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Response Modification Factor of Steel Frames with and Without Dampers

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Abstract: ***Response modification factor (R) performs as one of the main seismic design parameters of new structures during earthquake and is considered as significant parameter of nonlinear equivalent static analysis which is a widely used method to evaluate the seismic response of a structure. A review of the literature illustrates that although various numerical studies have investigated the effect of viscous dampers on the response modification factor (R), lack of experimental study has been conducted to verify the numerical models. This study evaluates the response modification factor of steel frame with and without viscous damper. Experimental and numerical analysis have been conducted in the present research. It is found that results from finite element analysis agree well with the experimental results. Besides, the use of damper increases significantly the response modification factors of steel structures, e.g., the factor of structures with dampers are approximate 32% higher than the structures without dampers. The determined response modification factors for the different structures used in this study can be applied to conduct equivalent static analysis of buildings as an initial design stage.***

Keywords**:** ***seismic response; viscous damper; response modification factor, steel structures.***

I. INTRODUCTION

Natural disasters occur worldwide and, among them, earthquakes are considered the most destructive as they leave severe social and economic impacts. One method to calculate the seismic response of structures is equivalent lateral force analysis. This approach is implemented by determining various factors i.e. the response modification factor (R), the importance factor, and the seismic zone factor. The R has been proposed for over strength, whereas the others are critical for structural systems at displacements exceeding the initial yield to obtain the ultimate load displacement of such systems. The thought of the R was proposed based on the assumption that well-detailed seismic framing systems could develop lateral strength beyond their design strength and could bear large deformations without collapsing [1].

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The response modification factor, together with several major assumptions and experiences, was proposed by the Applied Technology Council (ATC) [2] as follow:

$$R = R_S \,.\, R_\mu \,.\, R_R \qquad (1)$$

where

R_S is the over strength factor and defined as follow:

$$R_s = \frac{V_y}{V_d} \qquad (2)$$

Here, V_y and V_d are yield strength and design strength of the lateral force resisting system

R_μ is the ductility factor which is the ratio between lateral yield strength (Fy) at specific displacement ductility ratios (μ) as follow:

$$R\mu = \frac{Fy(\mu=1)}{Fy(\mu=\mu_i)} \qquad (3)$$

R_R is the redundancy factor which is considered based on the line of vertical seismic frame and usually is set as 1.

The R has been investigated by Andalib et al. [3]; and Hanson et al. [4], mainly concentrated on displacement responses. The propositions of Newmark [5] were applied to FEMA [1], UBC [6], ATC-40 [7], the Structural Engineers Association of California [8] and the International Building Code (IBC) [9] to design structural buildings with seismic isolation and passive energy dissipation systems. Abdi et al. [10, 11] studied the R of steel structures with viscous dampers and their effects on soft floor levels and R. The results indicated that the R of steel structures with dampers were greater than steel structures without dampers. Patil and Jangid [12] investigated the response of a 76-story benchmark building under across-wind loads. Miyamoto et al. [13] studied the collapse risk of tall steel moment-frame buildings (10-, 20-, 30-, and 40-story models) with viscous dampers subjected to severe earthquakes. The analysis showed that during extreme seismic events, the design exhibited satisfactory performance. Significant improvements were observed in reducing collapse hazard through an increased damper safety factor. Abdollahzadeh and Kambakhsh [14] studied the effect of height on the R of open chevron eccentrically braced frames. They found that increasing the height of the frame resulted in a relatively fixed R of the consequence of over strength. When frame height is increased, the R of the consequence of ductility is decreased. Lastly, when the height of the building is increased, the R of the frame based on the allowable stress design method is decreased. Zahid et al. [15] investigated the over strength factor of RC frames designed based on Euro codes (ECs), such as EC2 and EC8. They concluded that the geometry and ductility of the frames affected the over strength factor.

Seismic over strength in the braced frames of modular steel buildings (MSBs) was studied by Youssef and Naggar [16-18]. The results illustrated that height of systems affected the response modification factor.

A review of the literature illustrates that although several numerical studies have investigated the effect of viscous dampers on the response modification factor (R), lack of experimental study has been conducted to verify the numerical models. The current study aims to investigate the effects of viscous dampers on the response modification factor (R) of structures with viscous dampers. Numerical and experimental studies were performed to analyze steel structures with and without viscous dampers.

II. NUMERICAL ANALYSIS

A numerical model for evaluating the response modification factor is developed using finite element software (SAP2000). Single bay steel frames (height and width of 1m) is modeled in SAP2000 as shown in Figure 1. The distribution of loads was described as 4 kN/m2 dead load and 5 kN/m2 live load for each floor. Other parameters, i.e., a seismic zone factor of Z = 0.15, an importance factor of I = 1.25, soil type II, a response modification factor of R = 5.6, a seismic coefficients of C_V = 0.5, and C_a = 0.3, were considered according to IBC [9].

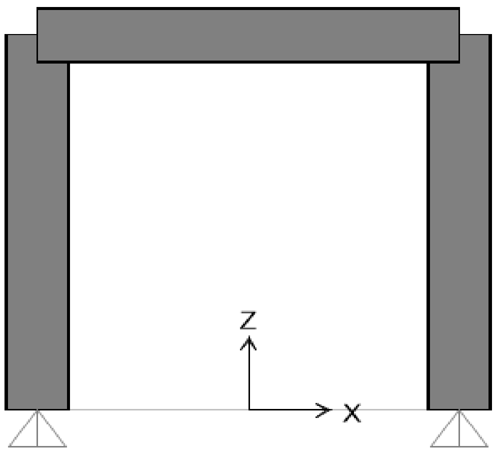

Figure 1. Steel frame modeled in SAP2000.

Figure 2 illustrates the load–displacement curves of the numerical models showing 33.15 % increase in response modification factor after adding a damper to the frame (Table 1).

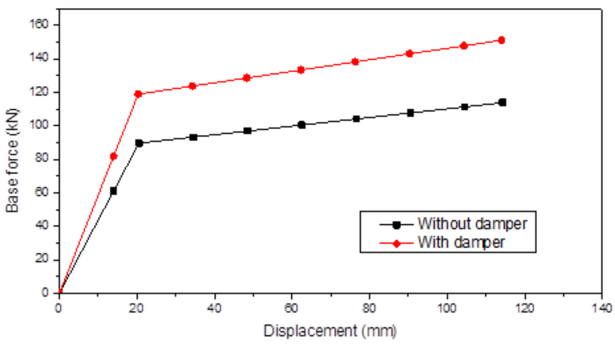

Figure 2. Numerical load–displacement results for the steel frames.

Table 1 Response modification factor for the numerical test

Numerical	V_0 (kN)	Δ_v (mm)	Δ_m (mm)	R	Diff
Without damper	89.73	20.54	114.3	18.64	-
With damper	119.1	20.35	114.1	24.82	33.15 %

III. EXPERIMENT

Table 2: Properties of the experimental steel members

Designation Size	(mm)	W6 (152×76)
Unit Weight	(Kg/m)	13.4
Length of beam and column	(mm)	1000
Depth of Beam	(mm)	150
Width of Beam	(mm)	75
Flange Thickness	(mm)	7
Web Thickness	(mm)	5
Root Radios	(mm)	8

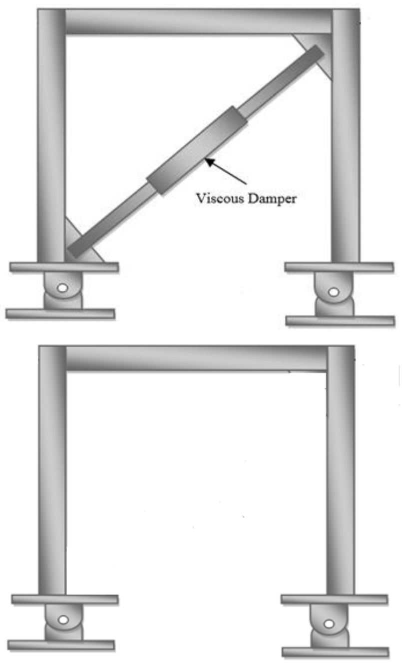

Figure 3. Schematic assembly of the experimental test.

Two frames with and without a viscous damper are tested. Schematics assembly of the experimental test are shown in Figure 3. The selected sections for the experimental steel frame are presented in Table 2. Ultimate tensile strength of 355 MPa and Elastic modulus of 200,000 MPa considered for steel member properties. The viscous damper model VANETTE (A1) from KYB Corporation (Tokyo, Japan) was used for experimental testing. The extension force of the implemented viscous damper was 1.092 kN at a velocity of 0.3 m/s and 1.402 kN at a velocity of 0.6 m/s. Moreover, the compression forces were 765 kN and 1079 kN at a velocity values of 0.3 m/s and 0.6 m/s, respectively.

The damping coefficient was 35 kN/(m/s), and the weight of the damper was 6.8 kg.The results are presented in Figure 4 and Table 3 The response modification factors of the frame with and without a damper were 26.1 and 19.82, respectively, indicating 31.7% increase in value of the response modification factor when viscous damper was used.

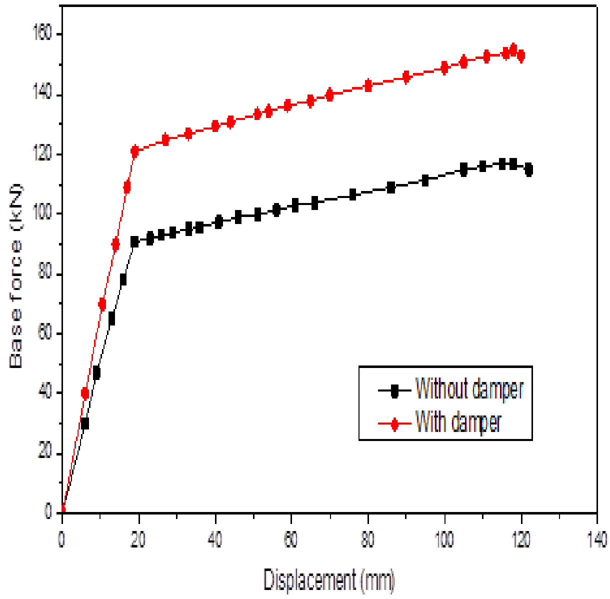

Figure 4. Experimental load–displacement result for the steel frames.

Table 3 Response modification factor (R) for the experimental test.

Experimental	V_0 (kN)	Δ_y (mm)	Δ_m (mm)	R	Diff
Without damper	91	19	118	19.82	-
With damper	121	19.5	118.1	26.1	31.7%

*V_0: Design base shear; Δ_y: Displacement of roof at yield stage; Δ_m: Maximum displacement; Diff: Different in compare to frame without damper

IV. COMPARISON AND DISCUSSION

Figure 5 presents the load–displacement curves of the different models determined by experimental and numerical analyses. Increments in the damping coefficient increase the base force and capacity of a model. Therefore, the obtained values of the response modification factor were higher than those of the codes. The difference in the pushover results may not only be attributed to loading on the frame but also to other factors that may affect the frames, such as the following:

i) The support condition in modelling is considered fully pinned. However, in the real testing, the friction is effect on the performance of pinned connection.

ii) The load increment and speed in the numerical testing may differ from those in the experimental testing.

iii) The joints in the numerical model are considered a tie. In a real steel frame, however, welding may not be performed as a perfect tie.

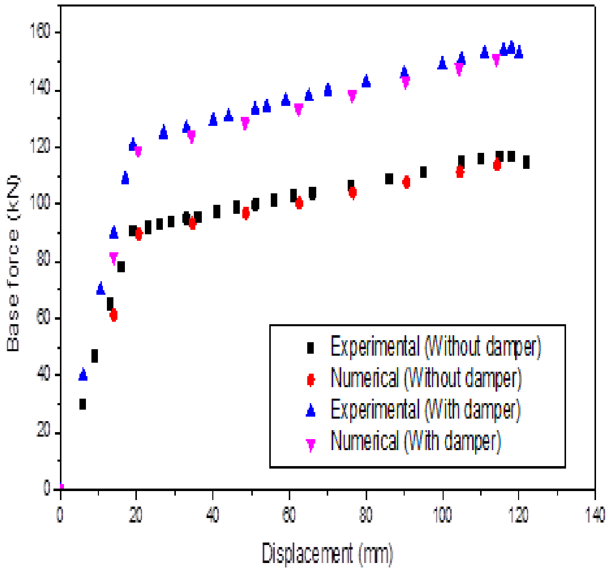

Figure 5. Load–displacement result

Table 4 Increase in the damped frame compared with the bare frame.

Model	R factor from numerical analysis (RN)		R factor from experimental test (RE)		Diff RN & RE
	R	%	R	%	%
Bare frame	18.64	–	19.82	–	
Frame with damper	24.82	33.15%	26.1	31.7%	1.45

Table 4 shows the increasing trend of damper implementation in the bare frame calculated from the numerical and experimental tests. The difference between the numerical and experimental test results for the frame with a damper decreased by 1.45%.

V. CONCLUSION

The effect of viscous dampers on the response modification factor (R) has been investigated. It is found that results from finite element analysis agree well with the experimental results. Furthermore, the numerical and experimental test results indicated that using a viscous damper effectively increased the performance of structures under lateral load. The effect of a damper on structure response to displacement and base shear increased the response modification factor compared with that of the bare frame by approximately 31.7% and 33.15% in the numerical and experimental test results, respectively. The aforementioned results show that installing viscous dampers in structures can be considered an effective solution to increase vibration energy dissipation in structures. The determined response modification factors for the different structures used in this study can be applied to conduct equivalent static analysis of buildings as an initial design stage.

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