Analitical study of viscous damper parameters at a simple reinforced concrete frame

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Abstract. The energy dissipation process in the structure is caused by the earthquake load can be done by using bracing, base isolation and damper system. Damper is a device that is able to transform one form of energy into another form of energy. When a structure is experiencing vibration then the damper system can transform the energy from mechanical energy to other forms of energy. Viscous damper gives the damper force highly determined by the damping coefficient and relative velocity. In determining the capacity of the viscous damper is strongly influenced by several parameters of the damper consisting of the period of natural structure (T), damping coefficient (C), stiffness (K), relative velocity (V), and relative velocity coefficient (α). So that viscous dampers can reduce enormous earthquake energy significantly. In this paper, by using ground motion of Imperial Valley, the largest of damper force results obtained is 5.062 kN at $T=0.128$ s and $\alpha=0.1$, the smallest of story drift results obtained is 0.087 mm at $T=0.128$ s and $\alpha=0.1$, and the largest of relative velocity results obtained is 107.6 mm/sec at $T=0.621$ s and $\alpha=1.5$.

1 Introduction

An earthquake can cause damage to the structure, the loss of the people and cause damage to the natural surroundings. Analyze the earthquake load is an important step in the anticipation of the effects of earthquake hazard to the structure of the building. To avoid earthquake hazard to the structure of them by doing the process of planning a structure that is able to dissipate the energy of the earthquake that occurred on the structure.

The process of energy dissipation load posed by the earthquake can be done by using bracing, base isolation system and damper. Damper system is a device that is able to transform one form of energy into another form of energy. When a structure is experiencing vibration then the damper system can transform the energy of mechanical energy form into other forms of energy.

Viscous damper is one of damper system controlled passively, so in the process of treatment requires a relatively cheaper cost compared to a system with actively controlled damper. Some technical problems on the structure can be handled with the use of viscous damper is mainly in dissipate energy that occurs due to earthquake loads that occur in the structure. In this study analyzed a variety of a viscous damper parameters so

that it can be analyzed the capacity of viscous damper to suit the needs of the structure in the field.

2 Review of Literature

Damping function to reduce or stop the vibration. Improved performance of the structure can be done by centralizing position of damper and optimize the position of the damper on the top floor (Balkanloua et al, 2013).

Trevor E Kelly S.E. (2001), viscous damper can affect the behavior of the dynamic structure, the higher the damping ratio of the damper system, the lower the dynamic response of structure in engineering structures, attenuation can be defined as an inherent material property which tend to impede movement.

The viscous damper's effectiveness can reduce relative displacement and base shear as the dynamic response of the structure (R. Purasinghe and G. Ranganathan, 2016).

2.1 Dash Pot

2.1.1 Linear Elastic Dash Pot

The explanation of material response of dash pot filling of cylinders with piston form viscous liquids. Strain is

achieved by means of piston movement through fluid. In this case the response of dash pot with a value of strains comparable to stress:

$$\varepsilon = \frac{1}{\eta} \sigma \quad (6)$$

η is the viscosity of the material. The greater the stress, the greater the strain.

Fig. 1. Dash pot linear elastic
(homepages.engineering.auckland.ac.nz)

Strain caused the initial load of σ_0 can be obtained by integrating the equation 2. The initial stretch of assuming zero obtained:

$$\varepsilon = \frac{\sigma_0}{\eta} t \quad (2)$$

Strain increases linearly and without bound as long as strength is constantly improved

2.1.2 Non Linear Elastic Dash Pot

As for a more realistic material response can be achieved using non-linear models. The spring equation shows the relationship of the strength-non-linear strain spelled out as follows:

$$\sigma = E\varepsilon^n \quad (3)$$

Non-linear equations for the dash pot can be explained as follows:

$$\sigma = A\varepsilon^n \dot{\varepsilon}, \quad \sigma = Ae^{-\varepsilon/\varepsilon_0} \dot{\varepsilon} \quad (4)$$

Non linear modelling will result in non-linear differential equation which will be more difficult to compare linear equations.

2.2 Analysis Of Viscous Damper Parameters

For multi-story buildings with viscous dampers mounted at the top of the building, it is necessary to do numerical ones whose accuracy is first verified against a closed-form solution of a simple model (Y.T. Chen and Y.H, 2008).

Stiffness of viscous damper is considered a spring stiffness and a non-linear analysis is performed in which the spring-reducing series model is performed together, (Balkanloua et al, 2013)

$$\frac{C}{K} \leq 0.01 \times 10^{-2} \quad (5)$$

The force-velocity relationship of the non-linear damper is given by:

$$F = C.V^\alpha \quad (1)$$

C : damping coefficient

V : relative velocity

α : relative velocity coefficient

This relationship is graphically depicted below:

Fig. 2. The relationship of force and velocity on the damper system viscous damper
(Douce_Hydro_Jarret_Viscous, 2012)

Fig. 3. Detail of Viscous Damper
(Fabio Pratesi, et al 2014)

In the equation (6) and figure 2, F is the damper force of viscous damper, C is the damping coefficient, V represents the relative velocity of the viscous damper and α is relative velocity coefficient α determines the relationship between damper force and relative velocity. Relative velocity coefficient takes value between 0 and 1, linear viscous for $\alpha=1$ and non-linear viscous damper for $0 < \alpha < 1$.

Equations of motion for the MDOF (Multi Degree of Freedom) structures that are subjected to excitation loads in the form of earthquake load time history with additional energy dissipation devices can be written as follows:

$$M\ddot{\mathbf{x}}(t) + (C + C_v)\dot{\mathbf{x}}(t) + K\mathbf{x}(t) = -M\mathbf{r}\ddot{\mathbf{x}}_g(t) \quad (7)$$

M_s : mass $n \times n$

K_s : structure stiffness matrix

C : matrix of damping coefficient

C_v : matrix of the added viscous damping

$\ddot{\mathbf{x}}_g(t)$: horizontal acceleration of ground motion

$\mathbf{x}(t)$: displacement matrix

$\dot{\mathbf{x}}(t)$: velocity matrix

$\ddot{\mathbf{x}}(t)$: acceleration matrix

$\mathbf{r}$: the influence vector

3 Research Methods

This research was conducted at simulated using damper in a way takes into account the values of C and K are calculated based on the value of bracing force (F), the relative velocity (V) and the value of the relative velocity coefficient (α). Furthermore the values of C and K input into the software SAP 2000 as another form of a damper parameters analyzed. Variation of parameters C and K are based on a percentage of 0%, 20%, 40%, 60%, 80% and 100% versus bracing (F) force. To calculate the various of bracing force, structural analysis based on 3 (three) of ground motion records obtained from the web site Peer Barkeley can be explained as follows:

(a) Imperial Valley

(a) Kobe

(c) Northridge

Fig. 4. Three of ground motion records obtained from the web site <https://ngawest2.berkeley.edu>

Fig. 5. The relationship of contraction with pseudo spectral acceleration on ground motion

Fig. 6. Type of frame structure

Column element = 4.00 m
Beam element = 4.00m
Bracing element = 5.66 m

Spectrum of ground motion affect the magnitude of the relative velocity and bracing force. Determination of the magnitude of the relative velocity and bracing force will have an effect on the determination of the value of the K and C based on a formula $F = CV^\alpha$ where the ratio $K/C = 10000$. Determination of the relative velocity values based on the frame without bracing whereas the determination of the value of the bracing forced is based on the force of the frame with bracing.

From the result of structural analysis with SAP 2000 obtained in table 1 and table 2.

Table 1. The natural period of the structure of the frame without bracing

No.	Dimension	Period (T) (sec)
1	Column = 25x25 cm Beam = 25x15 cm	Mode 1=0.1284 Mode 2= 0.0062
2	Column = 20x17.5 cm Beam = 17.5x17.5 cm	Mode 1= 0.225184 Mode 2=0.008604
3	Column = 17.5x12.5 cm Beam = 12.5x12.5 cm	Mode 1= 0.407571 Mode 2= 0.011742
4	Column = 10x10 cm Beam = 15x10 cm	Mode 1= 0.620628 Mode 2= 0.014505

Table 2. The natural period of the structure of frames with bracing

No.	Dimension	Period (T) (sec)
1	Column = 25x25 cm Beam = 25x15 cm Bracing = 10x10 cm	Mode 1= 0.03704 Mode 2= 0.0062
2	Column = 20x17.5 cm Beam = 17.5x17.5 cm Bracing = 10x10 cm	Mode 1= 0.038094 Mode 2= 0.08604
3	Column = 17.5x12.5 cm Beam = 12.5x12.5 cm Bracing = 10x10 cm	Mode 1= 0.039736 Mode 2= 0.011742
4	Column = 10x10 cm Beam = 15x10 cm Bracing = 10x10 cm	Mode 1= 0.041928 Mode 2= 0.014505

Table 3 and Figure 7 describe the relationship between the natural period of the structure with the relative velocity of frame structure without bracing on the ground motion of the Imperial Valley, Kobe and Northridge

Table 3. The natural period of the structure with the relative velocity of frame structure without bracing

No.	Ground Motion	$V_{relative}$ (m/sec)			
		Natural Period (T)			
		0.128	0.225	0.408	0.621
1	Imperial Valley	0.03170	0.0309	0.0961	0.1389
2	Kobe, Japan	0.0095	0.0319	0.1251	0.1655
3	Northridge	0.015	0.0299	0.075	0.0817

Fig. 7. Relationship with the relative velocity of natural period of the structure without bracing

Table 4 and Figure 8 describe the relationship between the natural period of the structure with the bracing force on frame structure using the bracing on the ground motion of the Imperial Valley, Kobe and Northridge.

Table 4. The natural period of the structure with the bracing force on frame structure using bracing.

No.	Ground Motion	Bracing Force (kN)			
		Natural Period (T)			
		0.037	0.038	0.040	0.042
1	Imperial Valley	8.306	8.227	7.645	7.572
2	Kobe, Japan	6.995	7.092	6.713	6.144
3	Northridge	5.671	5.56	5.58	5.87

Fig. 8. The relationship of the natural period of the structure of bracing force using bracing

Besides the analysis of the parameters of the damper varied also against three (3) ground motion, four (4) natural period of structure (T) and 7 (seven) the value of the relative velocity coefficient (α). On the study of natural period of structure (T1) vary with the value of 0.12840, 0.22518, 0.40757 and 0.62063 s. While the value of the relative velocity coefficient (α) varies with the value of 0.1, 0.25, 0.50, 0.75, 1.00, 1.50 and 1.25.

4 Results and Discussion

Furthermore, to analyze the characteristics of damper used the ground motion Imperial Valley will be input into SAP 2000 program.

This ground motion based on this value has a relative velocity which is located between ground motion Kobe and Northridge as described in the table 3 and figure 7. Table 5 describes an example of calculating the values of C and K based on the magnitude of the bracing force that occurs.

Table 5. Examples of calculating values of C and K at $T=0.1284$ s

	F_{bracing}	8.306	kN
	F	$= CV^\alpha$	kN
	α	1.5	
	V =	0.03170	m/det
	C	$= F/V^\alpha$	kN/(m/det)
% F bracing	F_{bracing}	C	K
100%	8.31	1471.64	14716449.13
80%	6.64	1177.32	11773159.30
60%	4.98	882.99	8829869.48
40%	3.32	588.66	5886579.65
20%	1.66	294.33	2943289.83
0%	0.00	0.00	0.00

Furthermore the value of C and K is input into SAP 2000 program. Based on the result of structural analysis using SAP 2000, the graph of the relationship between viscous damper parameters including damper force, story drift, relative velocity and relative velocity coefficient as described in Figure 9 through Figure 32.

Fig. 9. Graph of the Relationship bracing force versus the percentage of output bracing force at $T1 = 0.1284$ s

Fig. 10. Graph the relationship bracing force versus the percentage of output bracing force at $T1 = 0.2252$ s

Fig.11. Graph of the relationship bracing force versus the percentage of output bracing force at $T_1 = 0.4076$ s

Fig. 13. Graph of the relationship bracing force versus story drift at $T_1 = 0.1284$ s

Fig. 12. Graph of the relationship bracing force versus the percentage of output bracing force at $T_1 = 0.6206$ s

Fig. 14. Graph of the relationship bracing force versus story drift at $T_1 = 0.2252$ s

In Figure 9, 10, 11 and Figure 12 explained the relationship between the parameters C and K which are explained in the form of a percentage of the bracing force of the magnitude of 0%, 20%, 40%, 60%, 80% and 100% with an output force damper as a result of analysis of structures with SAP 2000.

The relationship between the parameters C and K are explained in the form of a percentage of the bracing force of the magnitude of 0%, 20%, 40%, 60%, 80% and 100% with an output story drift and relative velocity is explained In Figure 13, 14, 15, 16,17,18,19 and Figure 20.

Fig. 15. Graph of the relationship bracing force versus story drift at $T_1 = 0.4076$ s

Fig. 16. Graph of the relationship bracing force versus story drift at $T_1 = 0.6206$ s

Fig. 19. Graph of the relationship bracing force versus relative velocity at $T_1 = 0.4076$ s

Fig. 17. Graph of the relationship bracing force versus relative velocity at $T_1 = 0.1284$ s

Fig. 20. Graph of the relationship bracing force versus relative velocity at $T_1 = 0.6206$ s

Fig. 18. Graph of the relationship bracing force versus relative velocity at $T_1 = 0.2252$ s

The relationship between the relative velocity coefficient (α) with story drift, damper force and relative velocity is explained in Figure 21 through 32.

Fig. 21. Graph of the relationship story drift versus relative velocity coefficient at $T_1 = 0.1284$ s

Fig. 22. Graph of the relationship story drift versus relative velocity coefficient at $T_1 = 0.2252$ s

Fig. 25. Graph of the relationship bracing force versus relative velocity coefficient at $T_1 = 0.1284$ s

Fig. 23. Graph of the relationship story drift versus relative velocity coefficient at $T_1 = 0.4076$ s

Fig. 26. Graph of the relationship bracing force versus relative velocity coefficient at $T_1 = 0.2252$ s

Fig. 24. Graph of the relationship story drift versus relative velocity coefficient at $T_1 = 0.6206$ s

Fig. 27. Graph of the relationship in bracing force versus relative velocity coefficient at $T_1 = 0.4076$ s

Fig. 28. Graph of the relationship bracing force versus relative velocity coefficient at $T_1 = 0.6206$ s

Fig/ 31. Graph of the relationship in relative velocity versus relative velocity coefficient at $T_1 = 0.4076$ s

Fig. 29. Graph of the relationship in relative velocity versus relative velocity coefficient at $T_1 = 0.1284$ s

Fig. 32. Graph of the relationship in relative velocity versus relative velocity coefficient at $T_1 = 0.6206$ s

Fig. 30. Graph of the relationship in relative velocity versus relative velocity coefficient at $T_1 = 0.2252$ s

With a combination of damper force (F), natural period (T), damping coefficient (C), stiffness (K), relative velocity (V) and relative velocity coefficient (α) by using ground motion of Imperial Valley, the largest of damper force results obtained are 5.062 kN at $T=0.1284$ s and $\alpha=0.1$, the smallest of story drift results obtained are 0.087 mm at $T=0.1284$ s and $\alpha=0.1$, and the largest of relative velocity results obtained are 107.6 mm/sec at $T=0.6206$ s and $\alpha=1.5$.

5 Conclusion

1. Study the parameters of the damper gives a range of information to ground motion, the natural period of the structure frame and the value of the relative velocity coefficient (α) that can be used as a guide in planning the damper on the elements of a simple frame structure building in particular and the complex building.
2. Variation in percentage of the value of C and K that is the embodiment of bracing force percentage gives the value of the output values approach force of damper that occurs in the structure of the frame so that the capacity of the viscous damper which can be predicted since the early stages of planning the structure of the frame.

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