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Review on applicability of combinations of Damper for Steel Frame Structure.

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Abstract - *Combinations of Dampers have become more popular recently for earthquake load and wind load induced vibration of steel frame structures, because of their safe, effective and economical design. This paper presents an overview of literature related to the behavior of dampers on seismically affected structures. The review includes different types of dampers like metallic dampers, viscous damper, viscoelastic dampers, frictional dampers etc. However, there have been few investigations for the combinations of dampers, its advantages are discussed and a detailed review is carried out*

***Key Words*: Steel frame structure, combination of damper**

1. INTRODUCTION

Earthquake in the simplest terms can be defined as Shaking and vibration at the surface of the earth resulting from underground movement along a fault plane. The vibrations produced by the earthquakes are due to seismic waves. Of all the factors accounted for, in any building design, seismic waves are the most disastrous one. Conventional methods of base widening, (as in case of pyramids) or providing heavy massive structure at bottom has been used in the past, for retaining earthquakes and to combat wind effect. However, modern high rise buildings and tall structures cannot conveniently be geared up with these techniques. The safety and serviceability of any structure is thus endangered with the increasing elevation. An efficient ideology of providing dampers in the structure to reduce its vibrations has seen appreciating response in recent years. Numerous dampers with flexible designs and smart base isolation techniques have been used to effectively reduce vibrations caused by seismic waves.

1.1 Overview

Considering the ever increasing population, and increased industrial demand, there has been a boom in the construction industry. Economics and safety are the priorities for any structural engineer, which has cleared the way for more specific and sound structures. Various types of commercial and residential buildings are equipped with different types of base isolation techniques and damping systems. This has intensified the production and use of dampers in the western countries; where in optimum placing of the dampers has become an integral part of the building design. In India too, modern constructions have seen implementing these techniques, thus promoting the need for study and analyzing of methods of resisting seismic waves.
As per the standard codes, a structure that can resist the highest earthquake that could possibly occur in that particular area can be called as an earthquake resistant structure. However, the most efficient way of designing earthquake resistant structure would be to minimize the deaths as well as minimize the destruction of functionality of the structural element. The most disastrous thing about earthquake is its unpredictability of time and place of occurrence. This poses a great challenge to the economy and safety of the structure. It requires that the elements of the building, be designed to expiate the energy received by earthquakes to minimize the damage caused.

1.2 Techniques to resist earthquakes

The conventional approach to earthquake resistant design of buildings depends upon providing the building with strength, stiffness and inelastic deformation capacity which are great enough to withstand a given level of earthquake-generated force. This is generally accomplished through the selection of an appropriate structural configuration and the careful detailing of structural members, such as beams and columns, and the connections between them. But more advanced techniques for earthquake resistance is not to strengthen the building, but to reduce the earthquake-generated forces acting upon it.
Among the most important advanced techniques of earthquake resistant design and construction are:

- Base isolation technique.
- Energy dissipation devices (Damper).

1.2.1 Base isolation Techniques

A base isolated structure is supported by a series of bearing pads which are placed between the building and the building's foundation. A variety of different types of base isolation bearing pads have now been developed.

The bearing is very stiff and strong in the vertical direction, but flexible in the horizontal direction.

1.2.2 Energy dissipation devices (Damper)

The second of the major new techniques for improving the earthquake resistance of buildings also relies upon damping and energy dissipation. Different types of structural control devices have been developed and a possible classification is done by their dissipative nature. Structural control systems can be classified as passive, active, semi-active and hybrid.

A passive control device is a device that develops forces at the location of the device by utilizing the motion of the structure. Through the forces developed, a passive control device reduces the energy dissipation demand on the structure by absorbing some of the input energy. Thus, a passive control device cannot add energy to the structural system. Furthermore, a passive control device does not require an external power supply. Examples of passive devices include base isolation, tuned mass dampers (TMD), tuned liquid dampers (TLD), metallic yield dampers, viscous fluid dampers and friction dampers.

The active control systems are the opposite side of passive systems, because they can provide additional energy to the controlled structure and opposite to that delivered by the dynamic loading. Active control devices require considerable amount of external power to operate actuators that supply a control force to the structure. An active control strategy can measure and estimate the response over the entire structure to determine appropriate control forces. As a result, active control strategies are more complex than passive strategies, requiring sensors and evaluator / controller equipment's. Cost and maintenance of such systems are also significantly higher than that of passive devices. Examples among active control devices include active tuned mass damper, active tuned liquid column damper and active variable stiffness damper.

Semi-active control devices combine the positive aspects of passive and active control devices. Like passive control devices, semi-active control devices generate forces as a result of the motion of the structure and cannot add energy to the structural system. However, like an active control device, feedback measurements of the excitation and/or structural system are used by a controller to generate an appropriate signal for the semi-active device. In addition, only a small external power source is required for operation of a semi-active control device. Examples of semi-active devices include variable orifice dampers, variable friction dampers, variable stiffness damper, and controllable fluid dampers.

A hybrid control system typically consists of a combination of passive and active or semi-active devices. Because multiple control devices are operating, hybrid control systems can alleviate some of the restrictions and limitations that exist when each system is acting alone. Thus, higher levels of performance may be achieved. Since a portion of the control objective is accomplished by the passive system, less active control effort, implying less power resource, is required. A side benefit of hybrid systems is that, in the case of a power failure, the passive components of the control still offer some degree of protection, unlike a fully active control system. Examples of hybrid control devices include hybrid mass damper and hybrid base isolation.

1.3 Principles of Damping

Damping on a general basis means to stop the vibrations. In structural engineering, damping can be defined as the inherent property of the structure to oppose movement. The higher the damping of the structure, the quicker it will return to its original position from displacement. Damping, β also changes the period of response of the undamped structure T, to damped period Td.

$$Td = T/(1-\beta^2)^{0.5}$$

Where, $\beta = Wd/(4\pi Ws)$

W_d= cyclic energy dissipated.

W_s= is the strain energy.

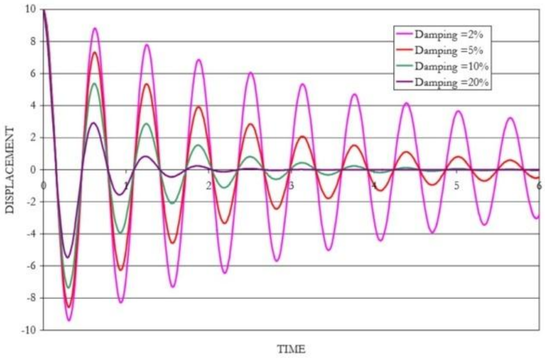

Figure 1: Effect of Damping

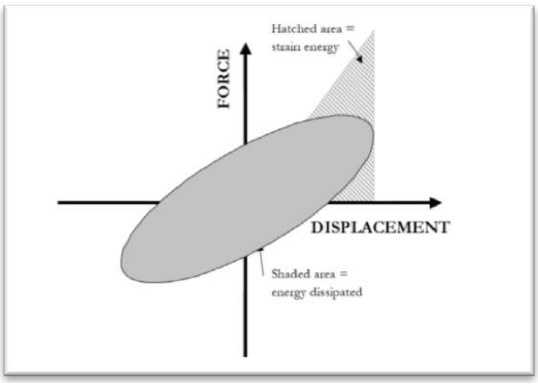

Figure 2: Hysteresis Loop

1.3.1. Effect of damping on response

Increased damping reduces the response of the structure with respect to displacement and acceleration. However, the reduction is not constant over the full period range of response and it also varies with Earthquake. At zero periods, damping has no effect as the spectrum value is equal to maximum ground acceleration. At very long periods, damping also tends to have little effect on accelerations but has more effects on displacement.

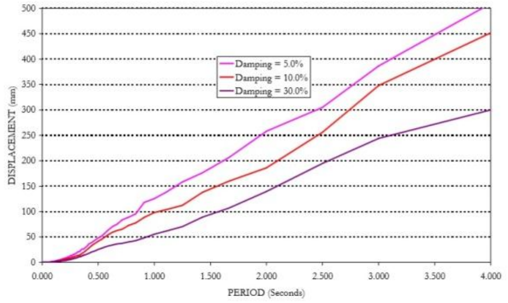

Figure 3: Effect of damping on Displacement

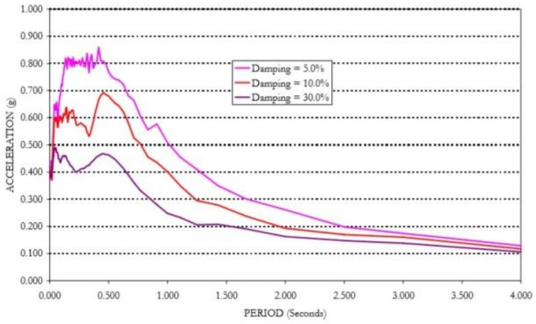

Figure 4: Effect of damping on Acceleration

2. Literature review

In order to survive a severe earthquake, a building must exhibit adequate strength, redundancy and ductility. In recent years, it has been proved that in some cases, increasing substantially the stiffness of an existing structure is not suitable. Therefore, supplying additional energy dissipaters with minimum effects on the strength and the stiffness of a building has been accepted.

The conventional approach to earthquake resistant design of buildings depends upon providing the building with strength, stiffness and inelastic deformation capacity which are great enough to withstand a given level of earthquake–generated force. This is generally accomplished through the selection of an appropriate structural configuration and the careful detailing of structural members, such as beams and columns, and the connections between them.

In contrast, we can say that the basic approach underlying more advanced techniques for earthquake resistance is not to strengthen the building, but to reduce the earthquake–generated forces acting upon it. Among the most important advanced techniques of earthquake resistant design and construction are base isolation and energy dissipation devices. However base isolation is limited to structures having time period less than 0.7 seconds as per IS 1893-2002.

This paper gives an overview of various studies carried out by different researchers and that are published in some of the international journals around the world. The overall goal of this paper is to critically evaluate the different methodologies so as to identify the appropriate approach for our future work.

2.1. Research work done on the analysis of dampers

Alireza Heysami (2014) investigates types of dampers and their performance during earthquake. Also, they have investigated the tall buildings in the world and satisfactory level of damper performance has been studied. And the results show that no only dampers have an acceptable seismic behavior against lateral forces such as wind and earthquake forces.

In seismic structures upgrading, one of the lateral force reduction caused by the earthquake is use of dampers. During an earthquake, high energy is applied to the structure. This energy is applied in two types of kinetic and potential (strain) to structure and it is absorbed or amortized. If structure is free of damping, its vibration will be continuously, but due to the material damping, vibration is reduced.

Damping increasing reduces structural response (acceleration and displacement) damping effect at low frequency (close to zero) have no effect on spectrum amount and at high frequency, it has low effect on response acceleration. Dampers are classified based on their performance of friction, metal (flowing), viscous, viscoelastic; shape memory alloys (SMA) and mass dampers. Among the advantages of using dampers we can infer to high energy absorbance, easy to install and replace them as well as coordination to other structure members.

Raheel Kazi, P. V. Muley et.al (2014) This paper presents the comparative analysis on the seismic performance of building structural systems having passive damping devices-viscoelastic damper. Dynamic behaviour of the structure for wind and earthquake loading with respect to response spectrum analysis is carried out. Changes in the responses of displacement, velocity, acceleration and drift for the damped structure are demonstrated illustrating the efficiency of dampers.

The model was analyzed using E-TABS 2013. And result carried out for the respective directions of wind and earthquake forces against displacement, drift, velocity and acceleration. When combination of various loading was considered. Prior to the analysis of this model a 20 storey building was worked on. The results show that the displacement and acceleration were around 15% and19% respectively. So the efficiency of dampers increases with elevation. Some other results that, the response of structure can be dramatically reduced by using viscoelastic damper without increasing the stiffness of the structure. It is also observed that, the acceleration can be reduced by substantial amount whereas displacement to a considerable amount. Viscoelastic dampers are unique in combating the wind forces, for its visco-elastic material, whereas other dampers are suitable mostly for earthquake forces only and the performance of visco-elastic damper devices is much better for the tall buildings with slender design.

Durgesh C. Rai (2000) this work deals with future trends in earthquake-resistant design of structures. It is fairly well accepted that earthquakes will continue to occur and cause disasters if we are not prepared. Assessing earthquake risk and improving engineering strategies to mitigate damages are the only options before us. Geologists, seismologists and engineers are continuing their efforts to meet the requirements of improved zoning maps, reliable databases of earthquake processes and their effects; better understanding of site characteristics and development of earthquake resistant design (EQRD). As for the engineer, the ultimate goal will remain the same: to design the perfect, but cost-effective structure, that behaves in a predictable and acceptable manner. The ongoing research and development activities in the area of EQRD of structures offer significant promise in realizing that goal in the coming years.
In the coming years, the field of EQRD of structures is most likely to witness the following significant developments:
(1) A complete probabilistic analysis and design approach that rationally accounts for uncertainties present in the structural system will gradually replace deterministic approaches, especially in the characterization of the loading environment.
(2) Performance-based design processes will take center stage, making conventional descriptive codes obsolete.
(3) The acceptable risk criterion for design purposes will be prescribed in terms of performance objectives and hazard levels.
(4) Multiple annual probability maps for response spectral accelerations and peak ground accelerations – along with more realistic predictions of the effects of site soils, topography, near-source rupture mechanisms and spatial variation – should provide better characterization of design earthquakes and expected ground motions.
(5) The development of new structural systems and devices will continue for base-isolation, passive energy dissipation and active control systems, along with the proliferation of non-traditional civil engineering materials and techniques.
(6) Analytical tools for reliable prediction of structural response (essential tools in performance-based design processes) will continue to improve and be updated frequently to include new devices and materials.
(7) The area of soil–structure interaction – perhaps the least understood aspect in the field of earthquake engineering is poised to witness the emergence of new numerical techniques to model nonlinear soils and structures in a manner that was not possible until now, due to the enormous computational efforts required.

Vajreshwari Umachagi *et.al* (2013) presents an overview on applications of dampers for vibration control of structures. The review includes different types of dampers like metallic dampers, viscoelastic dampers, frictional dampers etc. it concludes that use of seismic control systems has increased but choosing best damper and installing it into a building is very important for reducing vibration in structures when subjected to seismic loading. The controlling devices reduce damage significantly by increasing the structural safety, serviceability and prevent the building from collapse during the earthquake. Therefore, many researches are being carried out to find the best solution. This paper attempts to provide an overview of different types of seismic response control devices, and highlights some of the recent developments. The experimental and analytical investigations carried out by various researchers clearly demonstrate that the seismic control method has the potential for improving the seismic performance of structures.

2.2. Researches regarding damper used in steel frame structure.

Gang Li and Hong-Nan Li (2013). A new type of metallic damper is presented in this study. It is so-called as "dual functions" metallic damper, since it has two characteristics of high initial stiffness and good energy-dissipating capability. Its initial stiffness is increased through making it bearing exterior in-plane force, and its energy-dissipating capability is improved through making it different shapes. Quasi-static tests with scale and full-scale models of the metallic dampers specimens designed with above idea are carried out, respectively. Two outstanding metallic dampers named round-hole metallic damper (RHMD) and double X-shaped metallic damper (DXMD) were selected and the DXMD was applied in an actual steel structure to improve initial stiffness of original structure under normal use or frequency earthquake and to dissipate inputting energy during great earthquakes. In addition, a three-dimensional model was established using finite element software and dynamic response comparison of the steel structure with and without DXMDs was conducted. The results shown that the metallic dampers presented here not only provide certain stiffness in the normal application, but also are of good ability of energy dissipation.
The inelastic deformation of metallic is an effective mechanism for input earthquake energy dissipation. A steel structure with eight stories is located in China. The columns in the frame are square steel tubes and H type steel and the beams are H type steel. The DXMDs are installed on each floor of the steel structure.

Some conclusions and suggestions are presented as follows: The steel plate shape has an important influence on deformation and energy-dissipating capability of the metallic damper. The RHMD and the DXMD exhibit good performance on stiffness and energy dissipation. The dynamic analysis of the steel structure revealed that the DXMD presented in this study reduced the displacement response effectively. The acceleration response of the structure with the DXMD or RHMD is amplified corresponding to original structure under normal use and small earthquake, so more attention must be focused on the issue during elastic seismic design. The ratio of the height and width of these two dampers equals and less than 1.0 is suggested; because relatively larger ratio probably results in out-plane buckling of the damper. Yield displacement and yield strength of these two dampers as basic parameters have directly influence on controlling displacement response.

H. K. Miyamoto, A. S. Gilani, and A. Wada (2008). Steel Special Moment Resisting Frames (SMRFs) with Viscous Damping Devices (VDDs) have been used for design of many buildings, resulting in a reliable and cost effective solution, with a high confidence level. The dampers serve to reduce the seismic demand and damage to structures. It is also anticipated that the design will have lower repair cost and shorter downtime following an earthquake. The cost-effectiveness and the anticipated superior performance of this system present an opportunity for a more widespread application. However, no comprehensive and rigorous analysis has been conducted to address several outstanding issues: the probabilistic assessment of performance, the realistic confidence levels, and correlation between the engineering data and hazard evaluation parameters including probable maximum loss (PML) and business interruptions (BI). It is proposed to address such issues in an upcoming research program.

Steel special moment resisting frames (SMRFs) are one of the preferred options for seismic design in regions of high seismicity. The combination of viscous damping devices (VDDs) and steel SMRFs presents an attractive design option. The result is a highly damped, low-frequency building that limits seismic demand on structural and non-structural components. VDDs are an ideal option due to their high damping because they are velocity dependent, and hence, do not significantly increase demand on foundations or columns. They are activated by the transfer of incompressible silicone fluids between chambers at opposite ends of the unit through orifices; see Figure. During seismic events, the devices become active and the seismic input energy is converted to heat and is thus dissipated.

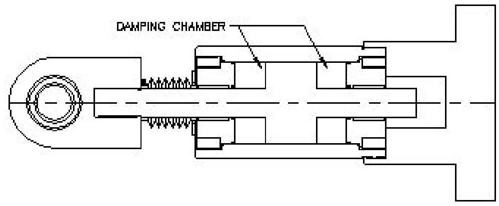

Figure 5: Schematic of VDD (Taylor 2007)

The additional cost of the dampers is typically offset by the savings in steel tonnage and foundation concrete volume. Hence, the conventionally designed and the damped buildings have similar initial costs. The four-story commercial building is 18.5 m tall and has a total floor space of 8,000 m^2. Computer program SAP (CSI 2007) was used to prepare three-dimensional mathematical models of the damped and conventional designs. Maximum response quantities, such as, building floor displacement and accelerations, story shears, VDD forces, and member stresses, were extracted. The extreme values from all analyses were then used for evaluation. For the damped building, the damage level is lower. This results in a lower repair cost, less loss of occupancy, shortened business interruptions (BI), and a reduced amount of non-structural damage. This also translates to shorted repair time. Hence, the damped building will more readily retain its pre-earthquake performance level.

Babak ESMAILZADEH HAKIMI, Alireza RAHNAVARD, Teymour HONARBAKHSH (2004). A Pall based friction damper located at intersection point of *X* or chevron bracing has been designed concerning Iranian workmanship. Tests have been performed to investigate the energy dissipation capacity of dampers with different types of slipping surface. Efficiency of the system has been investigated through time history nonlinear analysis performed on 2 and 3 story steel structures with a logical range of period under sets of 9 accelerograms matching with *S*2 and *S*3 types of soil. A nonlinear time-history analysis has been performed using Sap 2000 software.

Due to high performance of the system, damage index of the whole structure has been found to be governed rather by non-structural damage potential or casual p-delta effect leading to potential instability. The aspect ratio of the friction devices has been judged to be very effective in energy dissipation, so that with aspect ratios near to main frame one, the energy dissipation reached its maximum level. For aspect ratios far from the structure one, rigid body motion of device resulted in reduction of energy dissipation potential.

Pall system's hysteretic behaviours are almost rectangular and completely similar to ideal elastoplastic behaviour. Due to high dissipation energy capacity and stability of hysteresis loops, Pall system seems to show higher seismic performance, than other damping systems.

Ri-Hui Zhang et.al (1989). Some practical issues associated with the application of viscoelastic (VE) dampers to building structures for seismic performance enhancement are studied in this paper. A sequential procedure is developed for optimally placing VE dampers to structures, based on the concept of degree of controllability. This optimal placement procedure is then experimentally verified using a five-story steel model structure. Economical use of the VE dampers is made possible by adding them to the optimal locations found by this procedure, as is clearly demonstrated by the numerical examples and experimental results presented in the paper. A design procedure is also presented by which damper dimensions, number, and locations needed to achieve desired level of additional damping can be determined in accordance with the structural parameters and structural-response reduction requirement. Design of VE dampers for a 24-story steel frame is presented as an example, showing the complete design procedure for applying VE dampers to realistic structures.
The placement of a limited number of dampers may have a significant effect on the level of response reduction. A sequential procedure has been proposed based on the concept of degree of controllability. Examples show a superior control effect with dampers added at locations found from the optimization procedure. For the 10-story example structure, a saving of two to five dampers can be realized if story drift is taken as the criterion of response reduction. The optimality of locations found by this procedure is also supported by experimental results. It should be pointed out that since added viscoelastic dampers change both damping and stiffness of the original structure, the optimal damper locations found for one set of dampers may be different from those for another set of dampers with changed dimensions. A simple design procedure has been presented by which the dimension and number of viscoelastic dampers can be determined. The optimal damper placement procedure is incorporated in the damper design procedure to minimize the number of dampers needed by finding their optimal locations.

2.3. Research regarding combinations of damper used in steel frame structure.

Takahiro Atsumi, Daiki Sato, Haruyuki Kitamura, Takafumi Fujita, Mitsuru Miyazaki, Kazuhiko Sasaki, Masato Ishii and Keisuke Yoshie (2008). A lot of researches on the seismic vibration control system show that they have effect on mitigating seismic damage. Most researches on structures with damper devices subjected to earthquake ground motions have carried out considering with using the one type of dampers, hysteretic or viscous one, only. However, there have been few investigations for the combinations of dampers with different performances in a vertical direction. The authors have presented the “combination-system” which is the seismic vibration control system using both hysteretic and viscous dampers in the previous research. The combination-system is made up of hysteretic (friction) dampers placed on the lower stories of the building and viscous dampers placed on the upper stories of it. Being combined with both dampers brings forward seismic control effects by its multiplier effects. This paper reports the results of the shaking table tests using together with these dampers. The experiments, using a 10-story frame, are carried out to substantiate the progress of seismic control effects by applying combination-system. Performance of specimens is discussed by referring to story shear, relative story displacement, story accelerations and absorbing energy of the dampers. In the combination-system, the characteristics of the hysteretic dampers and the viscous dampers are combined well. The objective of this paper is to verify the effectiveness of the combination-system by the shaking table test of the compact 10-story frame. The combination-system was made up of the hysteretic (friction) dampers placed on the lower 6 stories of the frame and the viscous dampers placed on the upper 4 stories of it.
The tendencies of the analytical values were similar to that of experimental values. This showed these analysis models were appropriate for confirming the performance of this study’s structure. We confirmed that the seismic control effects of the combination-system are better than that of mono-using system. The effectiveness on reducing responses of the combination-system is considered to originate in the energy absorption efficiency of the viscous dampers arranged in the upper levels. Further, we consider that the rise of the energy absorption efficiency of the viscous dampers result from a boost in the natural frequency of the frame by the friction dampers arranged in the lower levels. It seems that it is necessary to analyse the mechanism of response reduction of the combination-system in detail from now on.

W.S. Pong, C.S. Tsai and G.C. Lee (1994). The concept behind passive vibration control is to add energy dissipating devices to a structure so that energy dissipation can be primarily constrained to the designed location of these passive control devices instead of the main load-carrying members. Since these passive control devices are separated from the main structures, they can be easily replaced if extensively damaged. The use of these energy-absorbing devices to dissipate the seismically induced energy is one of the most economical and effective ways to mitigate the effects of earthquakes on structures.

This report is concerned with a study of two different devices, a combination of tapered plate energy absorber (TPEA) and viscoelastic dampers and a combination of TPEA and fluid dampers. It starts with a general review of the developments in various energy dissipating devices. Then a finite element formulation for fluid dampers is developed for this study. A comparison is made between numerical solutions and experimental results when a 2/5 scale steel structure is equipped with added viscoelastic dampers. The structural response of high-rise buildings mounted with three energy-absorbing devices, tapered-plate energy absorber (TPEA), viscoelastic dampers, fluid dampers, and two combined devices, TPEA and fluid dampers and TPEA and viscoelastic dampers, respectively, have been investigated. Next, a parametric study of TPEA devices for high-rise buildings is conducted. The selected response parameters in this study include: (1) story shear force; (2) floor displacement; (3) base shear force and (4) ductility ratio.

Finally, two combined devices, TPEA and viscoelastic dampers and TPEA and fluid dampers are examined. Results show such combined devices provide a strong safe-failure mechanism as reliable energy absorbing devices. They also can sustain a wide range of loadings from minor to severe earthquake ground motion and wind loads. The combined devices can compensate for each other's shortcomings so that a satisfactory design for wind loads and seismic hazard mitigation of the structures can be achieved.

2.4. Abstract of Literature.

The study results in the following conclusions:

i. The seismic control effects of the combinations of damper are better than that of mono-using system.

ii. Combinations of dampers can increase the stiffness and the damping of structures, and reduce the seismic responses of structures effectively.

iii. The optimization design of the structure with combinations of dampers can be finished by the simplex method, i.e. the parameters and the location of dampers can be design optimally under fixed objective function and constrained conditions.

iv. Rational location of dampers can make the stiffness and the damping of structures well-distributed, and reduce seismic responses of structures effectively. In contrary, if the dampers are installed irrationally, the stiffness and the damping are not distributed well, seismic responses cannot be reduced effectively, even may be increased.

v. The more combinations of dampers do not mean the better shock absorption effect; the shock absorption effect of dampers is best when the location of dampers is optimal.

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