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Optimizing the Positioning of Fluid Viscous Dampers to Enhance Resilience of Tall Buildings against Earthquake-Induced Structural Vibrations-A Review

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Abstract: This study explores the effectiveness of Fluid Viscous Dampers (FVDs) in mitigating vibrations caused by lateral loads, such as earthquakes, in high-rise buildings. As urban areas demand taller structures, reduced natural frequencies make buildings more vulnerable to dynamic forces. The research evaluates a G+19-story reinforced concrete (RC) building using code-based methods to assess seismic responses, including lateral displacement, drift, base shear, and energy dissipation. Various FVD arrangements and quantities were analyzed to identify optimal placements for maximizing drift reduction, energy dissipation, and cost efficiency. Findings reveal that installing FVDs across all stories significantly reduces displacement, drift, and shear values, enhancing the building's seismic resilience. This study underscores the critical role of strategic damper placement in improving the performance and safety of tall structures in earthquake-prone regions, offering practical insights for designing earthquake-resistant buildings.

Keywords: High-rise building; Response Spectrum; Time History; Energy Dissipative System; Seismic Response; Etabs

I. INTRODUCTION

Earthquakes are among the most destructive natural disasters that significantly impact civil engineering structures. The seismic forces generated during earthquakes lead to structural failure, often causing severe damage or collapse. To reduce such risk, earthquake resistant systems have become a vital component in modern construction. Among these systems, dampers are highly effective as passive control devices. They work by dissipating seismic energy through specialized mechanisms, thereby reducing the motion and stress on structures during an earthquake. Different types of dampers, such as fluid viscous dampers (FVD), tuned mass dampers, and metallic dampers are available in the market. Fluid viscous dampers, in particular, stand out for their ease of installation and effectiveness in controlling structural responses [1-15].

During earthquakes, most structures are subjected to vibrations caused by seismic excita- tion. These vibrations, especially during strong earthquakes, can cause significant structural damage or even collapse. Fluid viscous dampers absorb shocks and vibrations, preventing severe damage and maintaining the structural integrity of buildings. The placement and number of dampers in a structure are critical to maximize their effectiveness. As passive control devices, FVDs dissipate energy without amplifying it and help restore the building to its original position after seismic activity. This makes them an essential tool in modern seismic design strategies [1-15].

Over the decades, earthquakes have caused widespread destruction and loss of life around the world, underlining the importance of robust seismic mitigation measures.

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Fluid viscous dampers play a crucial role in reducing the impact of seismic forces, particularly in high-rise buildings where structural responses can be more pronounced. By dissipating energy and controlling vibrations, these dampers enhance the safety and durability of structures. This study focuses on the application of fluid viscous dampers, their mechanism of action, and their influence on the seismic behavior of buildings, in order to highlight their significance in earthquake resistant design.

II. LITERATURE REVIEW

Kul Vaibhav Sharma et al. [1] did a study on the Modelling efficiency of fluid viscous dampers positioning for increasing tall buildings' Resilience to earthquake-induced structural vibrations. This research project aimed to explore the efficiency of fluid viscous dampers (FVDs) in reducing the structural vibrations caused by earthquakes. To achieve this goal, research was conducted on a G+20 building using the ETABS program. In addition, the regular frame of the structure was compared with three alternative potential situations. In the first scenario, FVDs were placed at random on each level of the building. In the second scenario, FVDs were installed on each story of the building. In the third scenario, the FVDs were positioned at the top, middle and bottom of the structure. The research showed that the alternate placement of FVDs across all levels resulted in a significant reduction in the values of displacement, drift, and shear.

Ramdas L et al. [2] did a study on high-rise RC structure with fluid viscous damper using python. In this study, a fluid viscous damper (FVD) is provided in a G+19-story high-rise RC building to reduce the vibration due to earthquake effects. IS 1893:2016 code- based methods are adopted to determine the seismic responses such as lateral displacement, drift, base shear, and energy dissipation of the building with and without damper using ETABS software version 2018. This paper focuses on the design of a nonlinear fluid viscous damper for the RC framed building under study and the optimal damper number and its position in the building. The responses such as top displacement, drift, base shear, and energy dissipation capacity are obtained and compared. They conclude that in most cases, damper placement reduced the dynamic responses of the building. The top displacement of the building without a damper is around 82 percent of the maximum value of 240 mm whereas in the case of buildings with dampers, it varies between 55 and 82 percent of the maximum value. The variation in base shear of the building with and without dampers is not very significant. The energy dissipation capacity of the buildings with dampers is improved. The analysis results clearly show the influence of dampers, their numbers, and their position in the building.

Kashif Javaid [3] did a study on the Seismic performance of irregular composite buildings: A comparative study of the effectiveness of buckling restrained braces and viscous dampers. In this research, they aimed to assess the impact of Restrained Buckling Braces (BRBs) and Viscous Dampers (VDs) on the seismic performance of asymmetrical 15-story steel–concrete composite moment resisting frames. A comprehensive response spectrum analysis was carried out to evaluate the seismic performance of the frames. Etabs Software was used for modeling and analysis. In this study, they conclude that VDs are more effective than BRBs in reducing time period by 65–73 percent, and VDs are also more effective in reducing base shear by 80–90 percent. In terms of inter-story drift ratio, the use of BRBs and VDs reduced the inter-story drift ratio by around 35–40 percent for regular buildings and 85–90 percent for C-shaped and L-shaped structures respectively. Both BRBs and VDs are effective in reducing the maximum overturning moment.

Khalil Yahya Mohammed Almajhali et al. [4] did a study on Seismic Response Evaluation of High-Rise Building with and Without Fluid Viscous Damper. In this study, the responses of the structures having square plans with different cross-sections are analyzed by the ETABS 2015 software. The fluid viscous damper has produced above than an 80 percent reduction in Time period of acceleration in Response spectrum curves. In the buildings, Fluid Viscous Damper the base shear has been reduced by 89.49 percent for Square Building with Square Column and 62.79 percent for Square Building with Rectangular Column in Time History analysis. It has been noticed that the structures with square columns performed very well in a period of response of the building when compared to structures with rectangular columns regardless of the flooring plan.

Wael M. Hassan [5] did a study on the Assessment of modal pushover analysis for mid-rise concrete buildings with and without viscous dampers. The purpose of this study is to extend the applicability of the MPA method to mid-rise special moment resisting frame (SMRF) concrete buildings with and without energy-dissipating devices. They conclude that the MPA can predict, with simple modifications, the seismic deformation response of SMRF mid-rise concrete buildings (with or without dampers) with reasonable accuracy. For SMRF RC buildings without dampers, MPA moderately overestimates peak floor displacement over the frame height.

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The maximum error was 30.2 percent on the 5th floor while the minimum was 6.5 percent on the 1st floor. For SMRF buildings with linear viscous dampers, the MPA procedure predicts roof displacement history accurately in buildings with dampers. It also reliably estimates peak roof and displacement. The modified MPA procedure is considered small, making this procedure a good candidate for this class of buildings.

Sima S. Ijmulwar [6] did a study on the Seismic design of reinforced concrete buildings equipped with viscous dampers using simplified performance-based approach. In this study, they used Etabs software. This study provides a simplified procedure for performance-based seismic design of Reinforced Concrete (RC) special moment resisting frame using nonlinear FVDs. It focuses on maximum displacement along with floor acceleration to control the overall behavior of the structure. Following the method, it was found that placing dampers according to the mean story drift profile reduced the acceleration throughout the height of the structure. Also, a reduction of 30 percent in base shear values was observed. After the installation of FVDs, column forces were reduced. In general, adding FVDs for increased damping in the range of 18–20 percent can help designers achieve the required performance in such structures during earthquake events. It is important to note that the accuracy of the proposed method is influenced by uncertainties in the selection of ground motions. The number of ground motions included in the study plays a crucial role in determining the method's reliability.

Vin Nguyen-Thai et al. [7] did a study on an effective optimum design for passive viscous damping control using FVDs in multi-story buildings. In this study, Nonlinear response history analysis (NRHA) is conducted using recorded seismic ground motions to assess the dynamic behavior of structures. The optimization problem is formulated to minimize a scalar sum of three components: the number of dampers, total inter-story drift ratio, and absolute floor acceleration. Etabs and Matlab software were used for this study. The main focus of this study was to optimize the placement of FVDs to minimize their quantity while ensuring that specified limits for Inter-Story Drift Ratio (ISDR) and peak floor accelerations are met. In this study, they utilized the Extended Symbiotic Organisms Search (ExSOS) algorithm to optimize the placement of Fluid Viscous Dampers (FVDs) in two 10-story RC Special Moment-Resisting Frame (SMRF) systems. The ExSOS algorithm proved to be highly effective in optimizing the placement of FVDs.

Dr. KV Ramana Reddy et al. [8] did A Comparative study on seismic analysis of a RCC framed regular and irregular building by using fluid viscous and metallic dampers. Different types of analysis methods such as time history analysis and response spectrum method are adapted to study the storey displacement on a G+20 storey RCC framed structure with dampers by using ETABS software. In this study they compare the performance and effects on RCC frame regular (square rectangle) and irregular (HL) structural systems by using fluid viscous and metallic passive energy dissipating dampers. In this analysis results are carried out by using ETABS software for RC framed structures to find out the various parameters like maximum displacement, storey drifts, storey stiffness. From this study they conclude that Maximum storey displacements are more in the H-shape irregular plan model than in other models. Fluid viscous dampers placed in the middle effectively reduce lateral displacements and drifts of the RC building than the metallic dampers. From the study, it is proved that regular structures are more effective to sustaining the seismic loads even with dampers.

Sherin P. Samuel et al. [9] did a study on seismic analysis of buildings using fluid viscous damper. A comparative study on the effect of a fluid viscous damper on the seismic response of a reinforced concrete structure is presented in this paper. The buildings and dampers were modelled using SAP2000 software. Nonlinear time history analysis was carried out and the results are compared. They observed that the placement of the damper plays an important role in the vibration control of the structure. Effectiveness is more when dampers are placed in corners instead of the middle. When the damper is placed on all the floors, there is a much larger reduction in the displacement, velocity, and acceleration. But it obstructs the placement of doors and the movement of people.

P. Santhosh Kumar et al. [10] did a study on Apllication of fluid viscous damper in multy- story building. They did a study on the model of the Chaitanya Imperial Building which is located at. Chennai. The structural dynamic analysis was carried out by the SAP2000 computing program, in which a viscous damper is modulated by a damping element. Four dampers are attached in the building, two at 15m level and another two at 32m level. A Non-linear time history is performed to evaluate the structural dynamic response with viscous dampers. They observed that the peak base shear will decrease up to 28 percent when VDs are introduced into the structure. After VDs introduced, the top displacement and maximum story drift decreased to 38 percent and 50 percent respectively. Nearly 2/3 of energy is dissipated by viscous dampers.

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III. RESULTS

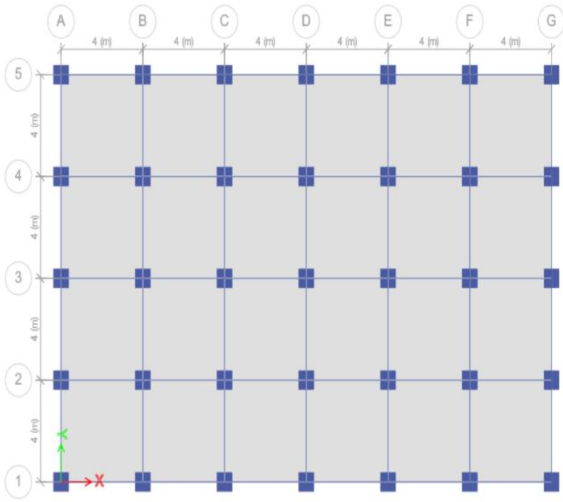

Fig.1 Plan of RC Building

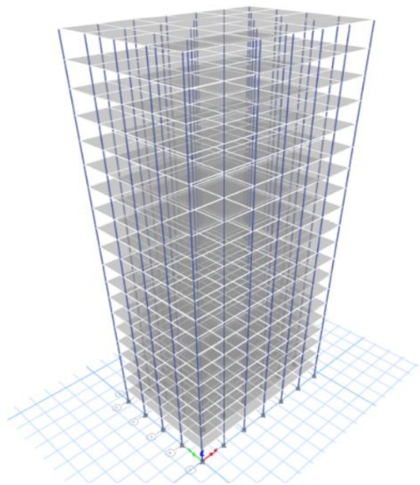

Fig.2 3-D view of RC Building

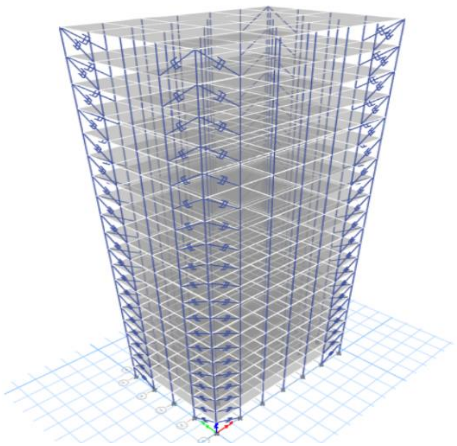

Fig.3 FVD at Corner

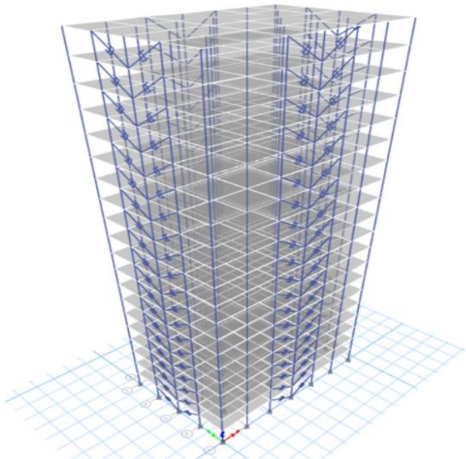

Fig.4 FVD at Centre

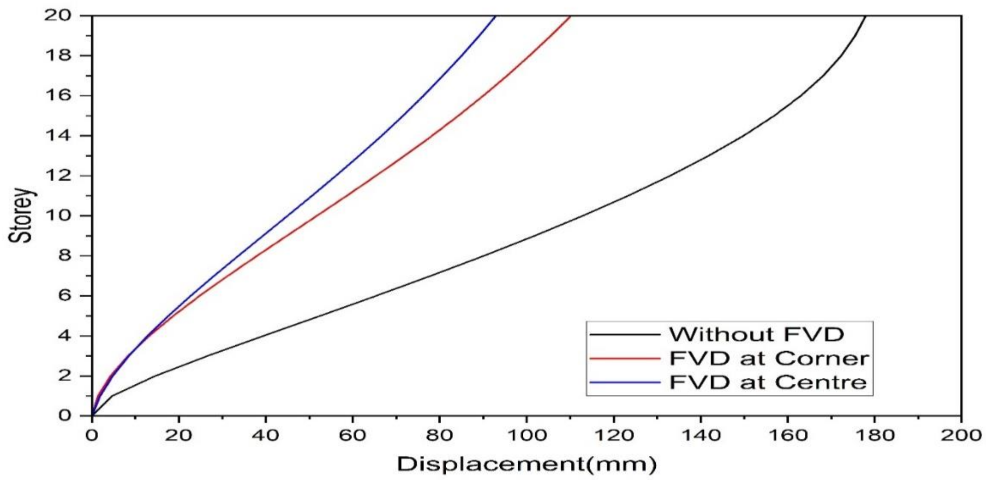

Fig.5 Displacement Graph

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- Fig5 shows that Minimum displacement observed when FVD placed at center of the building and position of FVD at corner also reduce displacement with compare to Without FVD building.

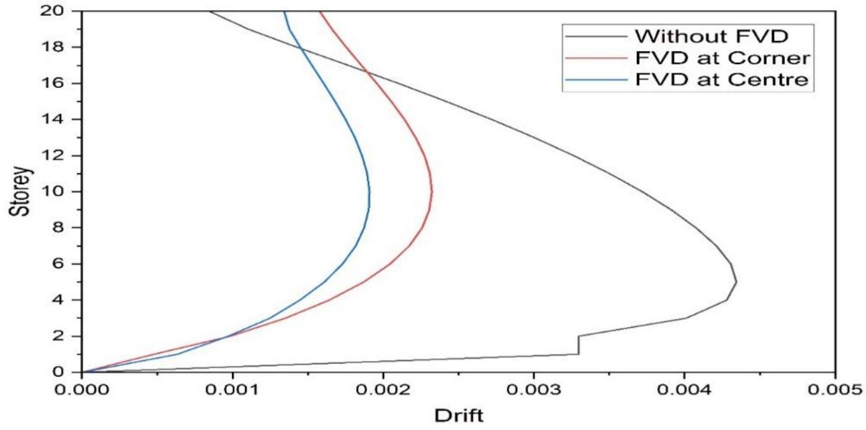

Fig.6 Drift Graph

- Fig6 shows that overall drift reduced when FVD placed at center position.

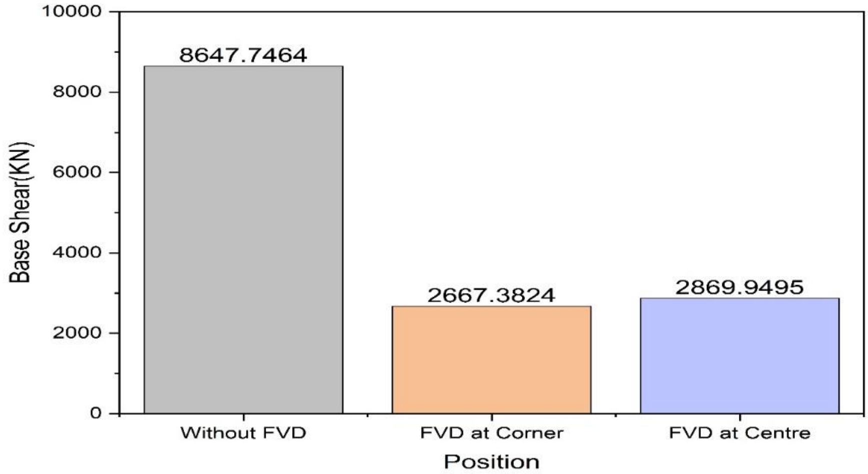

Fig.7 Base Shear Graph

- Fig7 shows that largely reduction in Base Shear observed when FVD is placed at centre and corner of the building.

IV. SUMMARY

Fluid viscous dampers (FVDs) have been extensively studied for their effectiveness in reducing seismic vibrations in buildings. Research on various structural configurations has shown that strategic placement of FVDs significantly reduces displacement, drift, and shear in buildings [1]. Comparative analyses of different configurations—such as random placement, installation on every floor, or positioning at the top, middle, and bottom, or centre and corner—highlight that optimized damper placement improves performance [1,2]. For instance, placing FVDs across all levels or at critical positions like corners or middle floors results in enhanced vibration control. While FVDs consistently reduce top displacement and inter-story drifts, their impact on base shear varies depending on placement and structural design.

Studies have demonstrated the advantages of using FVDs in both regular and irregular structures. High-rise buildings having FVD at centre reduce more displacement and drift with compare to building with FVD at corner and building without FVD.

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High-rise buildings with square columns tend to perform better in terms of time period and base shear reduction compared to those with rectangular columns [4]. For irregular buildings, such as L-shaped and C-shaped structures, dampers effectively reduce drifts and overturning moments, particularly when positioned at external corners or in a zigzag pattern [11]. Analytical methods, including time history analysis and response spectrum analysis, confirm that FVDs significantly improve energy dissipation, often reducing displacement and drift by 40–50 percent while lowering base shear by up to 30 percent.

Advanced optimization techniques, such as the use of algorithms for damper placement, have further enhanced the performance of FVDs [7]. Nonlinear dampers, when positioned ac- cording to story drift profiles, show notable reductions in acceleration and column forces. Simplified performance-based seismic design approaches and modal pushover analysis have proven effective in predicting and improving the performance of buildings with FVDs [5,6]. These dampers are also highly effective in controlling vibrations in irregular structures, with reductions in the time period and base shear reaching up to 90 percent. Overall, integrating FVDs into building designs provides

significant improvements in structural resilience and energy dissipation during seismic events, making them a practical and reliable solution for vibration control in tall buildings.

V. CONCLUSION

The analysis highlights the effectiveness of Fluid Viscous Dampers (FVDs) in enhancing the seismic performance of buildings by mitigating vibrations, displacements, and drifts. Research consistently demonstrates that the strategic placement of FVDs is critical, with configurations such as installation across all floors, at external corners, or specific zones like the middle, top, and bottom yielding significant improvements in reducing structural responses to seismic forces [1-15].

Comparisons show that FVDs are more effective than other damping systems, such as metallic dampers or buckling-restrained braces, in minimizing parameters like inter-story drift, base shear, and time periods. Optimization methods and advanced algorithms further enhance FVD efficiency by ensuring optimal placement and cost-effective designs while meeting performance goals [1-15].

Overall, the inclusion of FVDs significantly improves energy dissipation, reduces base shear, and enhances resilience for both regular and irregular structures, making them a practical and reliable solution for earthquake-resistant designs [1-15].

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