Evaluation and Comparison of Response Reduction Factor (R factor) for RCC Frame Provided with Viscous Damper by Response Spectrum Analysis

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Abstract: *During strong earthquakes the nonlinear performance of building structures is determined by the response reduction factor (R) which is a seismic design parameter. Whereas, an extensive review of related literature indicates that the effect of viscous dampers on the response reduction factor is not considered. Therefore, this study proposed the response reduction factors for reinforced concrete structures equipped with viscous damper devices and investigated the effect of implementing such devices in reinforced concrete structures on the response reduction factor. Response reduction factor was formulated based on three aspects, namely, overstrength, redundancy, and ductility factors. Fluid viscous damper is a device that enhances the performance of the building by adding damping. A nonlinear dynamic analysis was performed with ETABS-2016 software using structural models with damper devices installed in different locations at various story levels. Results revealed that the response reduction factors for reinforced concrete structures with damper devices are higher than those for reinforced concrete structures without damper devices and the effect of nonlinear viscous damper on overstrength, ductility and response reduction factor of special moment resisting frame (SMRF) frames is evaluated. From this result we came to know that the Indian standard recommends a higher value of R than that of actual value, which is potentially dangerous. Some limitations and other significant conclusions are also provides in this paper.*

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

1. INTRODUCTION

The fundamental objective of the traditional structural design for seismic actions is human life protection. This performance objective requires that the structure, when subjected to a strong seismic input, even if heavily damaged but does not collapse. This approach leads to the basic concept of structural ductility. This ductility of structure is considered in design 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. After a strong earthquake, the structure can lose its (entire) functionality and its retrofitting may be very difficult and expensive, or even not possible. Passive energy dissipation is an emerging technology that enhances the performance of the building by adding damping (and in some cases stiffness) to the building. Previous study on response of structure provided with viscous damper shows that it can reduce story drift, forces in member which lead to less damage to structure so that such structure can resist large lateral force. Important structures like hospitals, police stations, fire department barracks, communication centers, airports, nuclear power plants and all buildings which are strategic for public safety, must be designed to reach higher protection levels under strong earthquakes and undergo limited or even no structural damage. These structures can be designed to desired performance level using fluid viscous damper devices. Due to decrease in forces in member we can reduce member size which is economical and hence mass of structure will be reduced which is effective for response of structure against seismic action.

H. Abdi, F. Hejazi, R. Saifulnaz, A. Karim, M. S. Jaafar (2015) they have performed the effect of implementing viscous damper devices in steel structures on the response modification factor. A nonlinear static pushover analysis of G+3,7,11, 15 and 19 stories is performed with finite element software using structural models with damper devices installed in different locations at various story levels. Result obtained from analysis of structure show that response modification factors for steel structures with damper devices are higher than those for steel structures without damper devices. Dampers increase the base force capacity and in some cases displacement was less for the same base force. An equation was proposed to determine response modification for steel structure with viscous dampers.

ApurbaMondal, Siddhartha Ghosh, G.R. Reddy (2013) In this paper author concentrates on estimating of actual values of R factor for realistic RCC building, designed and detailed as per the Indian Standards. They analysed the Four RCC buildings 2,4, 8 and 12 storeys, located within zone IV and designed and detailed as per Indian standards with nonlinear static analysis to evaluate overstrength factor and global ductile capacity of RCC building. The results conclude that the Indian standard recommendation for a higher values of R than the definite value of R is less.

F. Hejazi, J. Noorzaei, M. S. Jaafar and A. A. Abang Abdullah (2009) They have conducted earthquake analysis of RC-framed structures with an added energy dissipation system (viscous dampers). They observed that using a damper device as a seismic energy dissipation system can effectively reduce the response of framed structures. They found that use of damper devices effectively reduced 80 percentage displacement response of structure compared to response of structure without dampers system when earthquake subjected to model. Optimum damper was obtained by evaluation of damper damping coefficient effect on the structures response in terms of displacement, drift, acceleration.

2. RESPONSE REDUCTION FACTOR

Response reduction factor is used to describe level of inelasticity expected in lateral structural systems during an earthquake. It is the factor by which the actual base shear force, that would be generated if the structure were to remain elastic during its response to earthquake, shall be reduced to obtain the design lateral force (IS 1893). The concept of R is based on premise that the well detailed seismic framing system could sustain large inelastic deformations without collapse.

Equation provided by IS 1893 to calculate design base shear is as given below

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

ATC 19 (1995) report introduced definition of response reduction and its key components, the definition provided in ATC 19 is represented in the equation given 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.

R_ξ accounts for damping offered by supplemental damping but seismic design codes are based force-based procedures and damping reduction factors, acceptable in codes, are derived from the effects of viscous damping on the displacement response of elastic single-degree of freedom (SDOF) systems. In documents such as ATC (1995) ratiocinate the effects of added damping to decrease the force response of buildings. Therefore equation of response reduction used in various studies is as per below equation

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

2.1 Overstrength Factor(R_o)

It is defined as ratio of excess strength of structure till significant yield to code specified minimum seismic design strength. This accounts the yielding of structure at higher load than design load because of different contributing factors like partial load factors that are applied to gravity loads and safety factors applied to material strengths. Sometimes member sizes provided from serviceability and architectural considerations are larger than those required from strength considerations, confinement of concrete and ductile detailing specified in codes adds to strength.

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

Where Vd is the design base shear force in the building calculated as per IS 1893:2002, and Vy is the yield base shear force that corresponds to actual yielding of structure i.e. Immediate Occupancy performance level.

2.2 Ductility Factor (Rµ)

The ductility factor (R_μ) is used to measure the nonlinear response of a structure that results from hysteretic energy. It reduces the elastic force demand to the level of idealized yield strength of the structure. The ductility reduction factor (R_μ) takes advantage of the energy dissipating capacity of properly designed and well-detailed structures and hence primarily depends on the global ductility demand (μ) of the structure. R_μCalculated in terms of maximum roof displacement (Δ_{max}) and the displacement corresponding to the yielding point (Δ_y), Δ_{max} is the maximum displacement for the life safety performance in structure.

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

$R\mu = 1$ for $T < 0.2$ s

$R\mu = \sqrt{2\mu - 1}$for 0.2 s $< T < 0.5$ s

$R\mu = \mu$ for $T > 0.5$ s

$\mu = \frac{\Delta_{max}}{\Delta_y}$

2.3Redundancy 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. Central frames are constructed for gravity loads, at times and perimeter frames are constructed as lateral load resisting systems hence the repetition in lateral load resisting system rely upon the structural system chose. The reinforced concrete structural system with multiple lines of lateral load resisting framing systems is generally considered in the category of redundant structural systems because the frames are outlined and described to transfer the earthquake-induced inertia loads to the foundation.

The lateral load is yielded by different frames relying on the relative stiffness and strength characteristics of respective frames for redundant framing systems. When uncorrelated (independent) the reliability of framing system is higher for a structure with multiple lines of frames but reduces when resistance parameters are perfectly correlated. 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)

Passive energy dissipation is an emerging technology that enhances the performance of the building by adding damping (and in some cases stiffness) to the building. The primary use of energy dissipation devices is to reduce earthquake displacement of the structure. These devices will also reduce force in the structure provided the structure is responding elastically but would not be expected to reduce force in structures that are responding beyond yield. For most applications, energy dissipation provides an alternative approach to conventional stiffening and strengthening schemes, and would be expected to achieve comparable Performance Levels. In general, these devices would be expected to be good candidates for projects that have a Performance Level of Life Safety, or perhaps Immediate Occupancy, but would be expected to have only limited applicability to projects with a Performance Level of Collapse Prevention. Fluid viscous dampers were initially used in the military and aerospace industry. They were adopted for use in structural engineering in the late 1980's and early 1990's. Fluid viscous dampers typically consist 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.

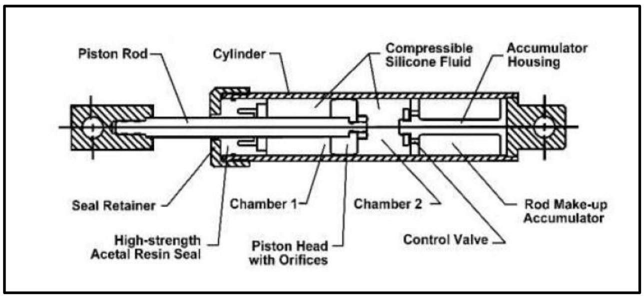


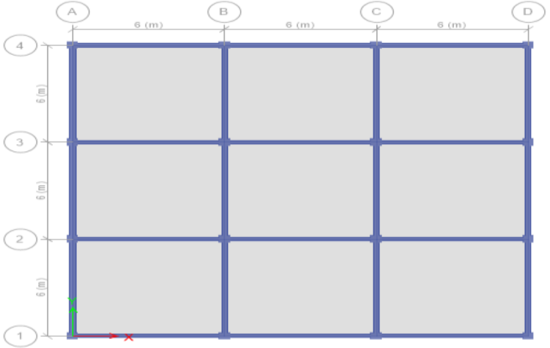
Fig -1: Fluid Viscous Damper (FVD)

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

Reinforced concrete buildings of G+3, G+7, G+11 and G+15 storey, symmetric in plan are considered in present study. Here, different storey structures are considered to represent effect of time period on response structure. It has 3 bays in both the directions with bay width of 6 m. The height of all stories is taken as 3 m. The seismic forces on these buildings are calculated following IS 1893:2002. These RC buildings are 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:

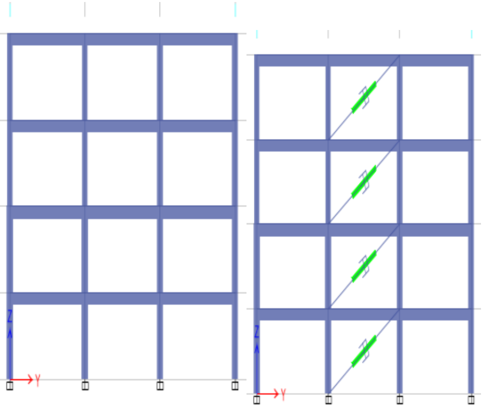
Table -2: Material Properties

Storey	Grade of concrete	Grade of steel
G+3	M20	Fe 500
G+7	M25	Fe 500
G+11	M30	Fe 500
G+15	M30	Fe 500

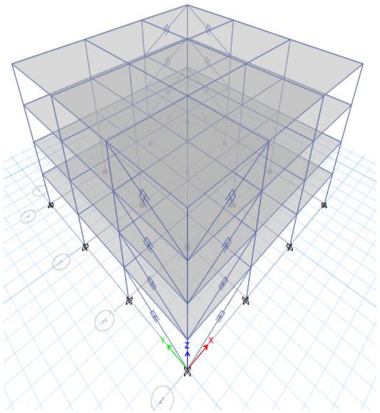
- Imposed load for Institutional structure is $3kN/m^2$.
- Floor finish load is $1.5\ kN/m^2$.
- Wall load on beams are assumed as 12kN/m for outer walls and 6kN/m for inner walls.
- Floor slabs are assumed as 200 mm thick.
- Damping coefficient 770 KNs/m.
- Building frame is modeled as rigid jointed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

Details of models considered in present study are discussed below. RC section details of frame are given. Two configurations for addition of viscous damper in building are used. 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. G+3 storey building



(a) (b)

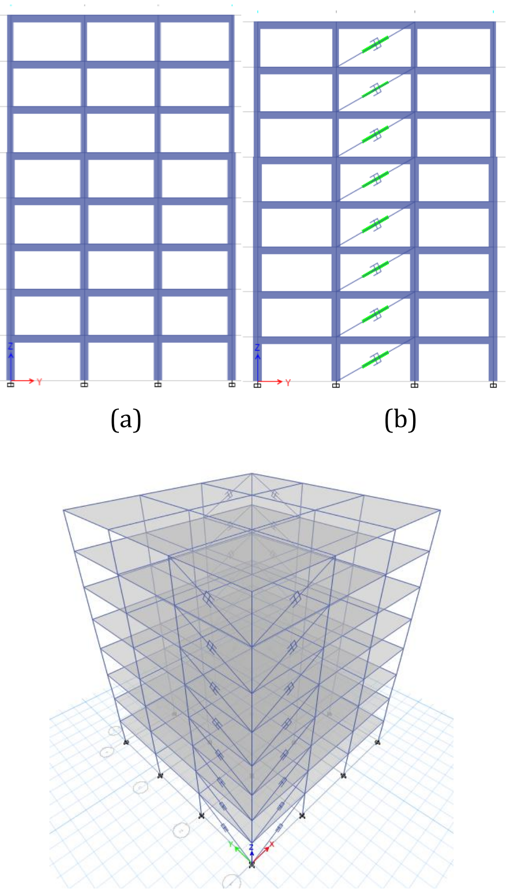


(c)

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

Fig -3: View of G+3 RCC building with different damper configurations

II. G+7 storey building



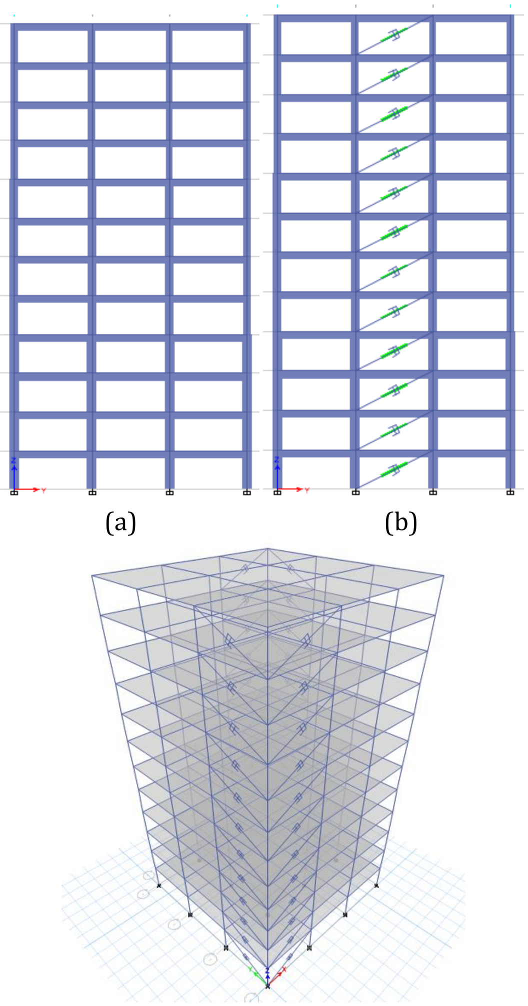
(a) (b)

(c)

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

Fig -4: View of G+7 RCC building with different damper configurations

III. G+11 storey building



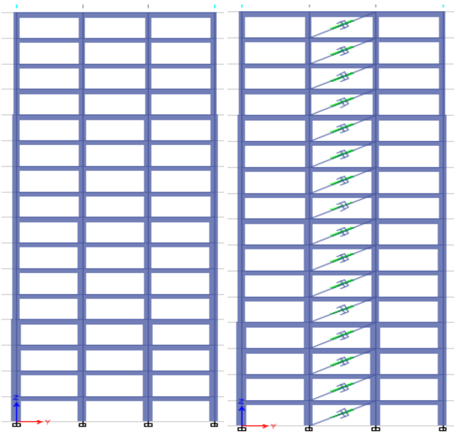
(a) (b)

(C)

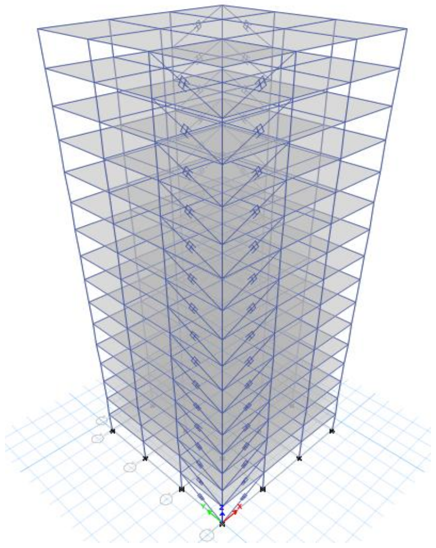
(a) Structure without damper; (b) Structure with damper CONFI-I; (c) Structure with damper CONFI-II

Fig -5: View of G+11 RCC building with different damper configurations

IV. G+15 storey building



(a) (b)



(c)

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

Fig -6: View of G+15 RCC building with different damper configurations

Table -3: RC section details for study frame

Building	Floor	Column(mm)	Beam(mm)
G+3storey	1-2	500x500	230x450
	3-4	450x450	230x450
G+7storey	1-5	650x650	300x500
	6-8	500x500	300x500
G+11 storey	1-4	750x750	300x600
	5-8	650x650	300x600
	9-12	550x550	300x600
G+15 storey	1-4	850x850	300x600
	5-8	750x750	300x600
	9-12	650x650	300x600
	13-16	550x550	300x600

4. SEISMIC ANALYSIS

It is mandatory to accomplish the seismic analysis of a structure to conclude the seismic responses. 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 behaviour of the structure andexternal action, the analysis is further categorized as (i) Linear Static Analysis, (ii) Nonlinear Static analysis, (iii) Linear Dynamic analysis, and (iv) Nonlinear Dynamic analysis.

4.1 Linear Dynamic Analysis (Response Spectrum Method)

The design of the peak or steady-state response of sequential differing natural frequency oscillators that are forced into motion by the same base of vibration is known as response spectrum. The derived design is then used to choose the response of any linear system, given its natural frequency of oscillation as in evaluating the peak response of the buildings to the earthquake. Some values of the ground response spectrum can be used in the study of strong ground motion for the correlation with the seismic damage. The steady-state result is recorded, if the input used in calculating a response spectrum is steady-state periodic.

The response will be infinite if damping is not present. The peak response is recorded for temporary input such as seismic ground motion. Some level of damping is usually assumed, but the value must be taken even with no damping. Response spectra can also be employed in evaluating the response of linear systems with multiple modes of oscillation. However, they are majorly accurate for low levels of damping.

5. RESULTS AND DISCUSSION

The Linear Dynamic Analysis was performed on a set of models for special moment resisting frame models of G+3, 7, 11 and 15 stories. Analytical results obtained from the response spectrum method. Using this, an approximate value of the response reduction factor was estimated.

Table -4: Response reduction factor for G+3 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 G+7 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

	G+11 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

	G+15 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 and 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

6. CONCLUSIONS

Following are the conclusions of the study:

1. It is observed that implementation of viscous dampers reduce the storey displacement, drift, acceleration occurred in RCC building and increases the base shear capacity.

2. R factors computed are highly dependent on the height of building, viscous damper capacity and the input ground motion.

3. Buildings with dampers can resist more lateral loads compared to building without damper at nearly same displacement.

4. It is observed that ductility factor is increased in building with dampers.

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.

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