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EFFECT OF VISCOUS DAMPERS ON RESPONSE REDUCTION FACTOR FOR RCC FRAME USING RESPONSE SPECTRUM ANALYSIS

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Abstract - *Response reduction factor (R) is the parameter which represents the capacity of structure to dissipate energy through inelastic behavior. Increased value of response reduction factor for a structure resembles increased inelasticity of the structure towards seismic forces. Viscous damper is a device which is installed in the structures to damp seismic forces by energy dissipation. Response reduction factor (R) is a seismic design parameter which determines nonlinear behaviour of RCC structures subjected to earthquake. From the literature review it is seen that the study on the effect of viscous dampers on the response reduction factor (R) is lagging. Thus, the effect of viscous dampers on the response reduction factor (R) of reinforced concrete structures installed with viscous dampers has been studied. Overstrength, redundancy and ductility factors are the parameters, used to formulate response reduction factor (R). The performance of reinforced concrete structures in seismic conditions is improved by damping action of viscous dampers. ETABS 2016 software was used to determine the effect of viscous dampers on the behaviour of reinforced concrete building installed with dampers on different locations of the building and at various storeys of building. The effect of nonlinear viscous damper on overstrength, ductility and response reduction factor of special moment resisting frame (SMRF) frames is also studied. The results of the analysis showed that, the value of response reduction factor (R) for reinforced concrete building installed with dampers was higher than the building without damper.*

Key Words: Response Reduction Factor, Viscous Damper, Ductility Factor, Overstrength Factor, Redundancy Factor, Dynamic Analysis.

1. INTRODUCTION

The main purpose & intention of conventional structural design for the structures in seismic zones is human life protection. To serve the intended purpose, it is necessary for the structure to refrain collapse, even though highly damaged by the seismic action. This is the basic concept of the ductility of structure. Response reduction factor for any structure represents ductility and the same is incorporated in the design of structure through response reduction factor. The response reduction factor (R) is a seismic design parameter that determines the nonlinear performance of building structures during strong earthquakes. The structure may loose all its functionality (partial / complete) after seismic actions. Retrofitting of such structures affected by earthquakes may become very intricate or even impossible in some cases. In order to reduce the deleterious effects of earthquakes on the stability of structures, it is necessary to mitigate the effect of seismic action on the structure by providing a catalyst in structure. This can be achieved by providing an emerging technology known as viscous dampers. Viscous dampers functions on the principle of passive energy dissipation by adding damping of seismic forces in the structure. Previous study on response of structure to earthquakes provided with viscous damper shows that it can reduce story drift, forces in members which leads to less damage to structure enabling it to resist large lateral force. It is very important to safeguard the structures such as airports, fire department barracks, nuclear power plants, communication centers, hospitals, bus stops, institutions etc from the earthquakes to reach higher level of safety. By the virtue of damping action of viscous dampers, it reduces forces in the members, enabling provision of smaller cross sections of structural members. This makes the construction of the structure more cost efficient and light weight which favours response of structure against seismic action.

2. RESPONSE REDUCTION FACTOR

Response reduction factor determines level of inelasticity of structure expected in lateral structural systems during an earthquake. The concept of R is based on assumption that the well detailed seismic framing system can sustain large inelastic deformations without collapse.
Calculation of design base shear is as given below (IS 1893),

$$V_d = \frac{Z \times I \times S_a}{2 \times R \times g}$$

The definition of response reduction is introduced by ATC 19 (1995) in the form of equation as shown below,

$$R = R_\mu \times R_o \times R_r \times R_\xi$$

Where R is response reduction factor, R_o is over strength factor, R_μ is ductility factor, R_r is redundancy factor and R_ξ is damping factor.

Effects of added damping is ratiocinated by documents such as ATC (1995) damping to reduce the force response of buildings. Equation of response reduction appeared in various literatures is as shown below,

$$R = R_o \, X \, R_\mu \times R_r$$

2.1 Overstrength Factor (R_o)

Overstrength factor determines the yielding of structure at higher load than design load because of various factors like partial load factors applied to gravity loads and safety factors applied to material strengths. It is represented in the form of equation as shown below,

$$R_o = \frac{V_y}{V_d}$$

Where Vd is the design base shear force in the building calculated (IS 1893:2002) & Vy is the yield base shear force that corresponds to actual yielding of structure.

2.2 Ductility Factor (Rμ)

The ductility factor (R_μ) determines nonlinear response of a structure that occurs from hysteretic energy. It reduces the elastic force demand to the level of idealized yield strength of the structure

Ductility factor was developed by Newmark and Hall (1982) as follows,

$$R\mu = 1 \quad \text{for } T < 0.2 \text{ s}$$
$$R\mu = \sqrt{2\mu - 1} \text{ for } 0.2 \text{ s} < T < 0.5 \text{ s}$$
$$R\mu = \mu \quad \text{for } T > 0.5 \text{ s}$$
$$\mu = \frac{\Delta_{max}}{\Delta_y}$$

2.3 Redundancy Factor (Rr)

The redundancy factor (Rr) is a measure of repetitions in a lateral load resisting system. The moment resisting frames, shear walls or their aggregates are the most chosen lateral load resisting systems in RC structures. ASCE 7 recommends a redundancy factor Rr = 1.0 for systems with parallel frames and the corresponding is adopted for this work as the case study structures fall in this category.

Table – 1: Redundancy factor (Rr) from ATC

Lines of vertical framing	Drift Redundancy factor
2	0.71
3	0.86
4	1.0

2.3 Fluid Viscous Dampers (FVD)

The primary aim of energy dissipation devices is to mitigate displacement of the structures due to earthquakes. Energy dissipation is better alternative to conventional stiffening and strengthening schemes and would be expected to achieve comparable performance levels. Fluid viscous dampers were initially used in the military and aerospace industry. They were used in structural engineering in the late 1980's and early 1990's. Fluid viscous dampers consists of a piston head with orifices contained in a cylinder filled with a highly viscous fluid, usually a compound of silicone or a similar type of oil. Energy is dissipated in the damper by fluid orificing when the piston head moves through the fluid. The fluid in the cylinder is nearly incompressible and when the damper is subjected to a compressive force, the fluid volume inside the cylinder is decreased as a result of the piston rod area movement. A decrease in volume results in a restoring force. This force is undesirable and is usually prevented by using a run-through rod that enters, the damper is connected to the piston head and then passes out the other end of the damper. Another method for preventing the restoring force is to use an accumulator. An accumulator works by collecting the volume of fluid that is displaced by the piston rod and storing it in the make-up area. As the rod retreats, a vacuum that has been created will draw the fluid out. A damper with an accumulator is illustrated in fig. 1.

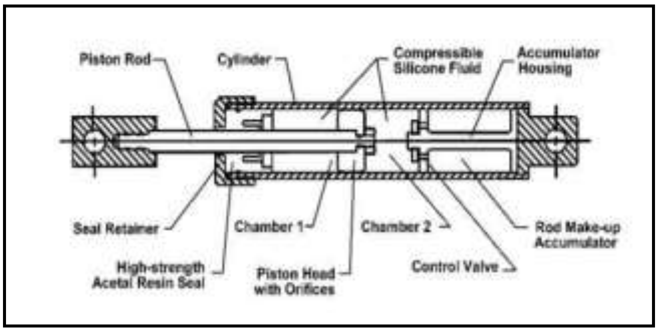


Fig – 1: Fluid Viscous Damper (FVD)

Fluid viscous dampers have the unique advantage of reducing the shearing and bending stresses at the same time, as the velocity-dependent maximum damping force is 90 degrees out of phase with the maximum deflection of the structure. In addition, installing FVDs in a structure does not alter its force displacement relationship.

3. STRUCTURAL MODELLING

RCC buildings of 4, 8, 12 and 16 storey, symmetric in plan are considered in present study. To represent the effect of time period on response structure, structures with various storey were considered. It had 3 bays in both the directions with bay width of 6 m. The height of all stories was taken as 3 m. The seismic forces on these buildings were determined as per IS 1893:2002. These RC buildings were designed for both gravity and earthquake forces based on guidelines given by IS 456:2000 and IS 13920:1993.

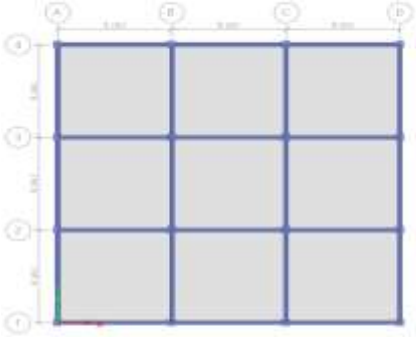


Fig – 2: Structural arrangement of four buildings in plan

The data used for design is as follows:

Table – 2: Material Properties

Storey	Grade of concrete	Grade of steel
4	M20	Fe 500
8	M25	Fe 500
12	M30	Fe 500
16	M30	Fe 500

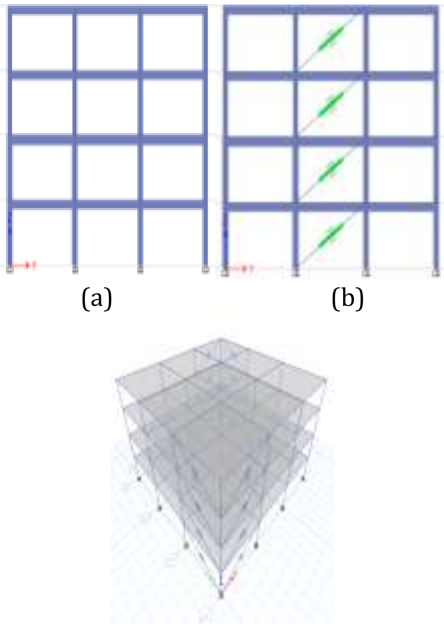
- Imposed load for Institutional structure is 3 kN/m^2.
- Floor finish load is 1.5 kN/m^2.
- Wall load on beams are assumed as 12 kN/m for outer walls and 6 kN/m for inner walls.
- Floor slabs are assumed as 200 mm thick.
- Damping coefficient 770 kNs/m.
- Building frame is modeled as rigid jointed frame i.e. Special moment resisting frame.

Table – 3: Properties of Fluid Viscous Damper

Sr. No	Damping coefficient (kNs/m)	Force (kN)	Stiffness (kN/m)	Mass (kg)
1.	770.0	733.9	3850000	150
2.	1027.4	978.6	5137050	215
3.	1541.1	1467.9	7705000	300
4.	2054.8	1957.2	10274000	450

Details of models considered in present study are discussed below. In configuration I (CONFI-I), viscous dampers are added in middle bays of frame and in configuration II (CONFI-II), viscous dampers are added in corner bay but i.e. different location of frame through overall height of structure.

I. 4 storey building



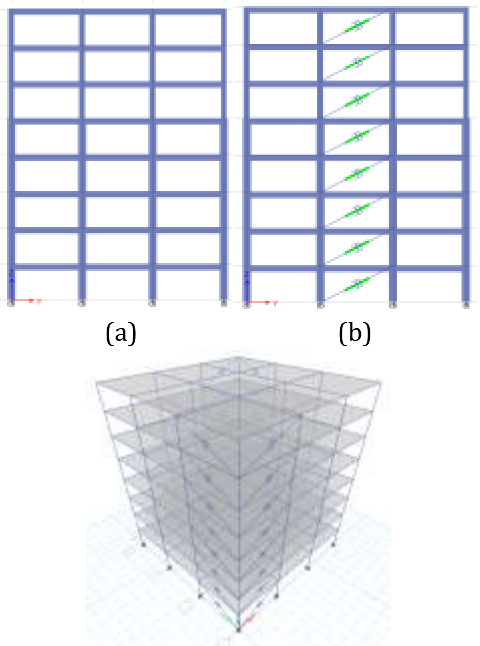
(a) (b)

(c)

(a) Structure without damper; (b) Structure with damper CONFI-I; (c) Structure with damper CONFI-II

Fig – 3: 4 storey RCC building with different damper configurations

II. 8 storey building



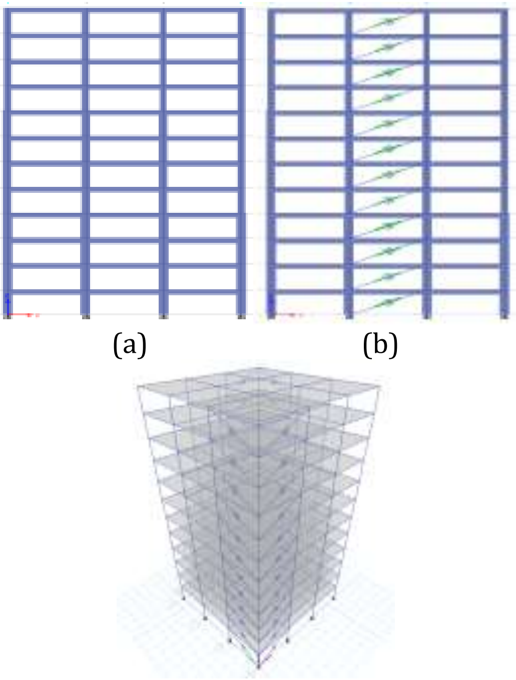
(a) (b)

(c)

(a) Structure without damper; (b) Structure with damper CONFI-I; (c) Structure with damper CONFI-II

Fig - 4: 8 storey RCC building with different damper configurations

III. 12 storey building

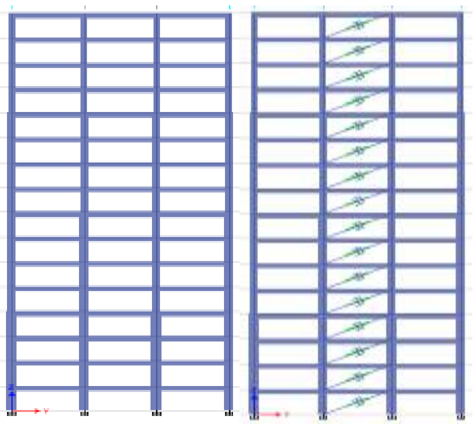


(a) (b)

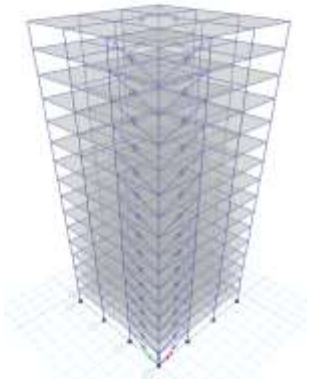
(C)

(a) Structure without damper; (b) Structure with damper CONFI-I; (c) Structure with damper CONFI-II
Fig – 5: 12 storey RCC building with different damper configurations

IV. 16 storey building



(a) (b)



(c)

(a) Structure without damper; (b) Structure with damper CONFI-I; (c) Structure with damper CONFI-II
Fig – 6: 16 storey RCC building with different damper configurations

Table - 4: Details of RC section

Building	Floor	Column(mm)	Beam(mm)
4 storey	1-2	500x500	230x450
	3-4	450x450	230x450
8 storey	1-5	650x650	300x500
	6-8	500x500	300x500
12 storey	1-4	750x750	300x600
	5-8	650x650	300x600
	9-12	550x550	300x600
16 storey	1-4	850x850	300x600
	5-8	750x750	300x600
	9-12	650x650	300x600
	13-16	550x550	300x600

4. SEISMIC ANALYSIS

Seismic analysis is a subset of structural analysis and is the calculation of the response of a building structure to earthquakes. It is part of the process of structural design, earthquake engineering or structural assessment and retrofit in regions where earthquakes are prevalent. The behaviour of structure, external action, and the kind of structural design selected, is the key to this analysis. Also, on the basis of the behavior of the structure and external action, the analysis is further categorized as (i) Linear Static Analysis, (ii) Nonlinear Static analysis, (iii) Linear Dynamic analysis, and (iv) Nonlinear Dynamic analysis.

Table – 5: Response reduction factor for 4 Storey building

	G+3 Storey							
	V_y	V_d	R_o	Δ_{max} (mm)	Δ_y (mm)	R_μ	R_r	R
Without FVD	984.421	949.680	1.0366	48	17.94	2.0860	1	2.1623
With FVD CONFI-I	985.542	950.961	1.0364	48	13.12	2.5130	1	2.6044
With FVD CONFI-II	985.542	950.961	1.0364	48	13.76	2.5543	1	2.5972

Table - 5: Response reduction factor for 8 Storey building

	G+7 Storey							
	V_y	V_d	R_o	Δ_{max} (mm)	Δ_y (mm)	R_μ	R_r	R
Without FVD	2203.277	2116.423	1.0410	96	46.62	2.0593	1	2.1438
With FVD CONFI-I	2205.679	2118.985	1.0409	96	33.81	2.8394	1	2.9556
With FVD CONFI-II	2205.679	2118.985	1.0409	96	34.09	2.8158	1	2.9310

Table – 6: Response reduction factor for G+11 Storey building

	12 Storey							
	V_y	V_d	R_o	Δ_{max} (mm)	Δ_y (mm)	R_μ	R_r	R
Without FVD	2477.673	3338.171	0.7422	144	51.93	2.7732	1	2.0583
With FVD CONFI-I	2480.297	3342.015	1.0419	144	40.11	3.5898	1	3.7400
With FVD CONFI-II	2480.297	3342.015	1.0419	144	41.22	3.4939	1	3.6401

Table - 7: Response reduction factor for G+15 Storey building

	16 Storey							
	V_y	V_d	R_o	Δ_{max} (mm)	Δ_y (mm)	R_μ	R_r	R
Without FVD	2536.220	4554.324	0.5569	192	69.81	2.7505	1	1.5317
With FVD CONFI-I	2538.873	4559.448	1.0423	192	51.99	3.6932	1	3.8493
With FVD CONFI-II	2538.873	4559.448	1.0423	192	54.06	3.5514	1	3.7015

Table – 8: Comparison of response reduction factor without viscous dampers, with viscous dampers Configuration I & with viscous dampers Configuration II

Storey	**Without Damper**	**With FVD CONFI. I**	**With FVD CONFI. II**
	Values of R		
4	2.1623	2.6044	2.5972
8	2.1438	2.9556	2.9310
12	2.0583	3.7400	3.6401
16	1.5317	3.8493	3.7015

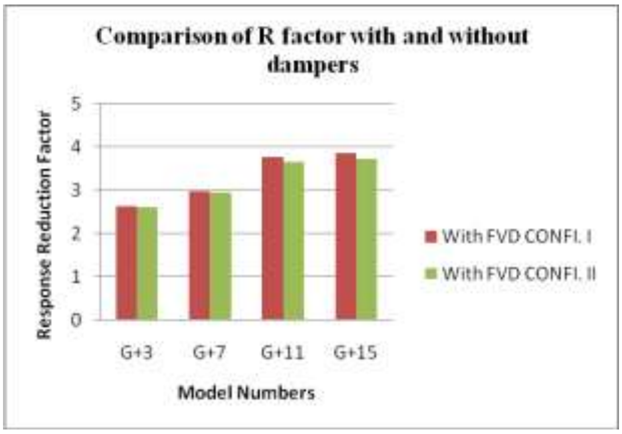


Fig – 7: Response Reduction Factor

6. CONCLUSIONS

Following are the conclusions of the study:

1. A constant value of R for any case of building cannot be justified. Well-defined methods are required to find out the R value accounting for strength, ductility, redundancy and damping for any particular building; present work takes efforts in the same line of action.
2. It is observed that implementation of viscous dampers reduce the storey displacement, drift, acceleration occurred in RCC building and increases the base shear capacity.
3. R factors computed are highly dependent on the height of building, viscous damper capacity and the input ground motion.
4. Buildings with dampers can resist more lateral loads compared to building without damper at nearly same displacement.
5. For this study, R factor for building with Configuration I and II increases as height of building increases.
6. The advantage of viscous dampers is clearly demonstrated by increase in response reduction factor and improvement in performance of the building during an earthquake has been proven. Therefore, FVDs are effective for enhancement of RCC buildings performance when subjected to dynamic excitations.
7. It is observed that overstrength factor slightly decreases with increase in damping capacity and also ductility factor is increased in building with increase in capacity of dampers.
8. It is observed that ductility factor is increased in building with dampers.

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