Seismic Response of Building using Fluid Viscous Dampers: A Review

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Abstract: According to the current trends of various methods used in reduction of seismic response of buildings, mostly it is done by applying various types of energy dissipative systems or devices such as dampers. It is also used for Rehabilitation & Retrofitting of damaged building structures and as a Shock Absorber in bridges. Various types of dampers are available in markets according to the choice of designers and researchers, but it was observed that Fluid Viscous Dampers (FVD) were preferred the most of the times. Comparative studies between FVD and other type of dampers also favour FVD due to its promising and noticeable results in some researcher's studies. And also the amount of flexibility in use, reduction in damping force, wide range of application makes it more preferable to use. This paper tries to emphasize on the various approaches and methods used along with FVD to effectively minimise the seismic response of buildings and to get better results against seismic forces.

Keywords: Fluid Viscous Dampers; Time History Analysis; Seismic Response.

Introduction: Today's rapid growth in population and industrialization limits the usage of resources like water, energy and landmass. Which leads the demand for high rise buildings in cities due to lack of available land and also we have to construct building structures in the land which comes under seismic zones of higher level. Hence it is necessary to design our building structures against the seismic forces using suitable techniques like energy dissipation devices, base isolations. It is easy to use dampers than that of base isolation technique due to its limitations. As dampers can be use for retrofitting purpose too and provides flexibility in the installation in the building system due to its wide variety available in the market. Various studies have been done using dampers in steel/concrete moment resisting frames, structural walls, toggle brace systems, pre-existing buildings to fulfil its seismic demand. For this various seismic analysis methods carried out by means of lab experiments or with the help of suitable stimulation software applications and obtained seismic response results are studied in terms of peak velocity, accelerations, displacement, drifts and overturning moments. Some studies also focused on determination of optimum locations of dampers and to reduce the damping force so as to achieve economical designs as dampers are costlier for high damping values.

Related research work:

Farzad Hejazi et al, (2017) investigated the response of two models of three story building frame with shear wall at corner and at core position. For this study ETABS software was used to prepare models for experiments. Viscous damper was used in diagonal position in cut out opening of shear wall in 4 different positions namely bottom, middle, top and all over the storey of the shear wall frame. A three dimensional seismic excitations have been applied to investigate the performance of building frame with viscous damper within shear walls which was the main objective of this paper. 3-D earthquake records of El Centro (1940) time history were applied to both the models. After that their results in terms of average peak displacement and maximum member forces of model 1 and 2 were compared. At the end of study its results shows that model 2 i.e. model with damper with shear wall at core was able to achieved higher values of percentage reduction in peak displacement compare to other model. And it was also concluded that dampers in shear wall installed at top position found as the optimum location against 3-D earthquake excitation.

X.L. Lu et al, (2012) performed the retrofitting of the 8 storey RC building in China, which was damaged due to Wenchuan earthquake. For retrofitting of the building, three types of dampers namely viscous dampers, steel dampers & viscoelastic dampers were used and their effect on seismic response of the building was compared in terms of shear forces, storey drifts of the building under various levels of earthquakes. The analytical investigation of building model structure was performed in ETABS. 2 accelerograms (artificial) and 3 earthquake records were applied to carry out dynamic analysis of the building to study its seismic response of the retrofitted structure using above mentioned 3 types of dampers. The hysteresis curves of viscous, steel & viscoelastic dampers obtained from El Centro records shows that the energy dissipated by these dampers was very large hence frame structure protected from severe damage. In frame with dampers, the inter storey drifts and shear in columns reduced about 1.5times compared to frame without dampers. The selected parameter for damping force ratio of actual to expected indicates that initial parameter is correct.

A. Munir et al, (2011) worked on inelastic seismic demand of high rise buildings. For that they carried out a case study on 40 storey residential high rise core wall building and compared it with its modal with suitable control measures. By creating model of the case study building as a linear elastic form and analyzed in ETABS of version 9.0.After that nonlinear time history analysis (NLTHA) was performed for maximum considered earthquake by applying 7 time history records. For NLTHA another model created in PERFORM 3D software version 4. After that nonlinear 24 FVD were placed in X direction as a control measures to reduce seismic demand and damping force. By applying FVDs, reduction in values of base shear, moment demand at foundation level and middle level of building was observed by 27%, 12% & 26% respectively. Typical inelastic behavior of high rise buildings with shear walls well explained in this paper.

Wen-Hsiung Lin et al, (2001) investigated seismic response of one storey single degree of freedom system equipped with nonlinear FVD. Investigation effectively studied supplemental damping ratio ζ_{sd} and the velocity exponent α as both dimensionless, independent parameters, response of the structure linearly varies with the intensity of the excitation applied to the system. Nonlinearity of the damper in spectral velocity sensitive region doesn't show any influence on peak response of the system. Where in the other spectral region 14% difference was observed. Supplemental damping able to achieve reduction in deformation of structure about 25% to 60% at ζ_{sd} equal to 5% and 30% respectively. But same values of reduction in system response were achieved by using nonlinear FVD with lower value of the damping force. Finally a practical procedure was provided to calculate designed structural deformation and forces values for nonlinear FVD system from design spectra.

Abdelouahab Ras et al, (2014) performed 3D numerical observation on a 12 storey building steel structure with FVD of nonlinear properties installed diagonally inside the frame. SAP 2000 was used to perform comparative study on model with braced and without braced FVD and FNA (fast nonlinear analysis) performed for time history analysis. Nonlinear damper modeling was carried out using mathematical expressions for different values of velocity exponent. It was found that damping ratio values increases with decrease in the amplitude value for exponent less than 1 and vice versa case for exponent greater than 1. In linear dampers no there was effect on damping ratio with respect to motion's amplitude of the system. Concluded results clarify that diagonal braces do not contribute axial forces in columns but reduces damping rather than unbraced system. Shear values also reduces due to drift reduction as structure behavior was like continuum.

A.K. Sinha et al, (2017) carried out comparative study between two models of 12 storey high moment resisting frame with and without FVD by applying 3D accelerograms. Analysis was carried out using ETABS choosing nonlinear properties of dampers and nonlinear time history analysis. Velocity exponent taken as 0.5 as per suggested from previous studies to limit the damping force. At the end of study except the base shear values, all other parameters gives good results in response reduction. Due to dampers weight, the overall seismic mass of the frame was increased by some margin which leads to increase base shear values.

D. I. Narkhede et al, (2014) tested properties and behavior of FVD under shock vibrations by comparing mathematical expressions for short period excitations. As linear dampers are not that good for shock vibrations (half sine) hence nonlinear damper was chosen for further experiment. The effect of different coefficients of damping and damping exponent has been studied. For shocks of high magnitude and less duration, nonlinear FVD performed significantly well as damping coefficient much smaller with less displacement.

Ying Zhou et al, (2012) carried out a two stage design process for retrofitting of a 7 storey building having cracked column-beam joints and damaged infill walls. Viscous damping was preferred with parametric study carried out for finding damping factor and exponential value. Later on, study confirms that the energy dissipation capacity of damper increases for both values of damping factor C and exponential α. Stiffness for the supported brace taken 3 times greater than dampers stiffness loss for its effective working. In second stage of design, structure was tested against deformations and drifts values according to codes. Results of this paper shows that the method explained in this paper suitable for regular structures subjected to minor, moderate or major earthquake which was tested in this paper.

Xue-Wei Chen et al, (2010) examined the seismic response of the 4 storey Wenchuan hospital located in china with viscous damper. Main aim of the design study was to reduce the response of the structure. For that, with and without installed viscous dampers in the concrete frame structure of the hospital building was carried out under various levels of seismic vibrations. Performed 3D and ETABS software were used to carry out static pushover and nonlinear time history analysis. Supplemental damping ratio also calculated using practical method in ETABS software. Storey drift, displacement at top, plastic damage of the structure got controlled by adding viscous damping within the acceptable values in the codes. Internal force values got increased due to addition of K-braced damping systems raised the stiffness of the structure. But in plastic condition of structure, it gets reduced along with deformation.

Mohsen Kargahi et al, (2004) developed a procedure to find out optimistic performance of the dampers against seismic forces for 4storey concrete frame building with waffle slab. By applying this procedure, overall cost of dampers reduces without compromising required amount of damping to the building. For that, pushover analysis and time history analysis data compared and it was found that nonlinear time history gives more detailed results. Along with optimal cost of viscous dampers, 50 % reduction in displacement was achieved and it was suggested to use genetic algorithms for future scope of study.

Amy Hwang (1998) discussed about various issues happens during the application of dampers especially for viscous dampers. Author describes the selection criteria for FVD by comparing with traditional methods of design and also the comparative study of FVD with ADAS, viscoelastic, friction dampers and with hybrid solutions. In this paper, optimal location of damper and its expression was explained, but still it concludes that it is an iterative method to find out optimal location. It is expensive to use dampers in new building system, except it is hospital, bridges or fire stations etc. facilities. Various softwares were used for carry out comparative study on dampers such as ETABS, SAP etc.

A. Ras et al, (2016) examined the seismic response and energy dissipation of 12storey steel frame model using linear FVD. An analytical modeling was done using Kelvin model and Maxwell model to calculate effective damping ratio for linear damper and according to that damping coefficient calculated and distributed to the structure. Modeling was done in SAP 2000 and NLTH analysis was carried out to check the deformation beyond the limit of the structure. 12 diagonal locations were applied to check suitable location for better results. After applying dampers, the structure's period, maximum displacement, acceleration, moment and drift values were reduced.

D. Lee et al, (2001) summarized the working methods, installation methods and future scope of the FVD technology. In this paper, various bracing methods of installing dampers in the buildings were described. Also the life expectancy of the dampers, effects of linear and nonlinear relationship and softwares for the modeling like SAP and ETABS were suggested for studying dampers for seismic response reduction purpose in future.

A. Bahnasy et al, (2013) compared the design optimization of the linear and nonlinear FVD considering seismic behavior of building structures. Observations made in this paper are 1) Damping forces and number of dampers required for structure increases as value of the alpha α decrease below 0.7. 2) Drift values way to increase in many cases for decreasing values of α. 3) for 3storey building decreasing α value reduces column ductility, but for 9 storey building ductility demand increases below 0.7 values. Finally study recommends that the value of α changes with respect to height of the building. For low rise (≤ three storey) α = 0.5, for medium and high rise (9-20 storey) α=0.85 will be more appropriate.

Rakesh K. Goel (2005) investigated the seismic response of the single storey, one way linear asymmetric and nonlinear systems along with non linear FVD by applying 20 time histories. The main purpose of this paper was to find out effect of nonlinear damper on the asymmetry in the plan of systems. For that comparison of the systems with linear and nonlinear asymmetrical plan added with nonlinear dampers was carried out. Iterative process was attempted to apply value of coefficient of damper in particular direction according to plan's eccentricity. SDOF systems have been studied to idealize the behavior against harmonic and seismic loading with linear and non linear FVD. Result of this paper shows some noticeable decrease in the damping force for higher period value of the asymmetrical systems but for short period systems, cost of damper force of higher value increases. The torque at base reduces using nonlinear damper for linear systems but inverse case for nonlinear systems. But the defect of the asymmetry of the plan can be canceled out by combining nonlinear system with nonlinear damper.

Giuseppe et al, (2014) studied the behavior of the moment resisting steel frame to seismic forces using viscous and hysteretic dampers. Iterative procedure was adopted to select the suitable dampers to protect structure against seismic records. The comparative study between 3 different types of steel frames (3storey, 4 storey of 3bays and 12 storey of 5 bay) with two types of dampers (hysteretic and viscous) installed in the middle bay subjected to 7 time history records was carried out to evaluate dynamic analysis to improve performance of the structure. The results shows that the collapse mechanism of medium and high rise building was improved by using dampers compared to bare frame, but for low rise case, this condition not satisfied.

Jinkoo Kim et al, (2003) adopted the simple method for designing the viscous damping using capacity spectrum to avoid time consuming iterative methods to achieve seismic design in performance based manner. In this method required viscous damping calculated such that it satisfies the demand of the structure undergoing plastic deformation.

This method was applied to SDOF system for various parameter required for design. After that 10 storey and 20 storey models of steel frame was subjected to same method to verify it. This method found effective after comparing the results obtained from dynamic nonlinear time history analysis and applicable for structure models which meets the requirement of the capacity spectrum method's conditions and assumptions.

J. K. Whittle et al, (2012) studied the various methods of dampers placement in the building to improve its seismic performance such as standard placement method (SPM), simple sequential search algorithm (SSSA), Lavan analysis and Takewaki application. Two steel frame models of regular and irregular profile taken for study above methods. SAP 2000 was used for building modeling and 20 records of the ground motion data applied to both models. Result from the study denotes considerable performance for regular and irregular frame models after applying various damper placement methods especially Lavan method found out best among others due to its less time consuming and easiness.

Summary:

Some methods preferred linear FVD properties for reducing seismic response while it was found that its effectiveness limited to low-rise structure only. But for medium and high rise structures, to fulfill demand for drift, peak displacement, peak acceleration the nonlinear viscous dampers have shown their effectiveness by minimum damping force and deformation. To achieve economy in response reduction, nonlinear dampers have shown wide range of variety of use. For retrofitting purpose, FVD are the most effective and long life as compare to other methods. Due to cost for large damping force of FVD is higher, optimal placement methods should be applied to minimize cost. But some methods are limited due to lack of sufficient equipments and detailed research in direction of optimization of dampers to achieve desirable seismic response within expected project cost.

Conclusion:

1. To minimize the seismic response of the building structures, FVD plays an important role by reducing inter-storey drifts, base shear, overturning moments, axial forces etc. with desirable cost control.
2. Compare to other types of dampers, FVD has higher life expectancy which is almost near or more than design life of building structure which totally nullify the maintenance cost for dampers.
3. Different methods of bracing for FVD (chevron, toggle, base plate, K-type) provide ease of installation in any desired shapes and position of the bare frame models with effective functioning.
4. For the seismic response reduction of high rise building, nonlinear FVD with $\alpha<1$ are most suitable compare to linear FVD due to their hysteresis behavior which allows them to dissipate more energy during seismic excitations.
5. For the optimization of the damper's placement more research have to be done to improve the accuracy of the placement and numbers of dampers required for the betterment in the economical aspect of the dampers.

References:

1. Hejazi, Farzad, Nima Ostovar, and Abdilahi Bashir. "Seismic Response of Shear Wall with Viscous Damping System." Global Civil Engineering Conference. Springer, Singapore, 2017.
2. Lu, X. L., K. Ding, D. G. Weng, K. Kasai, and A. Wada. "Comparative study on seismic behavior of RC frame structure using viscous dampers, Steel dampers and viscoelastic dampers." In Proceedings of the 15th World Conference on Earthquake Engineering. 2012.
3. Munir, A., and P. Warnitchai. "Optimal reduction of inelastic seismic demands in high rise reinforced concrete core wall buildings using energy-dissipating devices." The Structural Design of Tall and Special Buildings 22.7 (2013): 543-568.
4. Lin, Wen Hsiung, and Anil K. Chopra. "Earthquake response of elastic SDF systems with non linear fluid viscous dampers." Earthquake engineering & structural dynamics 31.9 (2002): 1623-1642.
5. Ras, Abdelouahab, and Nadir Boumechra. "Study of nonlinear fluid viscous dampers behavior in seismic steel structures design." Arabian Journal for Science and Engineering 39.12 (2014): 8635-8648.
6. Sinha, A. K., and Sharad Singh. "Structural Response Control of RCC Moment Resisting Frame Using Fluid Viscous Dampers." Technology 8.1 (2017): 900-910.
7. Narkhede, D. I., and R. Sinha. "Shock Vibration Control of Structures Using Fluid Viscous Dampers." 15 WCEE (World Conference on Earthquake Engineering). 2012.
8. Zhou, Ying, et al. "A practical design method for reinforced concrete structures with viscous

dampers." Engineering structures 39 (2012): 187-198.
9. Chen, Xue Wei, Jia Xuan Li, and Jack Cheang. "Seismic performance analysis of Wenchuan hospital structure with viscous dampers." The Structural Design of Tall and Special Buildings 19.4 (2010): 397-419.
10. Kargahi, Mohsen, and C. Ekwueme. "Optimization of viscous damper properties for reduction of seismic risk in concrete buildings." 13th World Conference on Earthquake Engineering. 2004.
11. Hwang, Amy. Viscous dampers: practical application issues for the structural engineer. Diss. Massachusetts Institute of Technology, 1998.
12. Ras, A., and N. Boumechra. "Seismic energy dissipation study of linear fluid viscous dampers in steel structure design." Alexandria Engineering Journal 55.3 (2016): 2821-2832.
13. Lee, David, and Douglas P. Taylor. "Viscous damper development and future trends." The Structural Design of Tall Buildings 10.5 (2001): 311-320.
14. Bahnasy, A., and O. Lavan. "Linear or nonlinear fluid viscous dampers? A seismic point of view." Structures Congress 2013: Bridging Your Passion with Your Profession. 2013.
15. Goel, Rakesh K. "Seismic response of linear and nonlinear asymmetric systems with nonlinear fluid viscous dampers." Earthquake engineering & structural dynamics 34.7 (2005): 825-846.
16. Brando, Giuseppe, Federica D'Agostino, and Gianfranco De Matteis. "Seismic performance of MR frames protected by viscous or hysteretic dampers." The Structural Design of Tall and Special Buildings 24.9 (2015): 653-671.
17. Kim, Jinkoo, Hyunhoon Choi, and Kyung-Won Min. "Performance-based design of added viscous dampers using capacity spectrum method." Journal of Earthquake Engineering 7.01 (2003): 1-24.
18. Whittle, J. K., et al. "A comparison of viscous damper placement methods for improving seismic building design." Journal of Earthquake Engineering 16.4 (2012): 540-560.