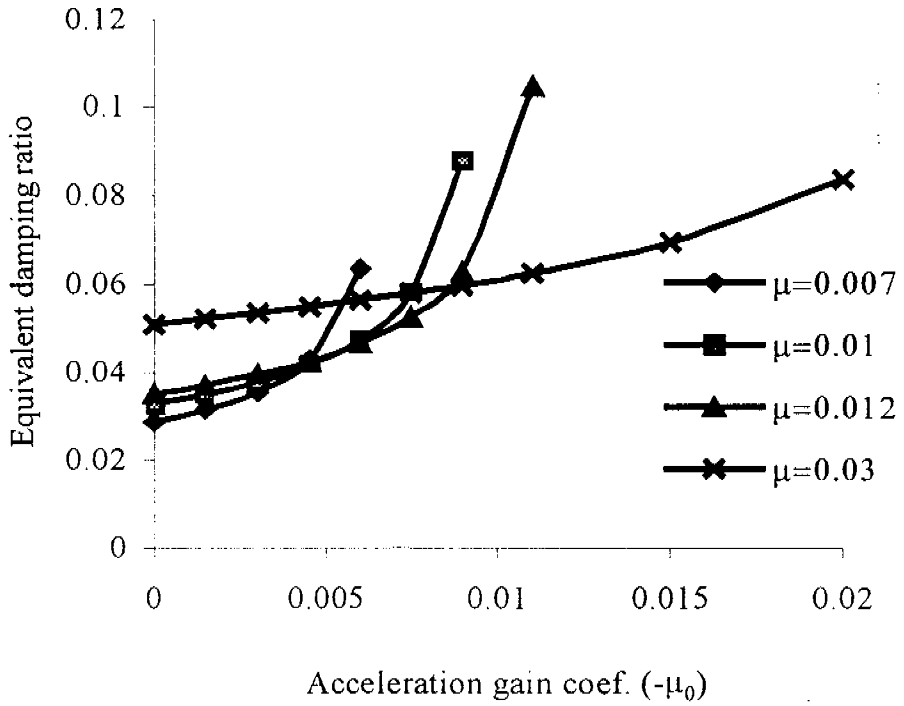

Fig. 6.13 Effect of acceleration feedback gain coefficient on equivalent damping ratio of 400 m high building with ATMD for four mass ratios

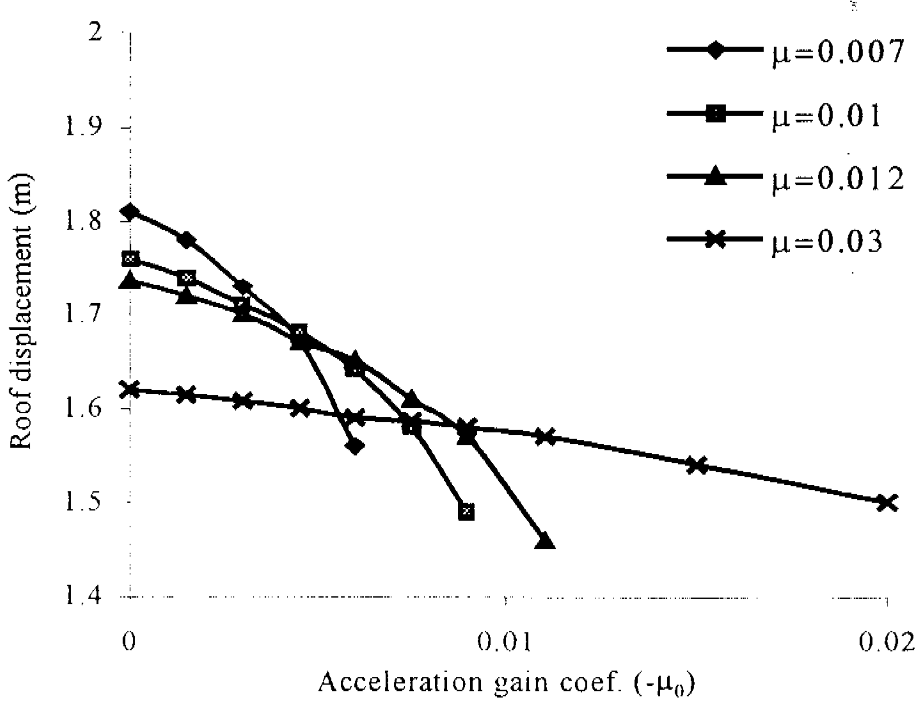

Fig. 6.14 Effect of acceleration feedback gain coefficient on maximum roof displacement of 400 m high building with ATMD for four mass ratio in along wind direction in exposure A

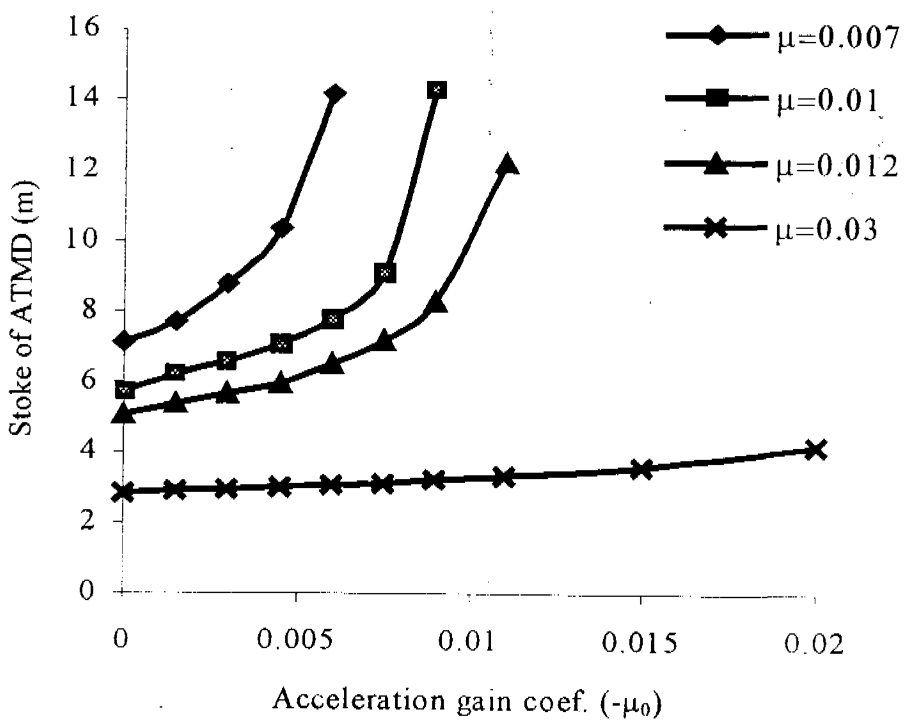

Fig. 6.15 Effect of acceleration feedback gain coefficient on peak stroke of ATMD on 400 m high building for four mass ratio in along wind direction in exposure A

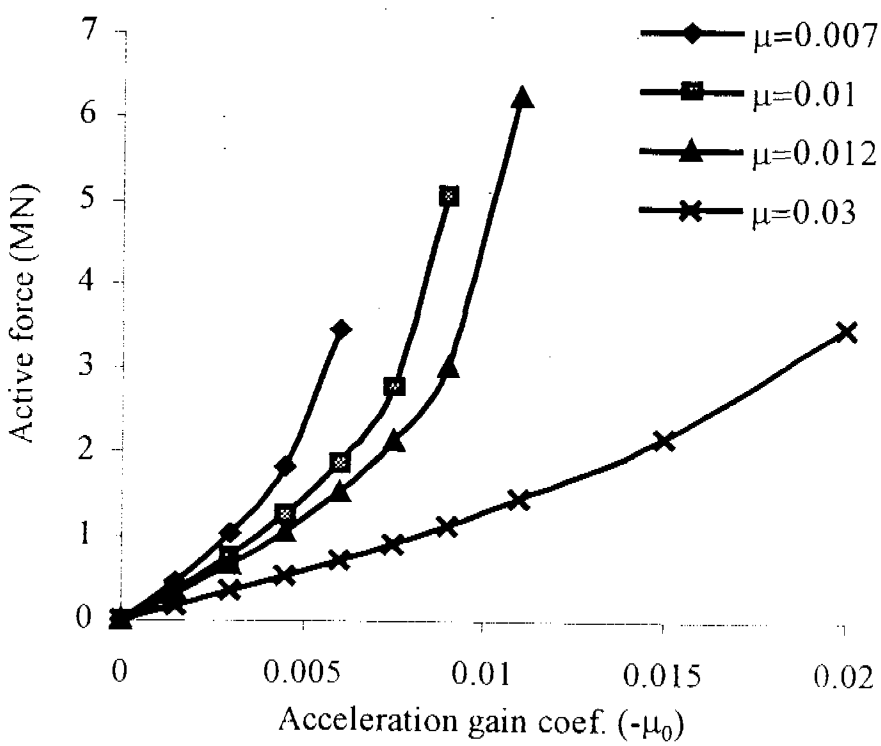

Fig. 6.16 Effect of acceleration feedback gain coefficient on peak active force of ATMD on 400 m high building for four mass ratio in along wind direction in exposure A

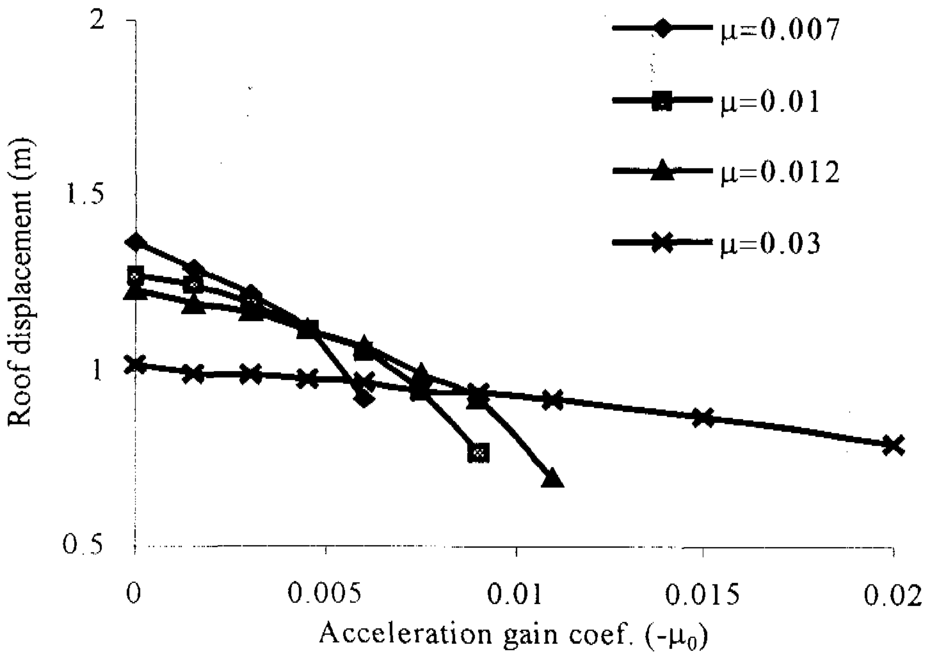

Fig. 6.17 Effect of acceleration feedback gain coefficient on maximum roof displacement of 400 m high building with ATMD for four mass ratio in across wind direction in exposure A

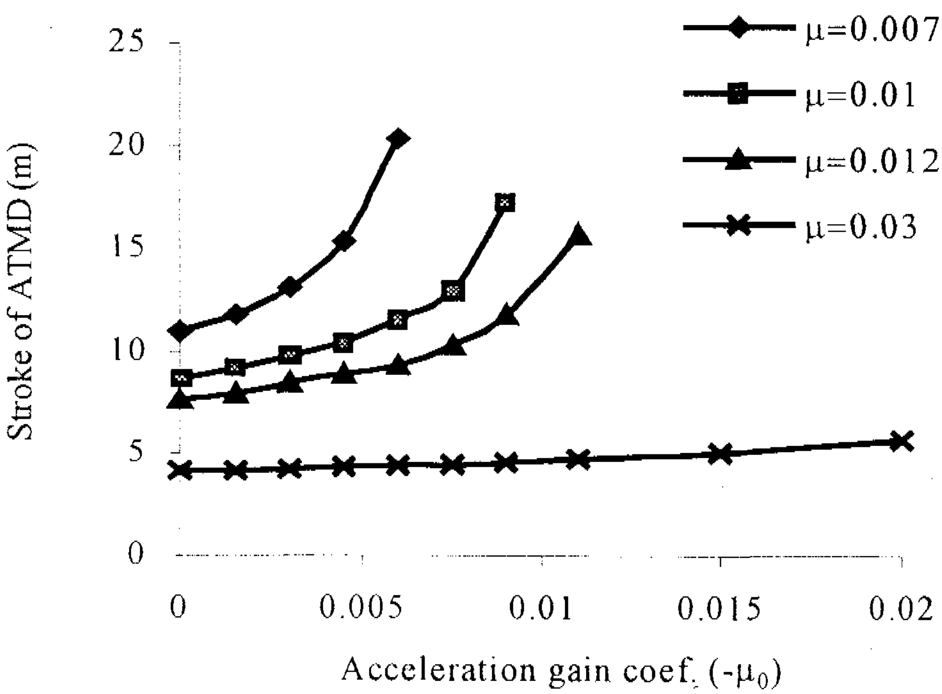

Fig. 6.18 Effect of acceleration feedback gain coefficient on peak stroke of ATMD on 400 m high building for four mass ratio in across wind direction in exposure A

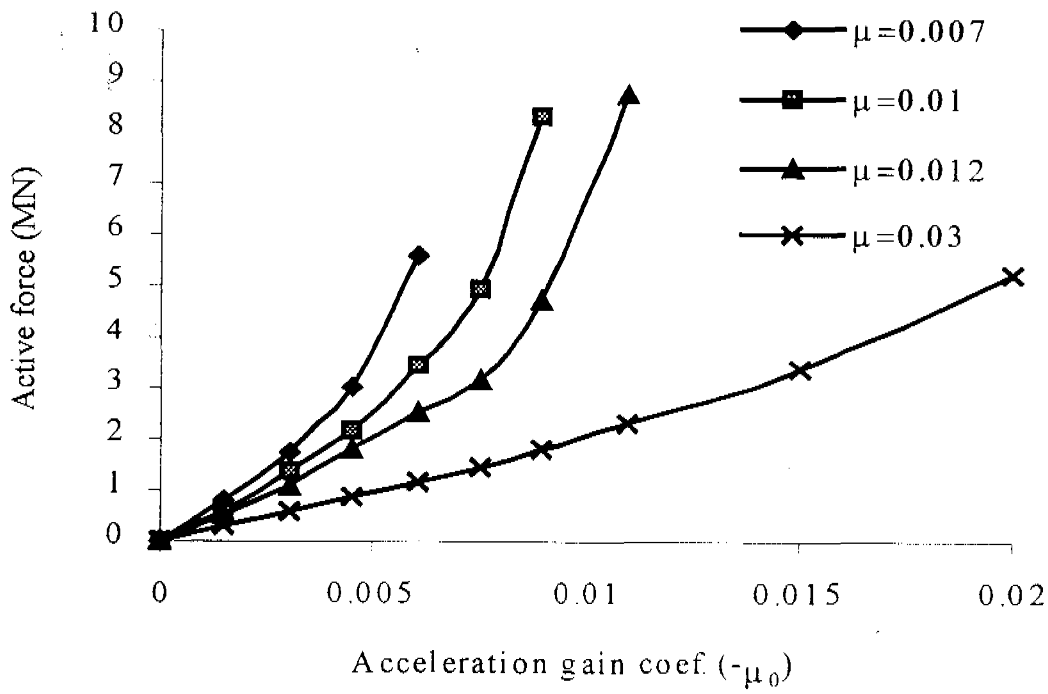

Fig. 6.19 Effect of acceleration feedback gain coefficient on peak active force of ATMD on 400 m high building for four mass ratio in across wind direction in exposure A

Table 6.1 Structural properties of three high-rise buildings

Height (m)	Structural properties							
	Depth (m)	Width (m)	along-wind ω (Hz)	across-wind ω (Hz)	ρ_b (kg/m^3)	m_s (ton)	ξ_s	Wind exposure
183.0	30.5	30.5	0.263	0.263	200	11349	0.015	B
317.5	38.1	38.1	0.1	0.1	192	29497	0.010	B
400.0	45.0	66.0	0.09	0.1	153	60588	0.010	A,B,C

Table 6.2 Dynamic damper design

Design Parameter	Dynamic Dampers			
	TLD	MTLD	TMD	MTMD
Building: 183 m high				
μ	0.01	0.01	0.01	0.01
γ	0.993	-	0.990	-
Δγ, δγ	-	0.14 , 0.035	-	0.14 , 0.035
total ξ	0.041	0.08	0.050	0.100
h/a (central ω tank)	0.257	0.160	-	-
h (m)	1.955	0.833	-	-
a , b (m)	7.62 , 7.62	5.22 , 5.22	-	-
Building: 317.5 m high				
μ	-	-	0.010	0.010
γ	-	-	0.990	-
Δγ, δγ	-	-	-	0.14 , 0.035
total ξ	-	-	0.050	0.100
Building: 400 m high				
μ	-	-	0.010	0.010
γ	-	-	0.990	-
Δγ, δγ	-	-	-	0.14 , 0.035
total ξ	-	-	0.050	0.100

Table 6.3 Comparison of vibration responses for three high-rise buildings with various dynamic dampers

Dynamic damper	Parameters / Responses					
	Optimal ξe	Cg	Roof pressure (kg/m^2)	Δ (m)	Peak roof acceleration/g	
					Along wind	Across wind
Building: 183 m high in exposure B						
Uncontrol	0.015	2.147	218.767	0.174	0.021	0.040
TLD	0.032	1.917	195.286	0.155	0.014	0.027
MTLD	0.035	1.900	193.552	0.154	0.013	0.026
TMD	0.037	1.888	192.362	0.153	0.013	0.025
MTMD	0.039	1.877	191.226	0.152	0.013	0.024
Building: 317.5 m high in exposure B						
Uncontrol	0.010	3.047	408.826	1.876	0.049	0.159
TMD	0.033	2.195	294.492	1.351	0.027	0.087
MTMD	0.035	2.158	289.559	1.329	0.026	0.084
Building: 400 m high in exposure A						
Uncontrol	0.010	2.567	386.69	2.364	0.046	0.093
TMD	0.033	1.913	288.15	1.762	0.025	0.051
MTMD	0.035	1.885	283.89	1.736	0.024	0.049
Building: 400 m high in exposure B						
Uncontrol	0.010	2.753	393.16	2.311	0.047	0.093
TMD	0.033	2.021	288.68	1.697	0.026	0.051
MTMD	0.035	1.989	284.16	1.671	0.025	0.049
Building: 400 m high in exposure C						
Uncontrol	0.010	3.075	407.784	2.357	0.050	0.092
TMD	0.033	2.209	292.962	1.694	0.028	0.051
MTMD	0.035	2.172	288.003	1.665	0.027	0.049

Table 6.4 Design of TLD

TLD Design	Water Mass	a	h	h/a	ω (Hz.)	factor	ξ	ω_{opt}	ξ_{opt}
183-m high	113.49	7.62	1.9546	0.2565	0.2613	0.674	0.00035	0.26124	0.041
317.5-m high	885	21.44	1.9253	0.0898	0.1	0.793	0.00051	0.09921	0.077
TLD Design	Water Mass	a	b	h	h/a	h/b	ω_{al} (Hz.)	ω_{ac} (Hz.)	$factor_{al}$
400-m high	1818	27.78	24.921	2.6256	0.0945	0.105	0.08996	0.09995	0.791
TLD Design	$factor_{ac}$	ξ_{al}	ξ_{ac}	ξ_{alopt}	ξ_{acopt}				
400-m high	0.7854407	4E-04	0.0004	0.077	0.0768				

Table 6.5 Comparison of % response reduction of high-rise buildings with TMD and TLD

Dynamic Damper	Parameters/Responses				
	Optimal ξe	P(%)	Δ(%) (m)	Peak roof acceleration/g, (%)	
				Along wind	Across wind
183-m high building in exposure A (μ=0.01)					
TMD	0.033	11.950	12.180	37.300	37.240
TLD	0.029	10.850	11.140	33.200	33.270
183-m high building in exposure B (μ=0.01)					
TMD	0.033	12.100	12.120	37.500	36.960
TLD	0.029	10.980	11.030	33.650	33.160
183-m high building in exposure C (μ=0.01)					
TMD	0.033	11.940	12.300	37.570	37.450
TLD	0.029	10.790	11.090	33.530	33.200
317.5-m high building in exposure A (μ=0.03)					
TMD	0.051	33.23	33.230	56.090	56.110
TLD	0.046	32.13	32.130	54.090	54.110
317.5-m high building in exposure B (μ=0.03)					
TMD	0.051	34.57	34.570	56.190	56.080
TLD	0.046	33.42	33.420	54.160	54.130
317.5-m high building in exposure C (μ=0.03)					
TMD	0.051	36.23	36.270	56.090	56.090
TLD	0.046	35.14	35.140	54.200	54.280
400-m high building in exposure A (μ=0.03)					
TMD	0.051	31.46	31.460	56.110	56.050
TLD	0.046	30.49	30.490	54.150	54.210
400-m high building in exposure B (μ=0.03)					
TMD	0.051	32.87	32.870	56.100	56.050
TLD	0.046	31.82	31.820	54.180	54.210
400-m high building in exposure C (μ=0.03)					
TMD	0.051	34.71	34.710	56.040	56.070
TLD	0.046	33.64	33.640	54.260	54.210

Table 6.6 TMD and ATMD properties for high-rise buildings, 183 m, 317.5 m, and 400 m high

Design parameter	Vibration controller properties					
	μ	μ_0	γ	ξ	ε	ψ
Building: 183 m high						
TMD	0.01	-	0.99	0.05	-	-
ATMD	0.01	-0.0075	-	-	0.0012	0.0153
Building:317.5 m high						
TMD	0.03	-	0.978	0.0856	-	-
ATMD	0.03	-0.02	-	-	0.0018	0.0037
Building: 400 m high						
TMD	0.03	-	0.978	0.0856	-	-
ATMD	0.03	-0.02	-	-	0.0018	0.0037

Table 6.7 Comparisons of vibration responses for three high-rise buildings with vibration controls

Vibration control	Parameters/Responses					
	Optimal ξ_e	C_g	Roof pressure (kg/m^2)	Δ (m)	Peak roof acceleration/g	
					Along wind	Across wind
Building: 183 m high in exposure B						
Uncontrol	0.015	2.147	218.767	0.174	0.021	0.040
TMD	0.037	1.888	192.362	0.153	0.013	0.025
ATMD	0.062	1.800	183.362	0.146	0.010	0.019
Building: 317.5 m high in exposure B						
Uncontrol	0.010	3.047	408.826	1.876	0.049	0.159
TMD	0.051	1.995	267.700	1.229	0.022	0.070
ATMD	0.083	1.828	245.304	1.126	0.017	0.054
Building: 400 m high in exposure A						
Uncontrol	0.010	2.567	386.686	2.364	0.046	0.093
TMD	0.051	1.760	265.017	1.620	0.020	0.041
ATMD	0.083	1.631	245.656	1.502	0.016	0.032
Building: 400 m high in exposure B						
Uncontrol	0.010	2.753	393.163	2.311	0.047	0.093
TMD	0.051	1.849	264.151	1.553	0.021	0.041
ATMD	0.083	1.706	243.622	1.432	0.016	0.032
Building: 400 m high in exposure C						
Uncontrol	0.010	3.075	407.784	2.357	0.050	0.092
TMD	0.051	2.006	266.016	1.538	0.022	0.040
ATMD	0.083	1.836	243.465	1.407	0.017	0.031