Review of the Performance of the Control Strategies Used in Wind Induced 76-Storeyed Benchmark Building

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Abstract

The aim of this paper is to review a state of the art of researches on performance of several control devices used to control the wind response of the benchmark tall building. They include Passive Tuned Mass Damper(TMD),Active Tuned Mass Damper (ATMD),Smart Tuned Mass Damper (STMD),Viscous Dampers, Tuned Liquid Column Dampers (TLCD) ,Smart Piezo Electric Friction Dampers(SPFD),Semi-Active Devices Controller, Friction Dampers, Double Friction Dampers(DFD), Semi-Active Variable Friction Dampers(SAVFD),Semi-Active Variable Double Friction Dampers (SAVDFD).Phase-Ibenchmark building problem is considered for the review. A comparative performance study among all the different control systems for wind response control of building is carried out by comparing various evaluation criteria specified in the benchmark problem. The RMS acceleration, RMS displacement, control forces, peak displacements and accelerations can be greatly reduced by the application of different dampers but the effectiveness and performance of the viscous dampers in a particular type-II arrangement i.e alternate floor was observed better than any other dampers both against displacement and acceleration.

Keywords*-component:Benchmark building, TMD, ATMD, DFD, STMD, TLCD, SPFD, SAVFD, SAVDFD, Viscous damper*

INTRODUCTION

Significant progress has been made in structural control against natural hazards, such as earthquakes and strong winds. Response control of the structure is the need of the hour. Wind –induced response can result in occupant discomfort and sometimes endanger structural safety and reliability. Therefore, the need to investigate modern systems for wind vibration protection motivates the consideration of Passive, Semi-active, Active and Hybrid control mechanisms to alleviate the wind effects. Displacement and Acceleration are the two important factors to be controlled in the structural control, if not properly controlled may lead to overturning of structure and the structure may collapse. The damping in a mechanical or structural system is a measure of the rate at which the energy of motion of the system is dissipated. In the case of wind sensitive structures such as tall buildings, as damping reduces motion, making the building feel more stable to its occupants. Controlling vibrations by increasing the effective damping can be a cost effective solution. Occasionally, it is the only practical and economical means of reducing resonant vibrations. In this paper, different systems like Passive Tuned Mass Damper (TMD), Active Tuned Mass Damper (ATMD),Smart Tuned Mass Damper(STMD), Viscous Dampers, Tuned Liquid Column Dampers (TLCD),Smart Piezo Electric Friction dampers (SPFD),Semi Active Devices Controller, Friction dampers, Double Friction Dampers (DFD),Semi

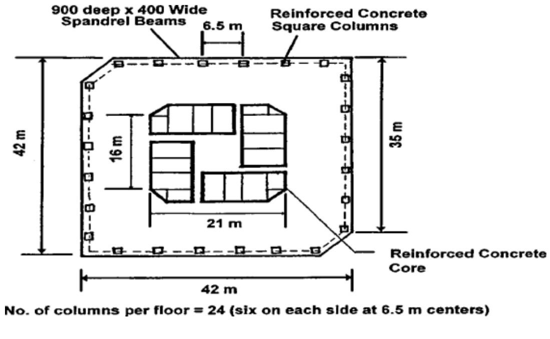
Active Variable Friction Dampers (SAVFD), Semi Active Variable Double Friction Dampers (SAVDFD) have been investigated for the reduction of wind induced vibrations of the benchmark building and their comparison has been done.

BENCHMARK BUILDING

The building considered is a 76-story 306 m office tower proposed for the city of Melbourne, Australia as shown in Figs.1 and 2.This is a reinforced concrete building consisting of a concrete core and concrete frame. The core wad designed to resist the majority of wind loads whereas the frame was designed to primarily carry the gravitational loads and part of the wind loads. The building has square cross section with chamfer at two corners as shown in fig.1.The total mass of the building, including heavy machinery in the plant rooms , is 153,000 metric tons. The total volume of the building is 510,000 m^3,resulting in a mass density of 300kg per cubic meter, which is typical of concrete structures. The building is slender with a height-to-width ratio(aspect ratio) of 306.1/4257.3;therefore, it is wind sensitive. The perimeter dimension for the center reinforced concrete core is 21mX21m.The reinforced concrete perimeter frame consists of columns spaced 6.5m apart, which are connected to a 900mm deep and 400mm wide spandrel beam on each floor.

There are 24perimeter columns on each level with six columns on each side of the building. The light weight floor construction uses steel beams with a metal deck and a 120mm slab. The compressive strength of concrete is 60MPa and the modulus of elasticity is 40Gpa.Column sizes, core wall thickness and floor mass vary along the height and the building has six plant rooms. The 76-story tall building is modeled as a vertical cantilever beam (Bernoulli-Euler beam).a finite element model is constructed by considering the portion of the building between two adjacent floors as a classical beam element of uniform thickness leading to 76 translational and 76 rotational degrees of freedom. Then, all the 76 rotational degrees of freedom have been removed by the static condensation. This results in a 76 degree of freedom (DOF), representing the displacement of each floor in the lateral direction. The first five natural frequencies are 0.16, 0.765, 1.992, 3.79 and 6.395 Hz. The (76x76) damping matrix for the building with 76 lateral DOF is calculated by assuming 1% damping ratio for the first five modes using Rayleigh's approach. This model having (76x76) mass, damping and stiffness matrices is referred to as the "76 DOF model"(For further details refer benchmark problem for response control of wind excited tall building by yang.et al)

Figure 1 Plan view of 76-storeyed building



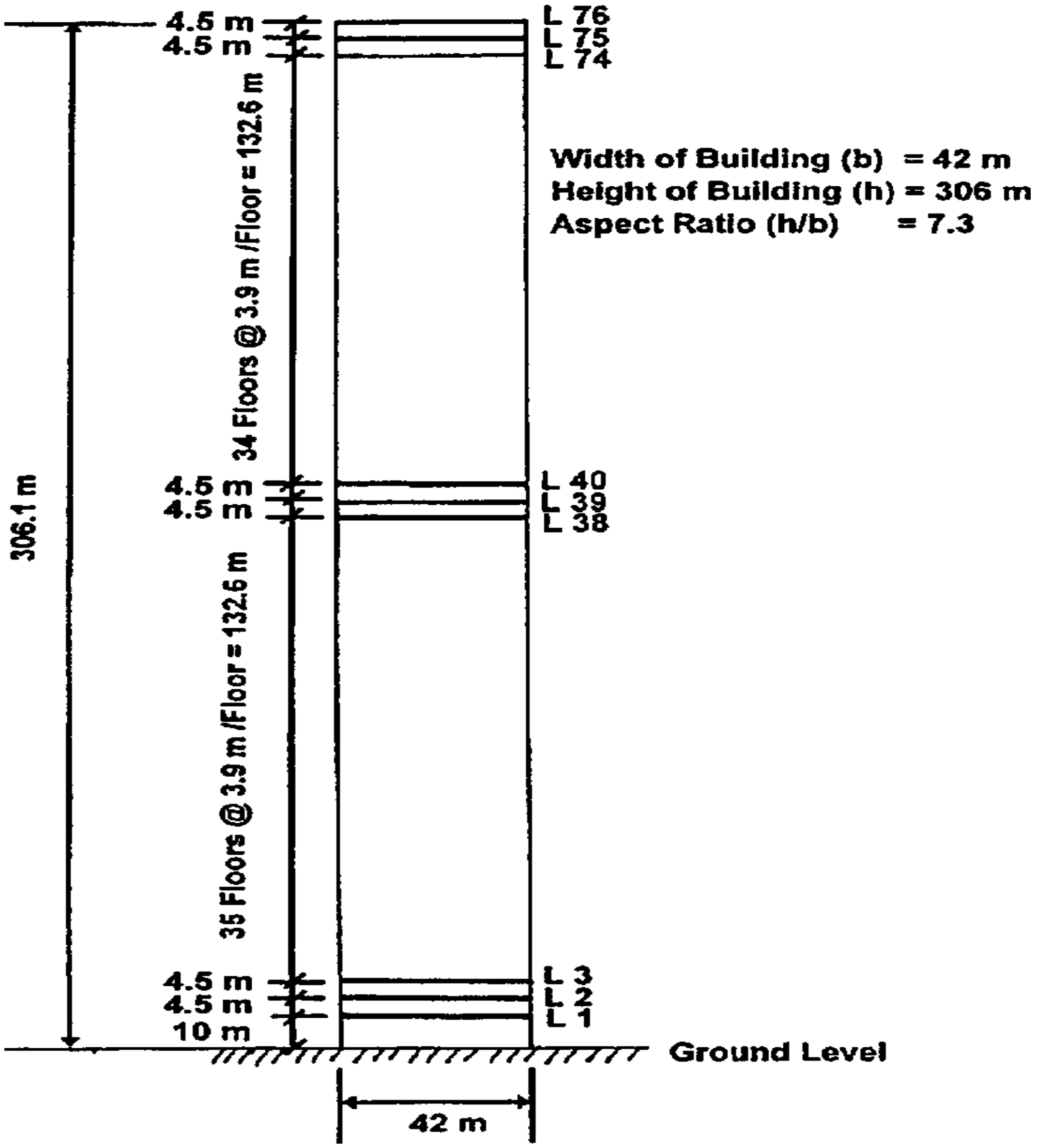


Figure 2 Elevation view of the building

EVALUATION CRITERIA

Critical responses for benchmark building subjected to wind loading are the displacements and accelerations in the building at key locations like displacements of top floors. The main objective of installing control systems on the tall building is to reduce the absolute acceleration to alleviate the occupant's discomfort. Response quantities of the building were evaluated in terms of 12 evaluation criteria consisting of RMS floor accelerations, top floor displacements, RMS actuator stroke, RMS actuator power, and peak and normalized values of accelerations and displacements. Objectives of installation of control systems on a wind-excited tall building are to reduce peak and RMS acceleration response quantities, while limiting peak actuator stroke required. These response quantities may be affected by uncertainties in the estimation of the stiffness of the building. Hence, in order to demonstrate the robustness of their control approach by considering ± 15% variations in the stiffness of the building.

CONTROL STRATEGIES ADOPTED FOR BENCHMARK BUILDING

A. PASSIVE CONTROL DAMPERS

A passive control system does not require an external power source. Passive control devices impart forces that are developed in response to the motion of the structure. .The energy in a passively controlled structural system, including the passive devices cannot be increased by the passive devices, cannot be increased by the passive control devices.

Friction Dampers :-

Friction dampers are usually classified as one of the displacement-dependant energy dissipation devices and the damper force is independent of the velocity and frequency content of excitation .The friction dampers have advantages such as simple mechanism, low cost, less Maintenance and powerful energy dissipation capability as compared to other passive dampers. Modeling of frictional force is done using hysteretic model which is a continuous model of the frictional force proposed by Constantinou et al, 1990. A friction damper usually consists of a frictional sliding interface and a clamping.

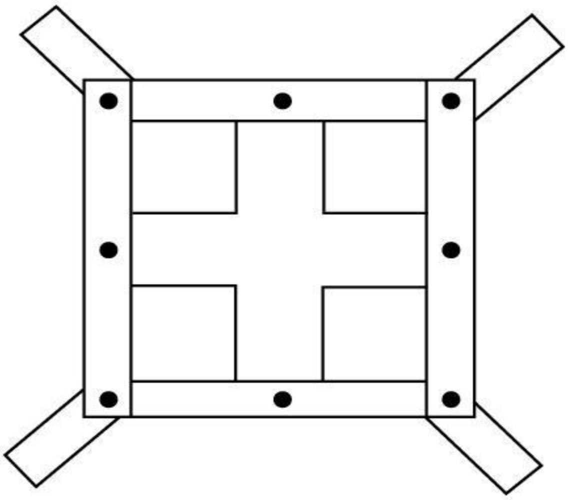


Figure 3 Type (a)

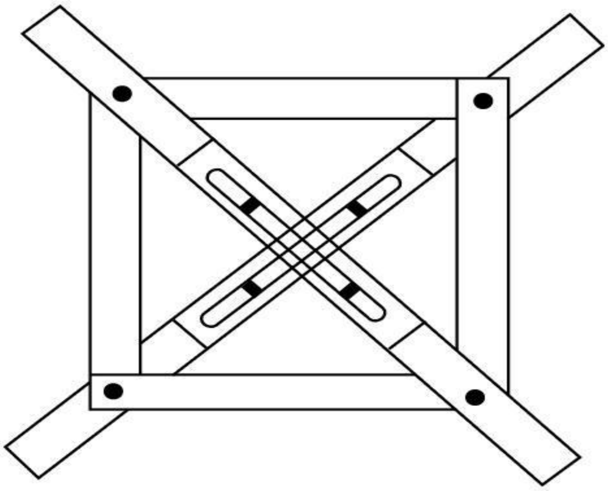


Figure 4 Type (b)

The frictional force developed in the damper are expressed by $f_{di}=f_{si}Z_i$ where Z_i is a non-dimensional hysteretic component.Each damper is successively installed in the storey where the inter-storey drift is maximum.This is done with a view that a damper is optimally located if it is placed in the storey in which the displacement (or relative displacement) of the uncontrolled (or modified)structure is largest. This procedure is repeated until the required level of performance is achieved. At optimized locations 47 conventional friction dampers are required to achieve the same performance criteria comparable to those obtained with the conventional friction dampers installed in all the floors .The optimized locations of friction dampers (both conventional and double friction dampers) are between 71 to 76th floors.

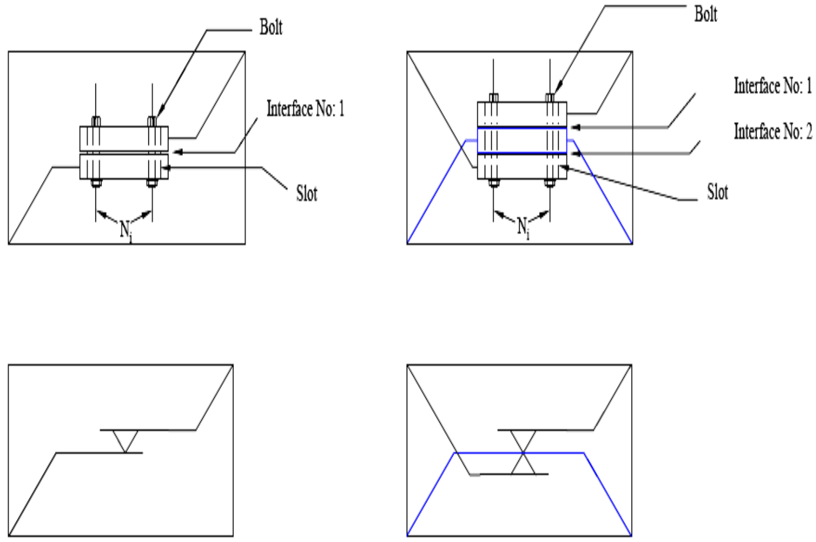
Table 1

Description	Index	Formula
Maximum floor RMS acceleration	J_1	$\text{Max}\square\square_{\ddot{x}1,}\square\square_{\ddot{x}30,}\square\square_{\ddot{x}50,}\square\square_{\ddot{x}55,}\square\square_{\ddot{x}60,}\square\square_{\ddot{x}65,}\square\square_{\ddot{x}70,}\square\square_{\ddot{x}75})_{/}\square\square_{\ddot{x}75o}$
Average RMS acceleration for selected floors	J_2	$\frac{1}{6}\sum(\square\square_{\ddot{x}i/}\square\square_{\ddot{x}io})$ For i=50,55,60,65,70 and 75
Maximum RMS displacement for selected floors	J_3	$\square_{x76}/\square_{x76o}$
Average RMS displacement for selected floor	J_4	$\frac{1}{7}\sum(\square\square_{xi/}\square\square_{xio})$ For i=50,55,60,65,70,75 and 76
RMS actuator stroke	J_5	$\square_{xm}/\square\square_{x76o}$
RMS control power	J6	$\{\frac{1}{T}\int_0^T(\dot{x}_m(t)u(t))^2{}_{dt\}}{}^{1/2}$
Maximum floor peak acceleration	J_7	$\text{Max}(\ddot{x}_{p1}, \ddot{x}_{p30}, \ddot{x}_{p50}, \ddot{x}_{p55}, \ddot{x}_{p60}, \ddot{x}_{p65}, \ddot{x}_{p70}, \ddot{x}_{p75})/, \ddot{x}_{p75o}$
Average peak acceleration for selected floors	J_8	) Where i=50,55,60,65,70 and 75
Maximum peak displacement of top floor	J_9	x_{p76}/x_{p76o}
Average peak displacement for selected floors	J_{10}	$\frac{1}{7}\sum(xpi/xpio)$Where i=50,55,60,65,70,75 and 76
Peak actuator stroke	J_{11}	x_{pm}/x_{p76o}
Peak control power	J_{12}	$\max\lvert \dot{x}_m(t)u(t)\rvert$

Double Friction Dampers

An attempt is made to enhance the performance of friction dampers by providing an additional plate (Figure 5) between the two existing plates and make an additional interface available to resist the external loads. The displacement and acceleration quantities have considerably reduced with double friction dampers than those with conventional friction dampers At optimized locations, only 24 double friction dampers are sufficient to achieve the performance criteria comparable to those obtained with the conventional friction dampers installed in all the floors.

Thus, at the optimized locations, the damper gives 50% improved performance as compared to its conventional counterparts.The optimized locations double friction dampers are between 71 to 76th floors. The amplitude of both displacement and acceleration frequency responses with double friction dampers are reduced as compared to its conventional counter parts, corresponding to the frequency of 0.16 which is the fundamental frequency of the benchmark building.



(a) Schematic andMathematical model of friction damper

(b) Schematic and mathematical model of double friction damper

Figure 5. Schematic and mathematical models of conventional and double friction dampers

Viscous Dampers

Linear Viscous Damper is applied for the extensive use of controlling vibrations in the building due to heavy wind force.The main components involved in this damper are cylindrical body, steel piston with an orifice. Cylinder is filled with a viscous fluid, such as silicon gel. The difference of the pressure on each side of the piston head results in the damping force. The damping constant of the damper is determined by adjusting the configuration of the orifice of the piston head. Due to pure viscous behavior , damper force and the velocity remain in phase. However, for a damper setup shown in (fig.6) the volume for storing the fluid will change while the piston begins to move. Thus, restoring force, which is in phase with displacement rather than the velocity, will be developed.

The ideal force out for a damper is

$$F_{di}=C_{md}|x|^{\alpha}sgn(x)$$

It is worth to note that a damper force is directly proportional to the relative velocity between the two ends of the damper. When a damper is connected between the alternate floors of a building, the relative velocity available would be larger than that available when connected between the successive floors. This fact is utilized to improve the performance of dampers.The damper with α □□1 is called an LVD. The dampers with $\alpha > 1$ have not been seen often in practical applications. The damper with $\alpha < 1$ is called a nonlinear viscous damper, which is effective in minimizing high velocity shocks.

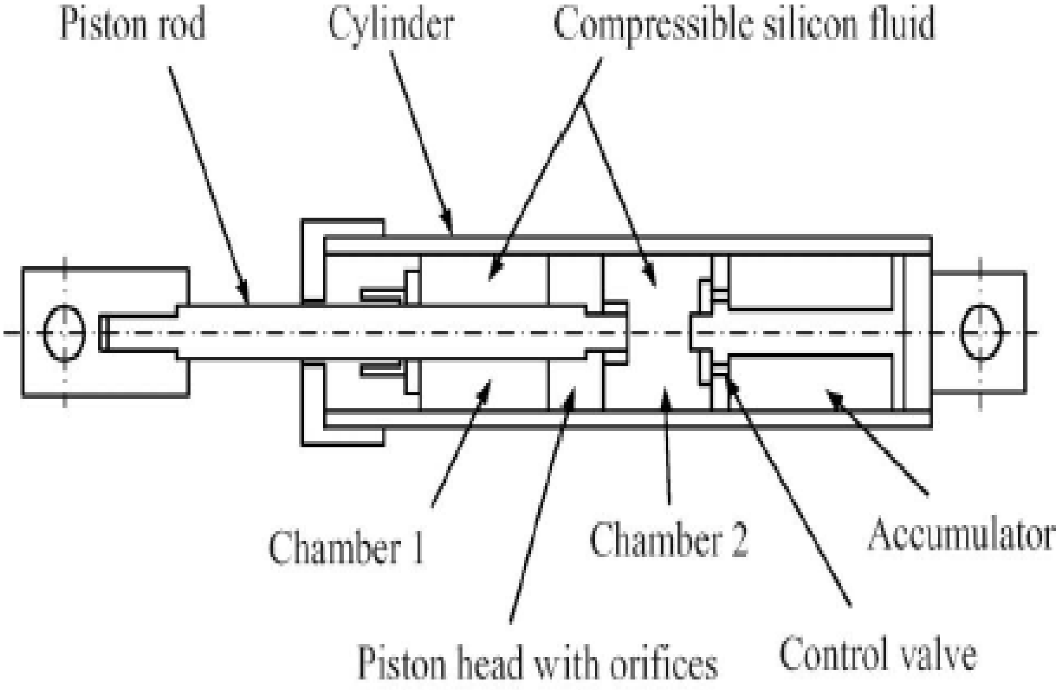


Figure 6. Viscous damper

This viscous dampers according to V.B Patil et al. was arranged in three different types namely type-I (dampers are connected to successive floors of a building),type-II and type-III (connecting them to alternate stories).

Tuned Liquid Column Dampers

The tuned liquid column damper (TLCD) has received the attention of researchers as a type of auxiliary mass system. A TLCD has control characteristics similar to those of a tuned mass damper (TMD), which is one of most frequently used dampers for vibration control .In a TLCD system, the secondary mass is liquid and damping forces are introduced through the motion of liquid in a U-shape tube container (Fig. 3). When the same mass is used and other parameters are properly tuned, a TLCD system provides performance similar to a TMD system.

TLCD has many advantages over a TMD can be referred from K.-W. Min et al.(2005).Due to which a growing number of bridge and building structures have been built with the TLCD system. The dynamic characteristics of the TLCD depend on the magnitude and the characteristics of excitation forces and the corresponding structural responses of the floor at which the TLCD is installed. The tuning frequency ratio, the head loss coefficient, and the length ratio are critical parameters in the design of TLCD.

Tuning frequency ratio: It is the ratio of frequency of a TLCD to that of the structure, and is expressed as

$$f = \omega_t / \omega_s$$

Where ω_s is the natural frequency of the structure and ω_t ($=\sqrt{(2g/L)}$) is the frequency of the liquid column.The sensitivity of performance to the tuning frequency ratio is reduced with increasing mass ratio. Men.et.al concluded that Equivalent linear damping provides almost the same RMS and peak structural responses as those of a nonlinear TLCD regardless of the amplitude of white noise.

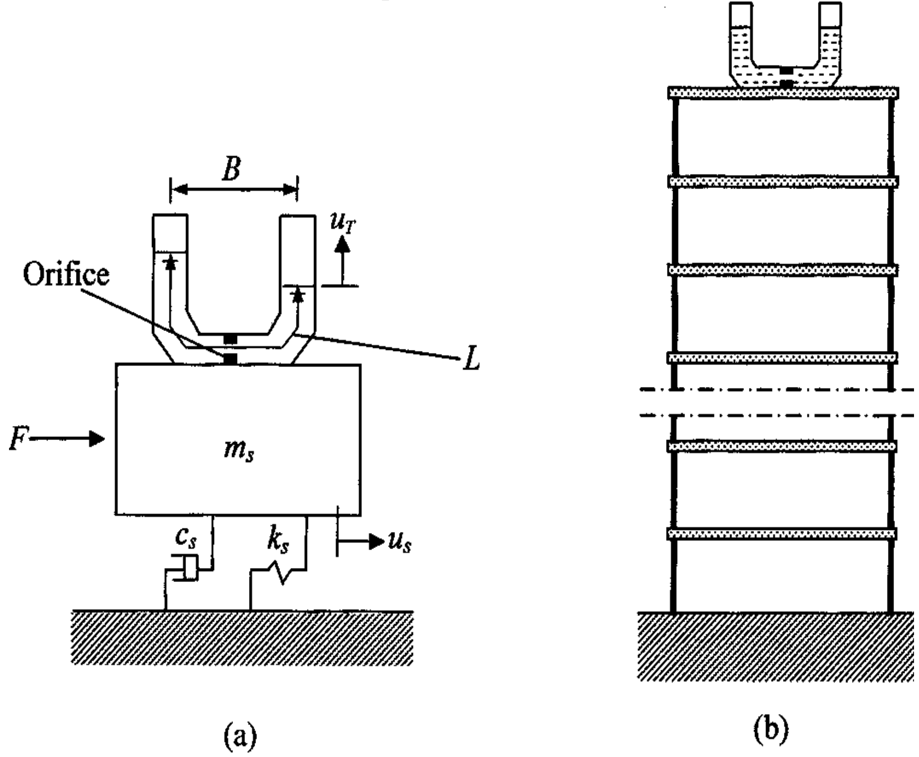


Figure 7 Tuned liquid column damper system: (a) second degree of freedom system with TLCD a (b) TLCD system installed on roof of multistory building structure

Optimal head loss coefficient: The value of head loss coefficient is determined according to inner resistance and cross sectional area of the liquid column and it should previously be identified using an experimental study.

Optimal length ratio: The variation of performance indices J1 to J4 with respect to the length ratio, α, and μ can be referred from K.-W. Min et al.(2005) . It is observed that the larger μ and α result in the better control performance in general. Accordingly, it is advantageous to increase α as much as possible. However, α more than a certain threshold value destroys the basic characteristics of TLCD sand thereby the following constraint condition on α should be satisfied for practical application.

$$\alpha \leq 1 - 2\frac{|umax|}{L}$$

Where umax denotes themaximum displacement of the liquid column. Since umax depends on the excitation forces, an iterative procedure is necessary for determining α.[7][20]

Multiple TLCD

The natural frequency of the structure may be different from the value assumed for the design of TLCDs, and this discrepancy results in the performance degradation of a single TLCD system. Accordingly, the MTLCD system was developed in order to compensate this shortcoming of the single TLCD. The MTLCD system is generally known to have more robustness than a single TLCD because it has a broader frequency distribution bandwidth. The design parameters of MTLCDs are the number of dampers, the frequency range, and central tuning frequency ratio. It is reported that tuning the frequencies of every TLCD to the fundamental mode in the MTLCD is more effective than tuning it to different modes.

Optimal number of dampers: The optimal number of dampers, N, should be determined to consider the control performance and economical and constructional efficiency.

Optimal frequency range: The frequencies of the MTLCD are distributed at the same interval of frequency with reference to central tuning frequency ratio. The frequency range is given by

$\Delta\omega = \omega t\ N - \omega t1$

where $\omega t\ N$ and $\omega t1$ are the frequencies of the first and Nth TLCD, respectively

Central tuning frequency ratio: The central tuning frequency ratio denotes the frequency of the TLCD at the center of frequency range, and is givenby

$fo = \omega t\ j/\omega s$ if N is odd number

$\frac{\omega t\ j + \omega t\ j+1}{2\omega S}$ Otherwise

where j is equal to (N + 1)/2 if N is an odd number and to N/2 otherwise.[7]

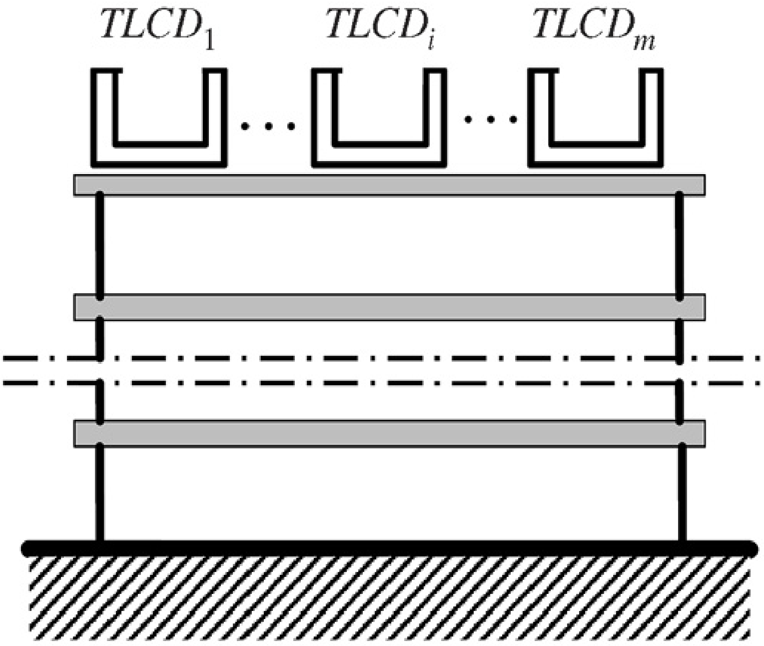


Figure 8. Multiple tuned liquid column dampers

MTLCD with Non-uniform mass distribution

Most studies on MTLCDs have been conducted setting the mass ratio of each TLCD to be identical. From K.-W. Min et al., It can be seen that the non-uniform MTLCD performs equal to or better than the uniform MTLCD near the resonance frequency, while it does not do so outside of the resonance frequency. These results are reasonable, considering that the non-uniform MTLCD has the largest mass ratio at the central tuning frequency where the resonance occurs.[7]

SEMI ACTIVE CONTROL DAMPERS

Semi active control systems are a class of active control systems for which the external energy Requirements are orders of magnitude smaller than typical active control systems. Semiactive control devices do not add mechanical energy to the structural system(including the structure and the control actuators),therefore bounded-input bounder-output stability is guaranteed. semi active control devices are often viewed as controlled passive devices

Semi-Active Variable Friction Dampers

A semi-active friction damper is able to adjust its slip force by controlling its clamping force in real-time, depending on the structure's motion .This adaptive nature makes asemi-active friction damper more efficient than a passive damper. the control performance of the semi-active dampers significantly relies on the control algorithm applied. The optimized location of all the semi-active variable friction dampers SAVFDs is at 76th floor.[1][8]

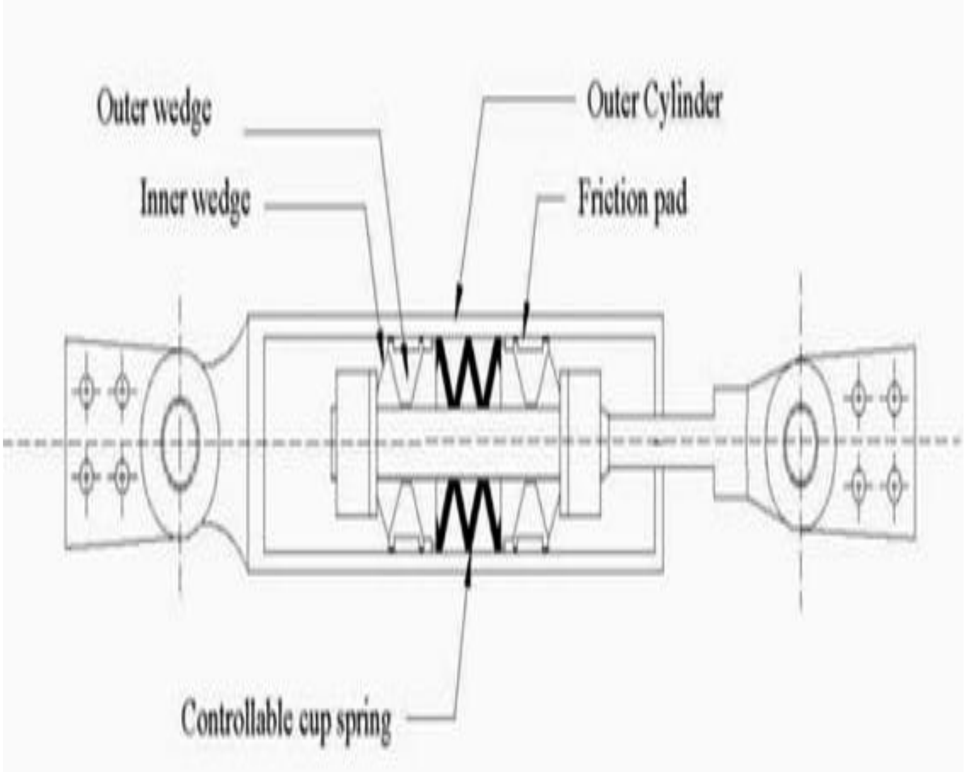


Figure 9. Schematic and mathematical models of SAVFD

Semi-Active Variable Double Friction Damper :-

By providing an additional friction pad on the inner side of the clamping mechanism of a SAVFD an additional resisting interface is brought into use with the same clamping mechanism, thus enhancing the resisting frictional force. This is how a SAVFD is converted into a semi-active double friction damper (SAVDFD).

Now in SAVDFDs in this two interfaces are used in the mode The performance of SAVDFDs using predictive control law installed in all the floors. The frictional force developed in the damper are expressed by

$$f_{di}=2f_{si}Z_i$$

Displacement and acceleration quantities of the 76th floor have considerably reduced with SAVDFDs as compared to those with SAVFDs. The amplitude of both displacement and acceleration frequency responses with SAVFD are reduced as compared to its conventional counter parts, corresponding to the frequency of 0.16 which is the fundamental frequency of the benchmark builing

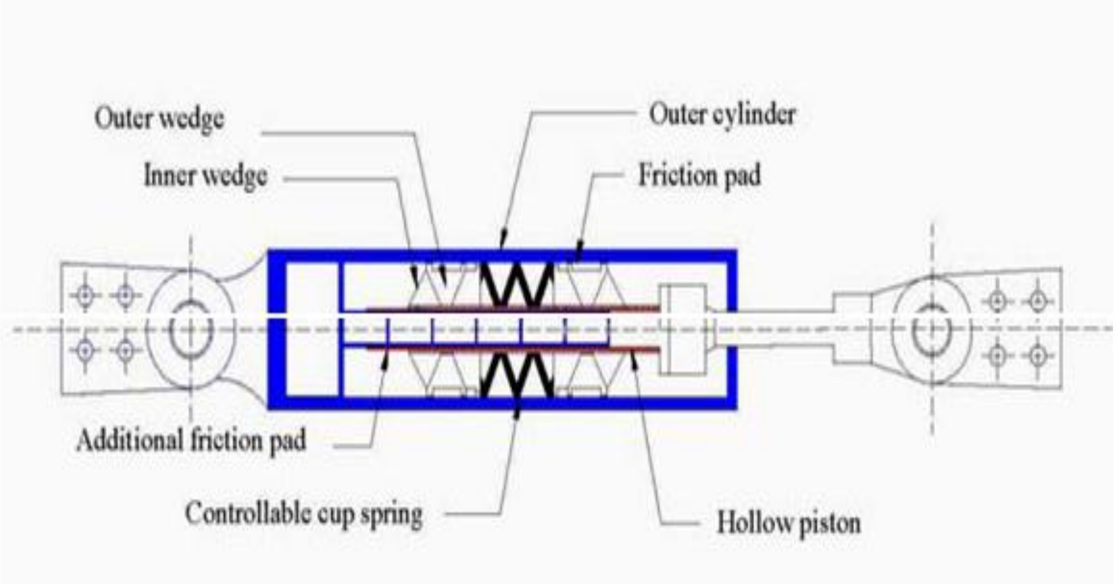


Figure 10 Schematic and mathematical models of SAVDFD

Semi-Active TLCD

The semiactive TLCD control system performs comparably to a sample active tuned mass damper (ATMD) system and thus is an attractive alternative to the ATMD system. The semiactive TLCD system does not need any actuator requiring a large electro-mechanic capacity and thus is able to operate with only small power, such as a battery, it is concluded that the semiactive TLCD system is an attractive alternative to the ATMD system.

Semi-Active Control Using A Fuzzy Controller

Semi-active control systems have the adaptability aspects of active control systems along with the reliability and stability of passive controllers. Semi-active control systems often require low power to operate a small electronic device to adjust the mechanical properties of the device. Among all of the control devices that have been used in semi-active control systems, variable dampers are the most popular. A comprehensive illustration of these systems has been described by Spencer and Sain and Symans and Constantinou

The fuzzy controller at uncertaining percentage “0” has better performance compared to 15 and -15% (S. M. Zahrai and A. Shafieezadeh(2009)) .Inputs to the fuzzy controller were the displacement and velocity of the 76th floor. Simulation results showed the passive damper reduces the 76th floor RMS displacement and acceleration response by 37% and 40% respectively, while the fuzzy controller reduced the same responses by 42% and 48% respectively, when compared to the uncontrolled case. Different performance criteria were used to evaluate the performance of the controller. In most cases, the fuzzy controller had a better performance, especially in J7, the average of the RMS displacement.Considering all the results from S. M. Zahrai et.al**.** fuzzy controller is seen to be more effective than the passive controller in retuning the damping of the semiactive device and reducing the structural response to wind excitations response.Semi Active Tuned Mass Damper using a fuzzy hybrid controller. A passive tuned mass damper (Den Hartog 1956; Warburton and Ayorinde 1980) is used to control the vibrations of structure but in order to improve the effectiveness of TMD , ATMD (Chang and

Soong 1980; Ankireddi and Yang 1996) have been introduced which is more costly, complex and needs careful maintenance which is less reliable. Recognizing the performance benefits as well as the lack of stability of active systems the concept of semi active smart tuned mass dampers (STMD) (Pinkaew & Fujino 2001; Nagarajaiah & Varadarajan 2000; Koo et el.2006) has been introduced by using a simplified DOF structures and idealised external loads. In this study magnetorheological (MR) damper is employed to comprise a semi-active smart TMD (STMD) for the control of the benchmark building. The single STMD is installed on the top floor of the 76-story benchmark building.

The maximum capacity of the MR damper used in this study is approximately 100 kN. The absolute values of the STMD displacement and the acceleration of the 75th floor are selected as inputs for fuzzy hybrid controller. The output is then the weighting factor.The“skyhook” and ground hook” which are conventional semi active algorithms used as sub controllers ,control policies are favorably used because of their simplicity and effectiveness and this shows good control performances for the vibration control of civil structures as well as vehicle applications (Liu et al. 2005; Koo et al. 2006; Narasimhan et al. 2006).A comparison between groundhook and skyhook controllers shows that groundhook controller provides much better control performance for all the structure responses than skyhook controller.For acceleration responses ATMD shows better performance than STMD and for displacement responses STMD show a better performance when compared to ATMD.[4][12][11].

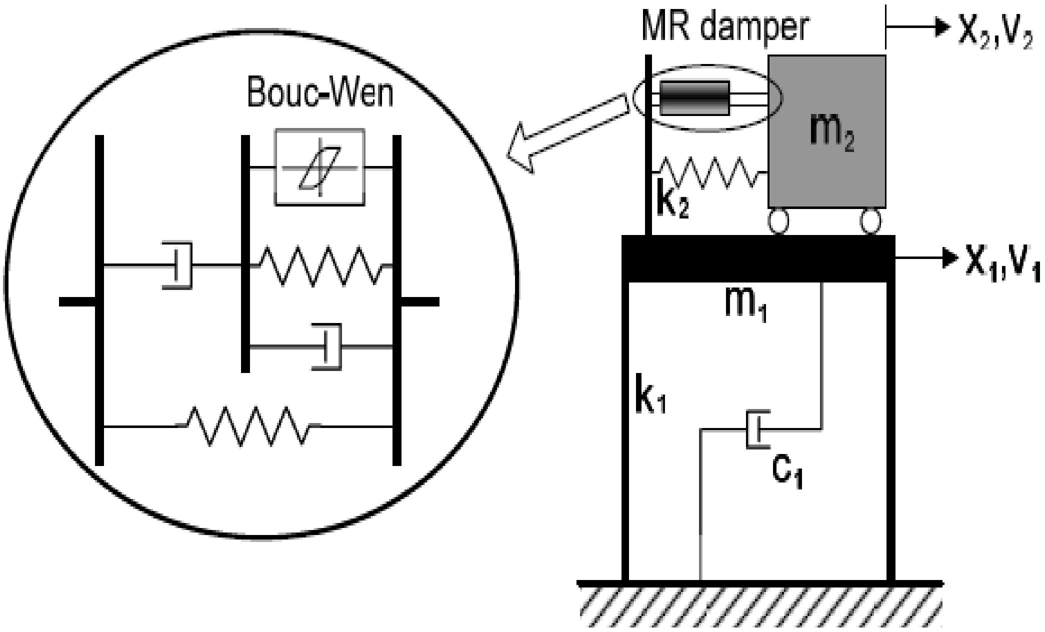


Figure 11 STMD installed using MR damper

HYBRID CONTROL DAMPERS

The common usage of the term “hybrid control” implies the combined use of active and passive control systems.for example, a structure equipped with distributed visco elastic damping supplemented with an active mass damper on or near the top of the structure, or a base isolated structure with actuators actively controlled to enhance performance

Hybrid Viscous Fluid Damper TLCD

More significantly, it is shown that the hybrid viscous fluid damper-TLCD system reduces the response of the building substantially more than the semiactive TLCD system at every natural frequency of the building. Furthermore, the hybrid damper-TLCD system is robust in terms of the stiffness modeling error for control of both displacement and acceleration responses. .By judiciously integrating the semiactive TLCD system with a passive supplementary damper system, the hybrid viscous fluid damper-TLCD system provides reliable and robust control of wind-induced vibrations of high-rise buildings in terms of power or computer failure. It is shown that the hybrid system can reduce the response of the building significantly more than the semiactive TLCD system at every natural frequency of the building.Further, the simulation results using stochastic wind loads with respect to Hongjin et.al. the proposed hybrid control system can perform effectively under various wind loads.[10][5]

ACTIVE CONTROL DAMPERS

An active control system is one in which an external source powers control actuatuor(s) that apply forces to the structure in a prescribed manner.these forces can be used to both add and dissipate energy in the structure. In an active feed back control system,the signals sent to the control actuators are a function of the response of the system measured with physical sensors optical, mechanical, electrical, chemical [3]

Active tuned mass damper using fuzzy logic

Active tuned mass damper is based on active control system installed in tuned mass damper.A simulation program is done using fuzzy controller by Yang.et.al. A fuzzy logic controller is robust and capable of handling any nonlinear behavior of the structure.The main advantages in adopting a fuzzy control algorithm is the uncertainties of input data are treated in a much easier way by fuzzy control theory than by classical control theory and the whole fuzzy controller can be easily implemented in a fuzzy chip, which guarantees immediate reaction time and autonomous power supply. The writers suggest using the acceleration of floors 50 and 76 as feedback variables for the fuzzy controller design because then response of the building is larger in the top floors compared to lower ones. The aim of using two input variables for the fuzzy controller is to show the performance of the fuzzy approach in the control problem. The small number of feedback variables means the use of fewer sensors; thus a simplification of the control system with advantages in terms of reliability and costs. The control schemes provided in the benchmark study is used in the simulation and a deterministic context has been selected. The fuzzy controller is implemented into the SIMULINK program using an integration time step of 0.001 s and the control signal is computed every 0.001 s. the performance of the fuzzy controller is similar and in some cases better than the LQG controller.(Bijan Samali.et.al(2004) When stiffness is increased by 15% its performance is not as good when stiffness is decreased by 15%. . The main advantage of the FLC is its inherent robustness and ability to handle any nonlinear behavior of the structure.According to to (Yang et al) The constraints on the actuator requirements RMS control force≤100 kN, RMS actuator stroke≤300 mm, peak control force ≤300 kN, and peak actuator stroke≤950 mm) Are satisfied for all cases using the fuzzy controller.[3]

Active tuned mass damper using LQG

A simulation program based on the linear quadratic Gaussian (LQG) control algorithm has been developed and made available for the comparison of the performance of various control strategies (SSTL 2000).A rigid model of 76 stored building has been made and wind tunnel test is done dividing the building into 32 panels . The results are initially in the form of combined pressure coefficientsreferenced to the building height they were combined to give a single pressure coefficient at each level. To convert these combined pressure coefficients into wind forces, appropriate mean wind speed at the top of the building is required in the following equation. $\text{Force}=0.5\rho\ V^2AC_P$ where ρ=density of air; V=mean wind velocity at the top of the building; A=corresponding single panel area; and p=combined pressure coefficient The controller is digitally implemented with a sampling time of $\Delta t=0.001$ s. A computational time delay of 1 ms is considered for the simulation of response.Based on the design code for office buildings, the maximum allowable floor acceleration is 15 cm/s^2 or a RMS value of 5 cm/s^2. Excluding the 76th floor on which there is no occupant, the design requirement is satisfied by the use of an ATMD (Jann N. Yang.et.al(2004)).On the other hand, the installation of a passive TMD does not satisfy the design code requirement, and the floor accelerations are excessive .Active controllers are not sensitive to the uncertainty in damping. Two additional buildings are considered by Jann N. Yang.(2004) one with a 15% higher stiffness matrix and another with a 15% lower stiffness. In comparison with the losed-loop response of the nominal structure the RMS displacement of the 75th floor, stroke, active control force, and control power for the 215% building increase by about 23%, 19.24%, 30%, and 38.5% respectively On the other hand, the RMS displacement response, stroke, active control force, and control power reduce by 15.7%, 20.2%, 16.97%, and 29.4%, respectively, for the 115% building in comparison with that of the nominal building (LQG controller case). [2][16][17][18].

Smart piezo electric Friction dampers

Piezoelectric friction damper (PFD) was introduced in structural control. Piezoelectric actuators used in the damper can quickly and accurately respond to a driven command such as a voltage signal. They are also effective over a wide frequency band with low power consumption and are very reliable and compact in design. A SPFD consists of piezoelectric actuators and friction devices is presented Damping force model of Smart Piezoelectric Friction Damper The normal pressure acting on the SPFD is N(t), friction factor is μ, the damping force model is then

$f(t) = \mu N(t)\text{sgn}[x(t)]$

Where x (t) is the relative velocity between the sliding plates of the damper. N(t) relates to the preload of the damper and the adjustable tightening force produced by piezoelectric actuator,

$N(t)= N_o \quad (E=0)$

$N_o+KEd_{33} \quad (E>0)$

Where N_o is the preload on the multilayered stack actuators required for the generation of the passive friction force; Ked_{33} is adjustable tightening force produced by piezoelectric actuators; d_{33} is piezoelectric strain coefficient; K is the shape factor of the damper and is only relating to the shape of the actuators and the bolts for a certain Young’s modulus,

$K=(Y_P A_P L_P Y_l A_l) / (Y_l A_l L_p +Y_p A_p L_l)$

Where Y_p is Young’s modulus of the piezoelectric material ; A_p is the area of cross section of the stacks; L_p is the axial height of the actuator; Y_l is Young’s modulus of the bolts; A_l is the area of cross section of the bolts ; L_l is effective length of the bolts.

The analysis and simulation of the control of Benchmark building with SPFD using two different semiactive control algorithms with LQR optimal control are conducted by Ping Dong.et.al (2011). Though the maximal friction force is only 160kN (not reach the maximal optimal active control force in the middle and upper floors of the building), the good control effects are still achieved. Compared to the structure without control ,the peak displacement of the building with Semi1 (Ping Dong.et.al(2011)) reduced by about 32%. The average rate of vibration reduction of Semi2(Ping Dong.et.al(2011)) is about 25%. The peak acceleration reduced 30% and 20% respectively for Semi1 and Semi2. The effects of acceleration control in upper floors are better than that of in lower floors.[5]

DISCUSSION

1. Performance of the different dampers have been studied with different control system.
2. It is observed that dampers under optimal location are having better performance.
3. Less no of dampers can be used by placing in optimal locations.
4. using of dampers have reduced acceleration and displacement to greater extent.

CONCLUSION

1. The performance of the 76 storeyed bench mark building with viscous damper under alternate floor arrangement is giving better performance when compared to the others.

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Table-1
Evaluation criteria of passive control strategies

Researcher & Year	Name of the Device	J1	J2	J3	J4	J7	J8	J9	J10
Patil& Jangid(2009)	Passive linear viscous damper (type-2 arrangement)	0.101	0.106	0.378	0.383	0.128	0.145	0.413	0.421
Patil& Jangid(2009)	Passive linear viscous damper (type-3 arrangement)	0.148	0.157	0.42	0.424	0.202	0.217	0.502	0.512
Patil& Jangid(2009)	Passive linear viscous damper (type-1 arrangement)	0.21	0.211	0.454	0.458	0.284	0.296	0.578	0.587
Patil& Jangid(2009)	Passive conventional friction damper (optimised)	0.312	0.304	0.473	0.477	0.377	0.4	0.653	0.663
Patil& Jangid(2009)	semi active variable friction dampers (type-2 arrangement)	0.266	0.267	0.482	0.485	0.328	0.337	0.619	0.628
Patil& Jangid(2009)	Passive linear viscous damper (optimised arrangement)	0.353	0.355	0.527	0.53	0.347	0.359	0.659	0.668
Patil& Jangid(2009)	semi active variable friction dampers (type-3 arrangement)	0.364	0.364	0.535	0.537	0.359	0.366	0.669	0.678
K-W.Min.et.al (2005)	Passive MTLCD with uniform mass distribution	0.376	0.334	0.543	0.545	0.414	0.371	0.573	0.581
K-W.Min.et.al (2005)	Passive MTLCD with non-uniform mass distribution	0.376	0.334	0.543	0.545	0.414	0.37	0.573	0.58
Patil& Jangid(2009)	Passive conventional friction damper	0.437	0.431	0.561	0.564	0.483	0.484	0.678	0.682
Patil& Jangid(2009)	Passive double friction dampers (optimised)	0.458	0.447	0.567	0.571	0.54	0.525	0.685	0.69
Patil& Jangid(2009)	Passive double friction dampers	0.463	0.452	0.571	0.575	0.544	0.53	0.689	0.694
.et.al(2009)	semi active control device, passive tuned mass damper	0.369	0.417	0.578	0.58	0.381	0.432	0.717	0.725
Patil& Jangid(2009)	semi active variable friction dampers (type-1 arrangement)	0.491	0.491	0.614	0.616	0.499	0.504	0.731	0.74
Hyun-su-kim.et.al(2009)	semi active control device,smart tuned mass damper	0.531	0.528	0.643	0.645	0.547	0.541	0.767	0.775
Hyun-su-kim.et.al(2009)	semi active control device, passive tuned mass damper	0.589	0.583	0.681	0.682	0.652	0.637	0.786	0.794
B.Samali.et.al. (2004)	active Fuzzy controller (time step=0.01)active tuned mass damper	0.366	0.414	0.689	0.691	0.442	0.511	0.77	0.78
B.Samali.et.al. (2004)	active Fuzzy controller	0.366	0.414	0.689	0.691	0.444	0.512	0.77	0.78
B.Samali.et.al. (2004)	active Fuzzy controller (time step=0.001) active tuned mass damper	0.366	0.414	0.689	0.691	0.444	0.512	0.77	0.78
J.N.Yang.et.al. (2004)	Active tuned mass damper	0.387	0.438	0.711	0.712	0.488	0.539	0.77	0.779