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A Comprehensive Seismic Evaluation of High-Rise Buildings with Fluid Viscous Dampers

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Key Words
High-rise building, fluid viscous damper, energy dissipation, ETABS software, response spectrum method

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Abstract

In response to increasing urban population and limited space, high-rise buildings have become essential. However, as building height increases, natural frequency decreases, making structures more susceptible to dynamic loads such as earthquakes, especially in seismic zones like Zone 3, 4 and 5. This study evaluates efficiency of Fluid Viscous Dampers (FVD) in reducing earthquake-induced vibrations in G+20, G+25 and G+30 storey reinforced concrete buildings in zone 5. A total of 18 models were developed using ETABS software, with and without FVD and analyzed using the Dynamic analysis i.e. linear Response Spectrum Method as per IS 1893-2016 standards. Seismic responses such as displacement, storey drift, base shear and time period were compared to determine the optimum placement of FVDs with (5) different structural configuration. This research is vital for improving the stability and protection of high-rise buildings in earthquake-prone regions and provides practical guidance for engineers in optimizing damper placement to mitigate seismic effects in tall structures.

INTRODUCTION

Fluid Viscous Dampers (FVDs) are a subtype of dampers that have gained popularity, especially in the context of seismic control, because of their ability to meet higher energy absorption requirements and operate within the elastic design limits of the primary system. One example is through skyscrapers, which can get damaged during seismic events or severe winds as a result of resonance which causes unwanted oscillations, thus having the construction absorb and dissipate energy with regard to reducing control system force enables the reduction of stress on the structure. Friction that occurs between the fluid molecules and the components of the damper dissipates energy, whereby the damper converts kinetic energy to heat energy instead, thus minimizing the energy transferred to the structure. Unlike other types of absorbers, FVDs perform mitigation of secondary impacts to the building's structure on reserve dampers, enabling the maintenance of seal voids which overcomes resistance forces occurring as a result of violently rotating flows of working liquid in a closed chamber.'' Unlike traditional dampers, which get damaged after an earthquake, viscous dampers help keep a structure rigid post disaster which is a key advantage of this absorber type. FVDs utilize non-toxic and environment friendly fluids such silicone oil for thermal stability and non-flammability."The damping force in these devices is proportional to the velocity of movement, expressed by the formula F=Cva, where C is the damping coefficient and a value varies between 0.3 and 1. Due to seismic hazard in most areas, dampers are essential in new structure as wall as for already built-up structure i.e. retrofitting for improving earthquake resistance.

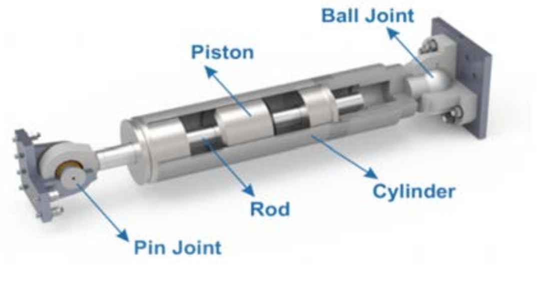

Fig. 1: Plan View of a Fluid Viscous Damper[1-3]

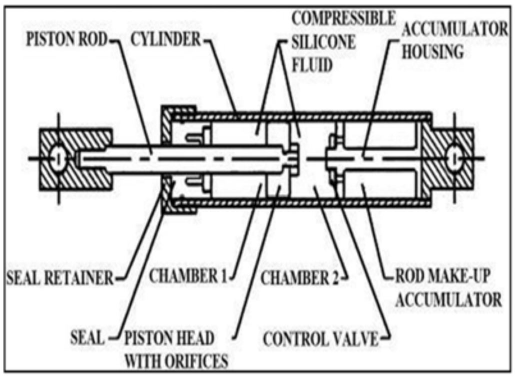

Fig. 2: Cross-Section of a Fluid Viscous Damper[4-9]

Literature Review: McNamara *et al.* (2000) built a G + 15 storied building in which viscous and friction dampers are used to control the response of the multi storey building. ETABS 2017 is used for this analysis. For the dynamic response evaluation of structures, time history and response spectrum methods are applied[10]. Kaveh and Nasrollahi (2014) displayed a performance level optimal seismic design for steel frames made with architecture using Charged System Search (CSS) optimization. Recently, a great deal of capability for structural optimization has been shown and applied to a number of optimization-based problems by semi-rigid connections. This technique is referred to as 'pushover analysis'[11]. Kaveh *et al.* (2015) have determined the optimal settings of Tuned Mass Dampers (TMD) that can decrease the dynamic response of multi-storey building systems to seismic excitations. This has been done by modifying active mass dampers, utilizing the well-known optimization CSS methodology. A MATLAB application has been developed for numerical optimization and time domain simulation[12]. Wang and Mahin (2018) In present paper, the authors discuss the response of G+20 irregular structures analyzed with linear dynamic method for seismic analysis. The response spectrum method is used for seismic occurrence. The analysis of the response parameters which is in the max displacement, storey shear of irregular building in relation with the regular building by assuming lateral force, compared with other works[13]. More *et al.* (2019) has done an analysis on G+10 building with Rcc and Steel column, viscous damper and base isolation. The purpose of analysis is to evaluate the performance of fluid viscous dampers (FVD) and base isolation in mitigating seismic responses[14]. Amanullah (2019) A 20 storey building was modeled using ETABS 2016. Total of 6 models are developed. Each model represents a unique set of time period, lateral deflection and base shear for seismic efficiency and are evaluated against each other. For the building analysis, equivalent static and linear, dynamic response spectrum methods were employed[4]. Kaveh *et al* (2020). The study aims at the implementation of the Tuned Mass Damper Inserter (TMDI) concept when controlling a ground-excited shear building benchmark of 10 stories. A metaheuristic method is used to obtain the optimal free vibration parameters of the TMDI which are natural frequency and damping ratios[15]. Kaveh *et al* established a robust optimal design of energy dissipater Tuned Mass Damper in 2020. The H2 and H8 norm of the roof displacement transfer function has been applied and compared as the objective functions under Near-Fault (NF) and Far-Fault (FF) earthquake motions. Also, the manner of a benchmark ten story-controlled building is analyzed under several near field ground motion parameters, such as fling-step and forward directivity. In order to determine optimal TMD parameters, Colliding Bodies Optimization (CBO) technique is utilized for optimization[5]. Kaveh and Ardebil (2021) the seven meta-heuristic Algorithms are employed. Soil-Structure Interaction (SSI) effects are taken into consideration while employing Plasma Generation Optimization (PGO) to identify mass damper (TMD) parameters. These techniques are then applied to a 40-story building model for evaluation[16]. Ramdas *et al* 2022 regarded the regular G+19 storey structure in plane. The building is modeled in ETABS software and Time history and response spectrum methods are used to analyze them A non-linear fluid viscous damper is designed and implemented in various locations within the structure in order to improve the structural response. The structural response of a building with and without FVD are examined based on the provisions of IS 1893:2016[17]. Jayadeep *et al* (2022) used the data from the Cheer Punj seismic events to evaluate the non-linear dynamic behavior of buildings equipped with dampers as well as to evaluate structural parameters such as displacement, inter storey drift and modal properties for G+5, G+10 and G+15 structures. Dampers are installed at every other floor[18]. Tiwari *et al* (2023) focuses on how nonlinear fluid viscous dampers (FVDs) are used to improve the seismic performance of reinforced cement concrete buildings. This study analyses engineering response such as displacement, drift ratio, residual displacement and floor acceleration from bare frames during phase two testing of the frame[19,1,2].

MATERIALS AND METHODS

- **Structural Properties:** The structural properties include, Geometrical parameters, loading condition, Various loads and Seismic parameters.
- **Geometrical Properties:**

Table 1: Geometrical Properties

Sr. No	Particulars	Geometrical details
1.1	Height of building G+20	63m
1.2	Height of building G+25	78m
1.3	Height of building G+30	93m
2	Height of each storey G+20/25/30	3m
3.	Thickness of RCC slab for G+20/25/30	150mm
4.1	Thickness of Shear Wall G+20	230mm
4.2	Thickness of Shear Wall G+25	350mm
4.3	Thickness of Shear Wall G+30	400 mm
5.1	Size of Beam G+20	400 X 500 mm
5.2	Size of Beam G+25	400X 800 mm
5.3	Size of Beam G+30	500 X 1000 mm
6.1	Size of Column G+20	700 X 500 mm
6.2	Size of Column G+25	800 X 800 mm
6.3	Size of Column G+30	1000 X 1000 mm
7	Reinforced concrete grade	M 40
8	Steel grade	Fe 500

Table 2: Loading Condition

Load combination	DL	LL	EQX	EQY
DL+LL	**1**	**1**	-	-
1.5(DL+LL)	**1.5**	**1.5**	-	-
1.2(DL+LL+EQX)	**1.2**	**1.2**	**1.2**	-
1.2(DL+LL-EQX)	**1.2**	**1.2**	**1.2**	-
1.2(DL+LL+EQY)	**1.2**	**1.2**	-	**1.2**
1.2(DL+LL-EQY)	**1.2**	**1.2**	-	**1.2**
1.5(DL+EQX)	**1.5**	-	**1.5**	-
1.5(DL-EQX)	**1.5**	-	**1.5**	-
1.5(DL+EQY)	**1.5**	-	-	**1.5**
1.5(DL-EQY)	**1.5**	-	-	**1.5**
0.9DL+1.5EQX	**0.9**	-	**1.5**	-
0.9DL-1.5EQX	**0.9**	-	-	-
0.9DL+1.5EQY	**0.9**	-	-	**1.5**
0.9DL-1.5EQY	**0.9**	-	-	**1.5**

Table 3: Loading

Sr. No.	Live Load in kN/m^2	Dead Load in kN/m^2	Wall Load kN/m
1	4	10.13	15

Table 4: Seismic Parameter's

Sr. No.	Importance Factor(I)	Zone Factor(Z)	Response Reduction Factor ®	Type of soil Medium	Damping Ratio
1	1.5	0.36	5	II	5%

- The Current study is based on RCC structure analysis with and without FVDs for different floor heights of building and with different damper position. The study used dynamic Analysis E-tabs software for analysis of seismic parameter i.e. displacement, Drift, Time period and Base shear and comparing its data for optimum location of damper in High rise building. And using M/s Excel for graphical and chart presentation. M40 Concrete grade and Fe 500 Steel grade is used for all slabs, beams and columns design. FVD500 is to use throughout the analyses with weight=500 (kN) and Mass=98 (kg) Taylor Device Model No. 17130. The structural elements considered are columns sizes, beams sizes, slabs thickness, Shear wall thickness, D.L, L.L, FF, Earthquake load:- As per IS 1893:2016, RCC design code: IS 456:2000 and Earthquake design code: IS 1893:2016 for seismic analysis.

- **Model and it's Analyses:** Total 18 models are designed and analyzed for finding Optimum Location of Damper By using different height of building w.r.t Structural Parameters and Structural Configuration.
- **Structural Parameters are:** Storey Drift, Displacement, Base Shear and Time Period. Structural configuration is: Bare Model, FVD Diagonal Model, FVD Cross X Model, FVD Zigzag Model, FVD V-Shaped Model and FVD Chevron Shaped Model.

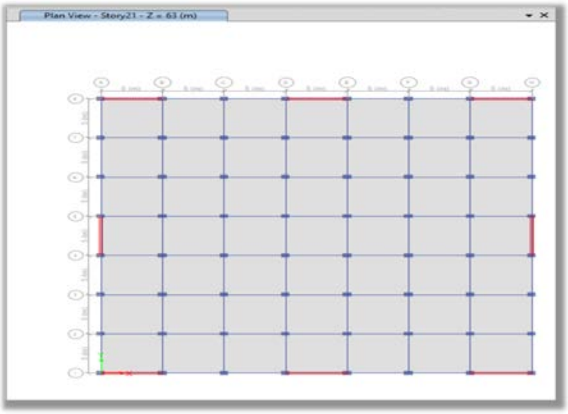

Fig. 3: Plan View

Symmetrical Grid System

X-Direction-7 Bays @5m each=35m

Y-Direction-7 Bays @5m each=35m

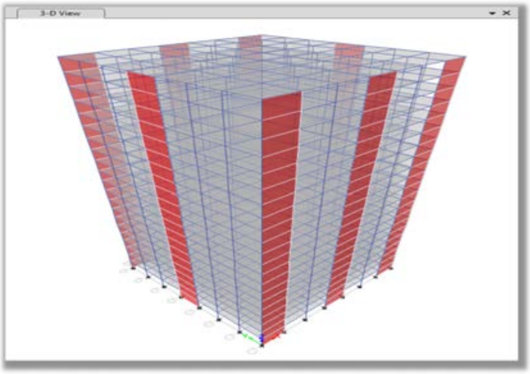

Fig. 4: 3D View of Model

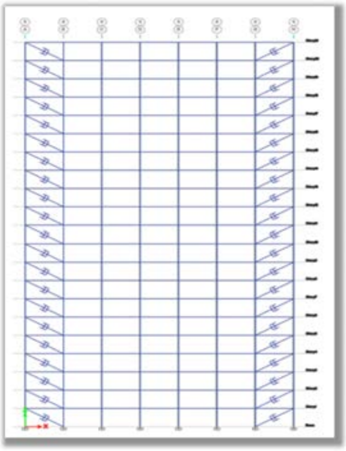

Fig. 5: Diagonal FVD Model

Fig. 6: Cross X FVD Model

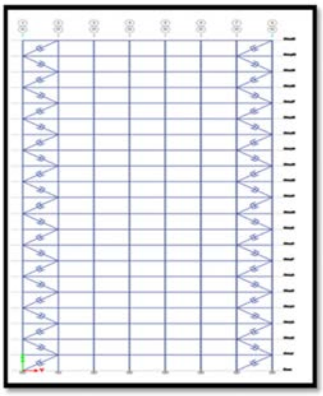

Fig. 7: Zigzag FVD Model

Fig. 8: V-Shaped FVD Model

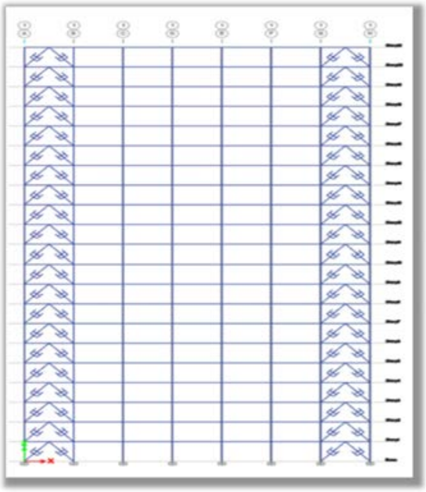

Fig. 9: Chevron FVD Model

RESULTS AND DISCUSSIONS

Table 5: Displacement Comparison (mm)

Model	G+20	G+25	G+30
Base Model	142.98	155.35	271.26
FVD Diagonal Model	120.31	128.51	220.79
FVD Cross X Model	94.89	114.4	178.77
FVD Zigzag Model	113	119.96	195.17
FVD V-Shaped Model	116.95	124.65	210.46
FVD Chevron Model	131.61	139.3	247.17

Table 6: Drift Comparison

Model	G+20	G+25	G+30
Base Model	0.0029	0.0033	0.0041
FVD Diagonal Model	0.0025	0.0027	0.0033
FVD Cross X Model	0.0019	0.002	0.0027
FVD Zigzag Model	0.0023	0.0024	0.0029
FVD V-Shaped Model	0.0024	0.0026	0.0032
FVD Chevron Model	0.0027	0.003	0.0037

Table 7: Base Shear Comparison

Model	G+20	G+25	G+30
Base Model	3495.64	4170.48	4489.92
FVD Diagonal Model	3294.63	3975.42	4085.28
FVD Cross X Model	1920.18	2939.87	3524.88
FVD Zigzag Model	2532.29	3569.91	3712.22
FVD V-Shaped Model	2778.81	3723.5	3799.9
FVD Chevron Model	3037.19	3898.69	3967.35

Table 8: Time Period Comparison

Model	G+20	G+25	G+30
Base Model	3.57	4.13	4.39
FVD Diagonal Model	3.446	3.8	3.9
FVD Cross X Model	3.167	3.57	3.7
FVD Zigzag Model	3.226	3.64	3.73
FVD V-Shaped Model	3.259	3.67	3.79
FVD Chevron Model	3.359	3.74	3.85

- Various height of a building is considered to find the superior location of the damper Using FVD 500 at corner throughout the height of building i.e. G+20, G+25 and G+30.
- The Result For G+20, G+25 and G+30 w.r.t Displacement are Max. Displacement is found in G+30, G+25 and G+20 Bare Model i.e. 271.26 (mm), 155.35(mm), 142.98(mm) respectively And by Applying FVD DAMPER the Min. Displacement is found in CROSS X MODEL i.e. 178.77(mm), 114.4(mm), 94.89(mm) respectively the percentage reduction is 34%, 26.35%, 33.63% Resp. by using Damper.
- The Result For G+20, G+25 and G+30 w.r.t DRIFT are Max. Drift is found in G+30, G+25 and G+20 Bare Model i.e. 0.0041, 0.0033, 0.0029 respectively And by Applying FVD Damper the Min. Drift is found in Cross X Model i.e. 0.0027, 0.002, 0.0019 respectively the percentage reduction is 34.14%, 39.39%, 34.48% Resp. by using Damper.
- The Result For G+20, G+25 and G+30 w.r.t Base Shear are Max. Shear is found in G+30, G+25 and G+20 Bare Model i.e. 4489.92(kN) , 4170.48(kN), 3495.64 (kN) respectively And by Applying FVD DAMPER the Min. shear is found in CROSS X MODEL i.e. 3524.88(kN), 2939.87(kN), 1920.18 (kN) respectively the percentage reduction is 21.49%, 29.50%, 45.06% Resp. By using Damper.
- The Result For G+20, G+25 and G+30 w.r.t Time Period are Max. Time is found in G+30 , G+25 and G+20. Bare Model i.e. 4.39(sec), 4.13 (sec), 3.57 (sec) respectively And by Applying FVD Damper the Min. Time is found in Cross X Model i.e. 3.7(sec), 3.57 (sec), 3.167 (sec) respectively the percentage reduction is 15.71%, 13.55%, 11.28% Resp. By using Damper.
- From the above result data we can find that the least Displacement is found in G+30 storey building having reduction of 34%, Min. Drift in G+25 with reduction of 39.39%, Base Shear in G+20 reduction of 45.06% and Time Period of G+30 with reduction of 15.71% in FVD Cross X Model compared to Base Model.

CONCLUSION

- From the above analysis the comparison has been done to get the Optimized Location of FVD with comparing it with various Height of a building and placing the Damper in one specific location i.e. at Corner.
- FVD 500 Damper is used for the analysis using dynamic response spectrum method.
- The result and discussion of the analysis gives the broad aspect of structural behaviors of a building without damper and with damper for different storey height with different structural parameters

regarding its Displacement, Drift, Base shear and Time period.

- Result shows maximum reduction in displacement at G+30 Storey, Drift at G+25 Storey, Base shear at G+20 and Time period at G+30 Storey in FVD Cross X Model when compared with Bare Model without FVD.
- In overall comparison of bare frame, FVD Diagonal, FVD Cross X, FVD Zigzag, FVD V-Shaped, FVD Chevron Model fluid viscous damper with Cross X Configuration has good structural performance as compare to other Configuration at same location of Damper.

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Author Contributions:

- All the 2 authors have significantly contributed in investigation, resources, data curation, writing-original draft, writing-review and editing and supervision of the research work.

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