Challenges, Opportunities and Solutions in Structural Engineering and Construction – Ghafoori (ed.)
© 2010 Taylor & Francis Group, London, ISBN 978-0-415-56809-8

Application of nonlinear damper in reinforced concrete structure control

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ABSTRACT: The application of modern control techniques to diminish the effects of seismic loads on building structures offers an appealing alternative to traditional earthquake resistant design approaches. Over the past decade there has been significant research conducted on the use of damper devices for dissipating seismic energy. This paper describes the development of a numerical finite element algorithm used for analysis of reinforced concrete structure equipped with shakes energy absorbing device subjected to dynamic load such as earthquake. For this purpose a new nonlinear viscose damper is proposed and a finite element program code for analysis of reinforced concrete frame buildings is developed. The effect of proposed damper is evaluated by implementation in a simple model of reinforced concrete frame building. The results show that using new proposed damper as seismic energy dissipation system effectively reduced structural response in earthquake excitation.

1 INTRODUCTION

The traditional approach to design earthquake resistance building is providing adequate strength and stiffness against lateral forces. Alternatively, latest concepts of earthquake energy dissipation system and damper device have been devoted via advance technology and techniques to reduce earthquake effect and preclude seismic damage of buildings.

Recently many investigations have been conducted to evaluate and analyze the seismic response of structures equipped different types of damper. Viscous dampers are known as effective energy dissipation devices improving structural response to earthquakes. The damping force developed by the viscous damper depends on the physical properties of the fluid used in the device (Constantinou & Symans 1992). So energy dissipation due to sloshing liquid in toms shaped dampers is studied analytically accounting for nonlinearities and viscous effects so as to be applicable at resonance (Modi et al. 1990).

Performance of viscous dampers based on the experimental study carried out on steel frame model, subjected to horizontal and vertical earthquake vibrations with varying intensities (Zhang & Soong 1992).

In the other hands, the role of viscous damping in preventing buildings from collapse during intense earthquake ground motion was extensively investigated by using numerical modeling (Soda 1996). The result of application of viscous dampers to structures are shown by analyzing of few structures equipped energy dissipation devices and demonstrated their advantages and disadvantages (Tezcan & Uluca 2003).

Examining the performance of application viscous dampers with other various type of dampers for control of structures (Hybrid systems) are conducted in many investigations to obtain a good compromise of energy dissipation systems combination (Yang & Agrawal 2002).

It is clear from critical literatures review that most of the investigators employed the finite element techniques for the purpose of idealization under plane strain idealization (Bouaanani & Lu 2008; Martinez-Rodrigo & Romero 2003; Sekulovic et al. 2002).

So far little or no information is available about three dimensional formulation framed structures, equipped with damper element. Hence there is need to improving upon physical and constitutive modeling of reinforced framed building equipped with viscous dampers. Hence in the present work a new three dimensional nonlinear viscous damper is formulated and it is applicable in reinforced concrete structures.

Then the proposed damper is applied to one story example of reinforced concrete framed buildings subjected to earthquake and seismic response of model is investigated.

2 PROPOSED FINITE ELEMENT MODELLING OF FRAMED STRUCTURE EQUIPPED WITH ENERGY DISSIPATION SYSTEM

The following elements have been used for the purpose of finite element idealization of reinforced concrete framed buildings equipped with viscous dampers:

2.1 *Beam column element*

In this study, a two node, three dimensional beam-column element having two rigid ends of different lengths for simulating the finite widths of the beam-column connection as shown in Figure 1 (Thanoon et al. 2004).

So the stiffness matrix of this element that derived using bending theory for small transverse displacements is and coefficients of this matrix are calculated using the following equation:

$$k_{rs} = \int_0^L EI(x)\psi_r(x)\psi_s(x)dx \tag{1}$$

where L is the member length, EI is the flexural rigidity of the member, $\psi_r(x)$ is the displacement function (shape function) along the member resulting from unit displacement along the rth degree of freedom ($ur = 1$), and $\psi_s(x)$ is the shape function when ($us = 1$) is impressed on the member.

For the member with two rigid ends, the stiffness coefficients are obtained in a similar way after modifying the shape function ψ for the member with uniform cross section.

These functions are written choosing the origins different for different segments of the element for convenience.

Stiffness coefficient is now obtained by re-writing equation (1) in the following form:

$$k_{rs} = \int_0^a EI\psi_r(x)\psi_s(x)dx + \int_0^c EI\psi_r(x)\psi_s(x)dx + \int_0^b EI\psi_r(x)\psi_s(x)dx \tag{2}$$

where a and b is length of two rigid block in both end of element and c is length of elastic part as showed in Figure 2.

The stiffness and damping properties of frame element are time dependent and a function of its deformation status and deformation histories, therefore member of stiffness matrix are changed in each time steps of imposing external load.

The beam-column element with two unequal rigid ends in three dimensional is shown in Figure 2. In this study rigid end blocks and plastic zone have zero length.

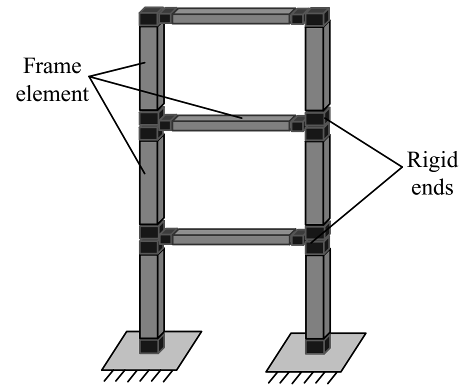

Figure 1. Mathematical model of building structure.

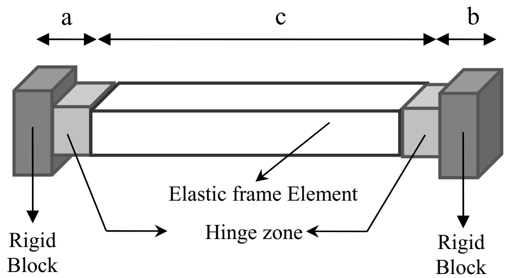

Figure 2. Inelastic modeling of frame member.

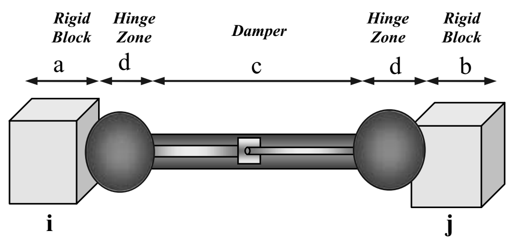

Figure 3. Three dimensional damper element with two plastic hinges at ends.

2.2 *Damper element as energy dissipation device*

Figure 3 shows the viscous damper element proposed in the present study (Hejazi 2008). The first zone is the rigid block zone located at each end of the member. This element also consists of three different zones. The second zone is the 3D plastic hinge zone at each end assumed to have zero length.

The remaining intermediate part of the member represents the third zone which is function of the viscous damper properties. These zones represent the finite width of the damper joints, the inelastic and the elastic properties of the member.

The central part of the member (located between two plastic hinges) is assumed to reflect the elastic behaviour of the member (elastic element), while the plastic hinge zones reflect the inelastic behaviour of the member (inelastic element). Damping coefficient (C_d) for proposed 3-D damper element was calculated using the following relation:

$$C_d = \int_0^L \bar{C}_d(\dot{x})\psi_r(x)\psi_s(x)dx \quad (3)$$

where L is the member length, $\bar{C}_d$ is the damper damping constant coefficient, $\psi_r(x)$ and $\psi_s(x)$ is the shape functions as defined before.

So, by expanding of equation (3) for three different zones of damper element, damping coefficient is now obtained in the following form:

$$C_d = \int_0^a \bar{C}_d(\dot{x})\psi_r(x)\psi_s(x)dx + \int_0^c \bar{C}_d(\dot{x})\psi_r(x)\psi_s(x)dx + \int_0^b \bar{C}_d(\dot{x})\psi_r(x)\psi_s(x)dx \quad (4)$$

Similar to the beam-column element, a and b is length of two rigid block in both end of element and c is length of damper part as showed in Figure 3.

If the relative velocity between two floors where damper installed intermediate of them in time (t) of earthquake excitation is denoted as $\dot{x}(t)$, then a linear viscous damper force in corresponding time is calculated with this equation (Chart & Wong 2000):

$$F_d(t) = C_d\dot{x}(t) \quad (5)$$

where F_d is linear viscous damper force and it is used in equation of motion. With the availability of high-technology manufactured dampers, the structural engineer has the freedom of imposing additional damping in the structure by introducing manufactured dampers.

Manufactured dampers that are used in buildings can produce forces that vary linearly with the relative velocities between the ends of the dampers. So the most common damper force design for structural engineering purposes is (Chart & Wong 2000):

$$F_d(t) = C_d \langle\dot{x}(t)\rangle^{\eta} \quad (6)$$

where η is velocity exponential coefficient or power law coefficient of damper and generally it is between 0 to 2. The first generation of manufactured viscous dampers used a power law coefficient equal to one. Structural engineers selected this value of η for design because for η equal to one the manufactured damping force, like the natural damping force, is a linear function of velocity. In the case of $\eta \neq 1$ damper is called nonlinear damper and the force is not linear function of velocity.

Therefore damper damping coefficient ($\bar{C}_d$) and power law coefficient (η) are two foremost effective parameters of damper force. So in the application of proposed damper in some model, effects of these parameters on structures response are evaluated.

3 CONSTITUTIVE MODELING TIME MARCHING SCHEME FOR FRAMED STRUCTURES EQUIPPED DAMPER

In the present study, the stiffness method for structural analysis has been integrated with the finite element method to analyze a building system equipped with damper.

Newmark's direct step-by step integration is used for dynamic analysis. Predictor-corrector method for the solution of the resulting equation of motions in the time domain (Newmark 1959). The equation of motion for an elasto-plastic system equipped control system subjected earthquake load obtained from the consideration of equilibrium of forces is given by:

$$M\ddot{u} + q(u, \dot{u}) = F_c + F_e \quad (7)$$

where q is the vector of internal resisting forces which depends upon the displacement u and velocity $\dot{u}$, M is the mass matrix of the system, $\ddot{u}$ is the acceleration vector, F_c is imposed control force and F_e is the applied earthquake load vector. The internal resisting forces are defined by the stiffness matrix K and damping matrix C and the control force due to viscous damper elements defined in pervious section.

4 DEVELOPMENT OF COMPUTER PROGRAM CODE

The existing finite element code developed by Thanoon (1993) has been extensively modified in view of the proposed physical and material models and adopted computational procedures for carrying out the 2D and 3D analysis of reinforce concrete framed buildings equipped viscous damper devices subjected to static and seismic/dynamic loads. The computer program has been written in Fortran language compatible with power station environment.

5 CALIBRATION OF THE DEVELOPED PROGRAM CODE

In order to verify the accuracy of the developed finite element program code, an example has been analyzed. The verification proceed has been done by employing the commercial package SAP2000 software to analyze the same example. Figure 4 shows the structural and dynamic model for single storey reinforced concrete frame building, the material and section properties are also shown in same figure.

The structure was subjected to an actual earthquake that occurred in Zanjiran-Iran (1985), as depicted in Figure 5.

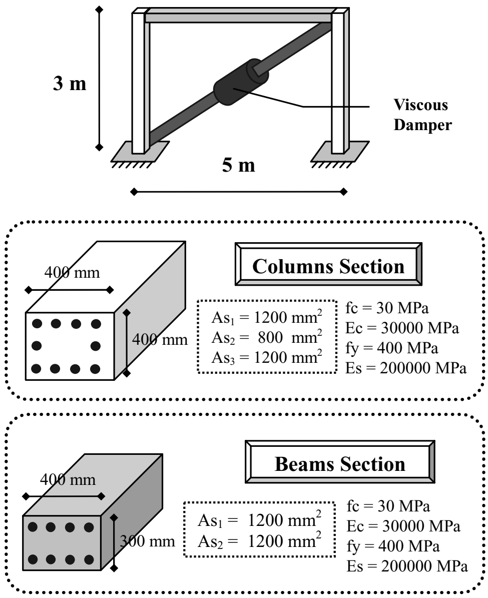

Figure 4. Single storey frame example and sections properties.

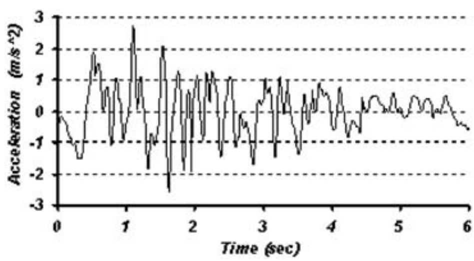

Figure 5. Zanjiran-IRAN (1985) earthquake acceleration record (m/Sec^2).

6 PARAMETRIC STUDY ON EFFECT OF DAMPING

To evaluation, effect of application proposed damper on the structure and analysis of frame buildings by demonstrated computational strategies, a numerical examples have been selected and attempt has been made to analyze the models through developed finite element program code in various viscous damper properties.

A damper element is used as a diagonal member as frame bracing system shape. Figure 6 shows the comparison of the horizontal displacement at the tip of the frame.

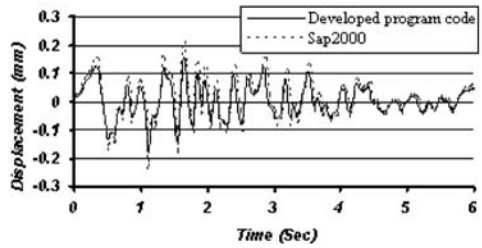

Figure 6. Comparing the results of developed finite element program code and SAP2000 software (displacements of top node in X direction).

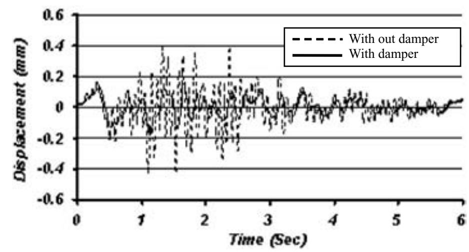

Figure 7. Displacement of top node of single story model in X direction ($\bar{C}_d = 1300$).

It is obvious from this plot that the displacements predicted by proposed model follows a similar trend obtained via commercial package SAP-2000.

6.1 *Example: Single story framed building*

The single story reinforced concrete structure shown in Figure 4 further has been analyzed for the cases of with and without supplemental viscous damper acting under seismic excitation. In this model damper damping coefficient ($\bar{C}_d$) and power law coefficient (η) are assumed equal to 1300 and 1 respectively.

Figure 7 shows the typical time history response of tip deflection of the frame. It is clear from these plots that the magnitude of the displacement response of the structure to earthquake excitation has been decreased significantly, when the building structure is equipped with damper device compare to those without any energy dissipation system (uncontrolled structure). Considerable reduction in values of displacements is about 75% for the structure analyzed. Also time history displacement of same node in Y direction is shown in Figure 8.

Similar to previous response, using damper in the modeled framed, is effectively reduced structure response in vertical direction though the displacement is very low. In article, it was seen that damping coefficient ($\bar{C}_d$) and power law coefficient (η) are two major parameters on damper force. So effects of

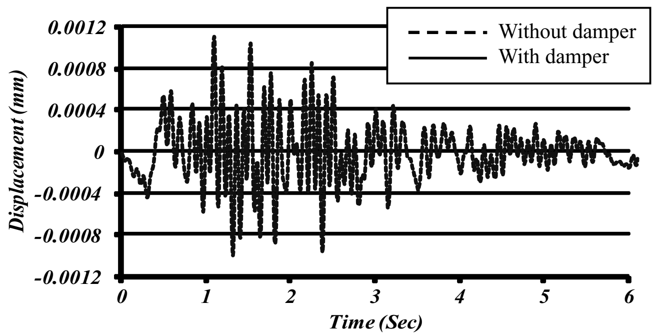

Figure 8. Displacement of top node of single story model in Y direction ($\bar{C}_d = 1300$).

these parameters on response of single story model are evaluated and results are showed in Figure 9. In this figure maximum displacement of top node in X direction during earthquake excitation for various damping coefficient ($c = 0$, $c = 50$, $c = 100$, …, $c = 1300$) and power law coefficient ($\eta = 0$, $\eta = 0.2$, $\eta = 0.4$, …, $\eta = 2$) is plotted. Increasing of damper damping coefficient is lead to enhance of damper damping matrix member's values and finally increase the damper force. Then by increasing the damper force, more values of earthquake force is diminished by this force and therefore the structure response will reduce. As seen in plot, by increasing the damper damping coefficients, response of structure is reduced.

When this coefficient is equal to zero, the damper force be come zero and response of structure is similar of model without damper element. The range of damping coefficient is different in various structures and it is depends on structures properties, imposed earthquake load density and buildings target performance levels.

As seen in Figure 9 in this model, damping coefficient equal to 1300 is most effective on reducing of structures response against earthquake, therefore this coefficient value is suggest for this model.

In the other hand, power law coefficient or damper velocity exponential coefficient, is define the effect of relative velocity between the ends of the dampers with damper force. If this coefficient is equal to one, the damper operation be come linear function of velocity and in other case, damper has nonlinear performance. Whatever this exponential coefficient is increased, effect of velocity on damper force will enhanced and, more part of earthquake energy will dissipate by damper device.

As observed in figure, by increasing of power law, displacement is decreased. It is clear that in case of velocity exponential coefficient equal to 1.4 in range of damping coefficient equal to 500, damper performance is maximum in order to reduce displacement of structure. So these values are optimum values of

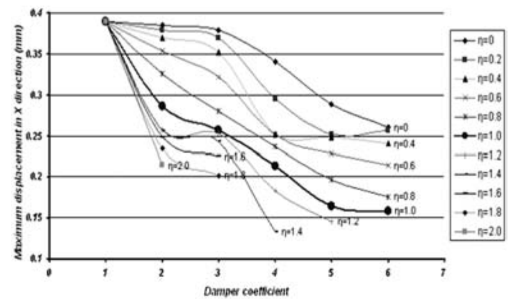

Figure 9. Comparison top node displacement of single story example in X direction with various damper velocity exponential coefficients (η) and damping coefficient ($\bar{C}_d$).

damper parameters to design effective passive control system to dissipate the earthquake energy and reduced structures seismic response.

This type of damper devices can be designed and installed into both new buildings and existing structures. As they are relatively small and inconspicuous, they can be incorporated into a structure without compromising its appearance. So by notice to high performance of dampers device to reducing structural seismic response, this system is suitable technique for rehabilitation and retrofitting of exist buildings.

Hence, as seen through explained example, by evaluation of damper parameters effect on the structures response, the structural design engineers are able to choose suitable damper properties for desire design of structure base on the request performance demand level of building and maximum effect of damper devices to diminish the seismic load.

7 CONCLUSIONS

This paper has reported development of special energy dissipation device for use as the seismic response control dampers for structures innovative from finite element technique. A three dimensional viscous damper element applicable in reinforced concrete structures is proposed and formulated. For this propose a finite element program code for analysis of reinforced concrete structures equipped proposed damper elements is developed. The application of finite element code has been shown by analysis of one story reinforced concrete framed structures with supplemental viscous damper devices. Validation of developed program code is carry out by compare of results with SAP2000 software and it showed the accuracy and admissibility of program.

By comparing seismic responses of structures without energy dissipation system, and structures with proposed viscous damper elements shows that using damper devices effectively reduced structural response subjected to earthquakes. (75% reduction for single story example). Also the optimum design of damper is eligible by evaluation of damper parameters effect on the structures response, and chooses suitable damper properties for desire design of structure base on the request performance demand level of building and maximum effect of damper devices to diminish the seismic load.

ACKNOWLEDGMENT

The research was financially supported by Ministry of Science, Technology and Innovation of Malaysia under Research Project No. 5450366 and gratefully acknowledged.

REFERENCES

Constantinou, M.C. and Symans, M.D. 1992. "Experimental and Analytical Investigation of Seismic Response of Structures with Supplemental Fluid Viscous Dampers". Tech. Rep. NCEER-92-0027, National Center of Earthquake State Univ. of New York (SUNY) at Buffalo N.Y.

Farzad Hejazi. 2009. "Optimization of Earthquake Energy Dissipation in Framed Buildings". PhD Thesis, University Putra Malaysia, Malaysia. (under process).

Chart, G.C. and Wong, K. 2002 "Structural Dynamic for Structureal Engineers". John Wiley & Sons.

Jann N. Yang and Anil K. Agrawal. 2002. "Semi-active hybrid control systems for nonlinear buildings against near-field earthquakes". Journal of Engineering Structures.Vol. 24. p271–280.

Martinez-Rodrigo, M. and Romero, M.L. 2003."An optimum retrofit strategy for moment resisting frames with nonlinear viscous dampers for seismic applications". Journal of Engineering Structures.Vol. 25. p913–925.

Miodrag Sekulovic, Ratko Salatic, and Marija Nefovska. 2002. "Dynamic analysis of steel frames with flexible connections". Journal of Computers and Structures. Vol. 80. p935–955.

Modi, V.J. Welt, F. and Irani, M.B. 1990. "On the suppression of vibrations using nutation dampers". Journal of Wind Engineering and Industrial Aerodynamics.Vol. 33. p273–282.

Najib Bouaanani and Fei Ying Lu. 2008. "Assessment of potential-based fluid finite elements for seismic analysis of dam-reservoir systems". Journal of Computers and Structures. Article in press.

Newmark, N. 1959. "A method of computation for structural dynamics". Journal of Eng Mech Division ASCE.Vol. 85. p67–94.

Ri-Hui Zhang and Soong, T.T. 1992. "Seismic design of viscoelastic dampers for structural applications". Journal of Structural Engineering.Vol. 118. p1375–1392.

Soda, S. 1996. "Role of viscous damping in nonlinear vibration of buildings exposed to intense ground motion". Journal of Wind Engineering and Industrial Aerodynamics.Vol. 59. p247–264.

Semih S.Tezcan and Ozan Uluca. "Reduction of earthquake response of plane frame buildings by viscoelastic dampers". Journal of Engineering Structures.Vol. 25. 2003. p1755–1761.

Waleed, A. Thanoon, D.K. Paul, M.S. Jaafar, and D.N. Trikha. 2004. "Influence of torsion on the inelastic response of three-dimensional r.c. frames". Journal of Finite Elements in Analysis and Design.Vol. 40. p611–628.

Waleed, A.M. Thanoon. 1993. "Inelastic Dynamic Analysis Of Concrete Frames Under Non-Nuclear Blast Loading". PhD Thesis, University of Roorkee. India.