Earthquake Analysis of Reinforce Concrete Framed Structures with Added Viscous Dampers

F. Hejazi, J. Noorzaei, M. S. Jaafar and A. A. Abang Abdullah

***Abstract*—**This paper describes the development of a numerical finite element algorithm used for the analysis of reinforced concrete structure equipped with shakes energy absorbing device subjected to earthquake excitation.

For this purpose a finite element program code for analysis of reinforced concrete frame buildings is developed. The performance of developed program code is evaluated by analyzing of a reinforced concrete frame buildings model. The results are show that using damper device as seismic energy dissipation system effectively can reduce the structural response of framed structure during earthquake occurrence.

***Keywords*—**Viscous Damper, finite element, program coding

I. Introduction

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.

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. [1]

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. [2], [3]

Also some numerical studies are performed to evaluation influence of structural passive supplemental damping systems on structural and nonstructural seismic fragilities of buildings [4]. Comparison of the fragility on building with and without passive control systems indicated that the viscous dampers are very effective in attenuating seismic structural response. [5]

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Due to the widespread technique for computer simulation and analyzing of structures with supplemental dampers subjected to steady-state excitation is direct integration technique which is generally implemented in finite element method. [6].

In the present study an effort has been made to development of finite element program code for analysis of reinforced concrete frame buildings with supplemented viscous dampers device.

Then application of the developed program code is shown by analysis of a reinforced concrete framed building subjected to earthquake though this program.

II. Proposed Finite Element Modelling

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

A. Beam Column Element

Two nodes, three dimensional beam-column element having two rigid ends of different lengths is used for simulating the finite widths of the beam-column connection as shown in Fig. 1. [7]

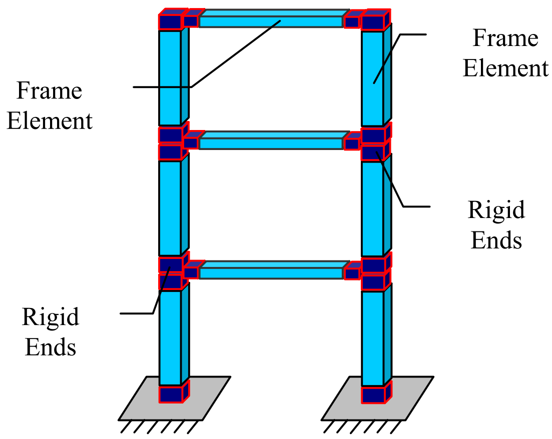

Fig. 1 Mathematical model of building structure

B. Damper Element

The viscous damper element has been has been used in this study as passive energy dissipation system. The finite element model of this damper is shown in Fig. (2). [8]

If the relative velocity between two floors where damper installed intermediate of them in time (t) of earthquake excitation is denoted as, then a linear viscous damper force in corresponding time is calculated with this equation [9]:

$$F_d(t) = C_d \dot{x}(t) \tag{1}$$

Where C_d is the damping matrix of the damper member and F_d is linear viscous damper force and it is used in equation of motion.

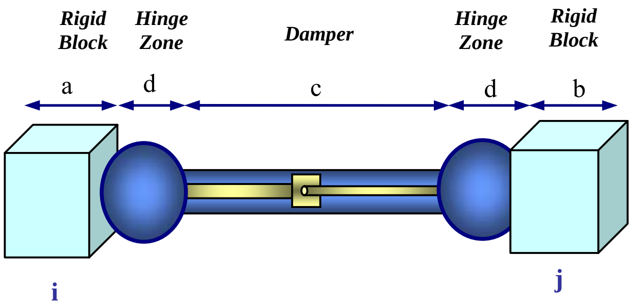

Fig. 2 Three dimensional Damper Element with two plastic hinge at ends

III. Computational Procedures for Time Marching Integration Scheme

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.

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: [10]

$$M\ddot{u} + q(u,\dot{u}) = F_c + F_e \tag{2}$$

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.

In this research Newmark's predictor-corrector computational algorithm has been adopted to solve the equations of motion for the vibrating structural system equipped passive control devices and following relations are defined:

$$M\ddot{u}_{t+\Delta t} + q(u_{t+\Delta t}, \dot{u}_{t+\Delta t}) = F_{c_{t+\Delta t}} + F_{e_{t+\Delta t}} \tag{3}$$

Where $F_{c_{t+\Delta t}}, F_{e_{t+\Delta t}}$ are imposed control force and applied earthquake load vector in time (t+Δt) respectively. Also $u_{t+\Delta t}$ and $\dot{u}_{t+\Delta t}$ are displacement and velocity of system in time of t+Δt. The Newmark's algorithm can be summarized into the following steps [11]:

Step 1. Set iteration counter j = 0.

Step 2. Predict displacements, velocities and accelerations by using past history at the previous time step as:

$$u^j_{t+\Delta t} = \bar{u}_{t+\Delta t} = u_t + \Delta t\dot{u}_t + 0.5(\Delta t)^2(1-2\beta)\ddot{u}_t \tag{9}$$

$$\dot{u}^j_{t+\Delta t} = \bar{\dot{u}}_{t+\Delta t} = \dot{u}_t + \Delta t(1-\gamma)\ddot{u}_t \tag{10}$$

$$\ddot{u}^j_{t+\Delta t} = \left(u^j_{t+\Delta t} - \bar{u}_{t+\Delta t}\right)/\left((\Delta t)^2\beta\right) = 0 \tag{11}$$

Step 3. Evaluate residual forces r^j using the following equations: [12]

$$r^j = \left(F_{d_{t+\Delta t}} + F_{e_{t+\Delta t}}\right) - M\ddot{u}^j_{t+\Delta t} - C^j\dot{u}^j_{t+\Delta t} - Ku^j_{t+\Delta t} \tag{12}$$

Where F_d is viscous damper force where obtained with equation (1). The matrix K is evaluated by considering occurrence of all new events (plastic hinges, cracking, yielding, crushing and separation) in the structure.

Step 4. If required, form the modified effective stiffness matrix using the relation:

$$K^* = M/\left((\Delta t)^2\beta\right) + \gamma C^j/(\Delta t\beta) + K^j \tag{13}$$

Step 5. Solve for the incremental displacements by this equation:

$$K^* du^j = r^j \tag{14}$$

Step 6. Update the displacements, velocities and accelerations as equation (15), (16), (25) corresponding:

$$u^{j+1}_{t+\Delta t} = u^j_{t+\Delta t} + du^j \tag{15}$$

$$\ddot{u}^{j+1}_{t+\Delta t} = \left(u^{j+1}_{t+\Delta t} - \bar{u}_{t+\Delta t}\right)/\left((\Delta t)^2\beta\right) \tag{16}$$

$$\dot{u}^{j+1}_{t+\Delta t} = \dot{u}_{t+\Delta t} + \Delta t\,\gamma\,\ddot{u}^{j+1}_{t+\Delta t} \tag{17}$$

Step 7. If du^j and/or r^j do not satisfy the convergence condition then set j = j + 1 and go to step 3; otherwise continue.

Step 8. Set $u_{t+\Delta t} = u^{j+1}_{t+\Delta t}$, $\dot{u}_{t+\Delta t} = \dot{u}^{j+1}_{t+\Delta t}$, $\ddot{u}_{t+\Delta t} = \ddot{u}^{j+1}_{t+\Delta t}$ for use In the next time step. Also set t = t +Δt to begin the next step.

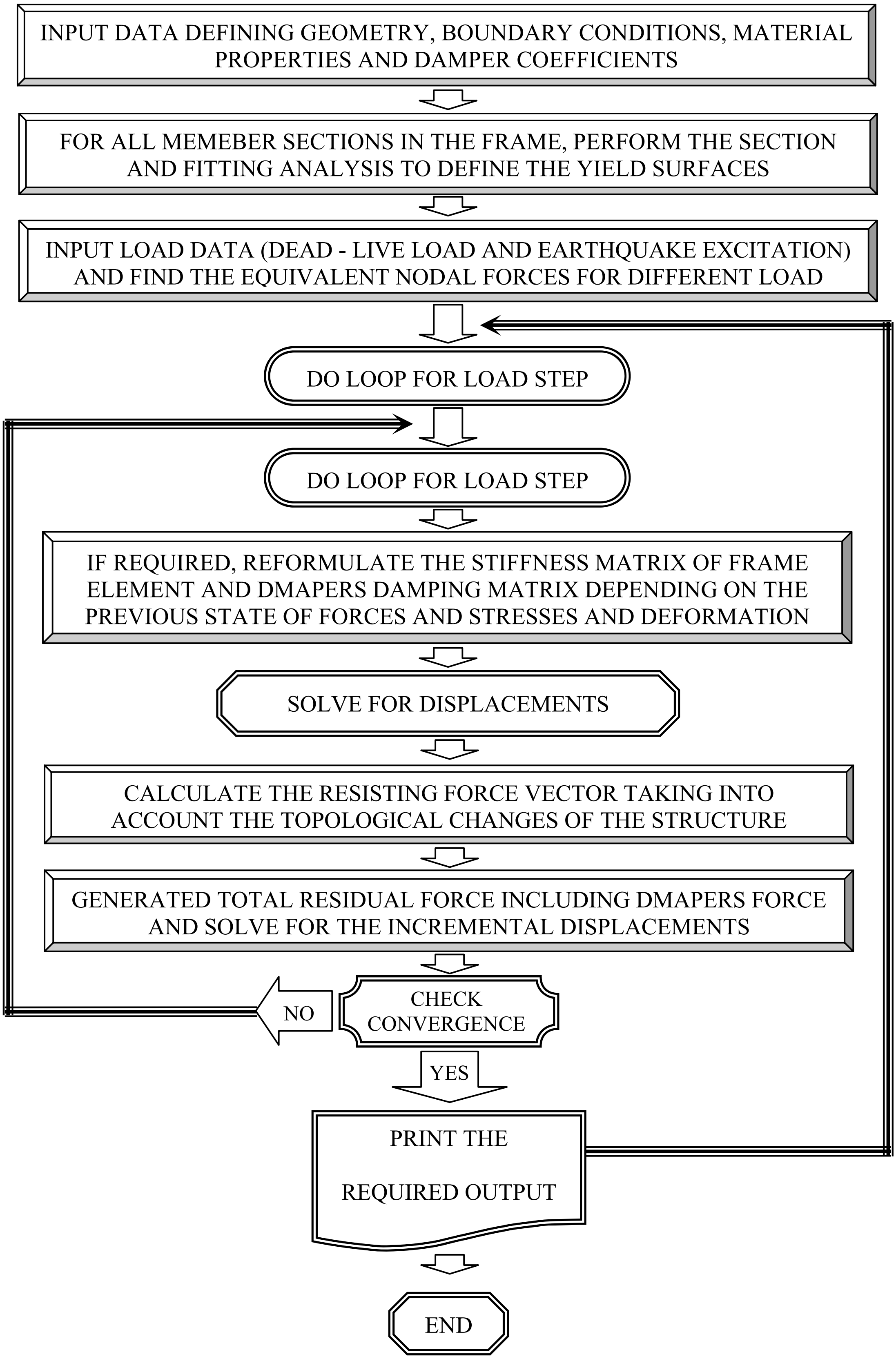

Fig. 3 Flow Chart of developed Finite Element Computer Program Code

IV. Development Of Computer Program Code

The existing finite element code developed by Thanoon [13] has been extensively modified in view of the proposed physical and material constitutive 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. The Procedure and flowchart of the developed finite element code has been illustrated in Fig. 3.

V. Parametric Study On Effect Of Damping

To evaluation, performance of developed program code and analysis of structure equipped passive control systems by demonstrated computational strategies, a three story reinforce concrete framed structure with supplemental viscous damper device where showed in Fig. 4 is chosen to subject with an actual earthquake that occurred in Zanjiran-Iran (1985), as depicted in Fig. 5.

VI. Results And Disscusion

Figure (6) shows the time history of displacement response of tip node of frame in horizontal direction. Damper damping ($\overline{C}_d$) is assumed to be to 700 for this example.

It can observe that using damper devices effectively reduced magnitude of displacement response of structure when earthquake subjected to model about 80 percentage compare of response of structure without dampers system. Time history displacement of same node in Y direction is shown in figure (7). It can observe that using damper devices effectively reduced magnitude of displacement response of structure when earthquake subjected to model about 80 percentage compare of response of structure without dampers system.

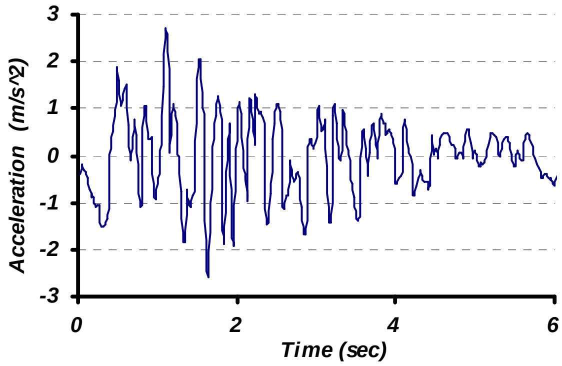

Fig. 5 Zanjiran-IRAN (1985) earthquake acceleration record (m/Sec2)

Time history displacement of same node in Y direction is shown in figure (7). Again in this direction, response of structure is effectively reduced in buildings equipped energy absorber system. The effects of different damper damping coefficient ($\overline{C}_d$) on maximum displacements of three story model in horizontal and vertical direction respectively in each story levels are shown in Figure (8 and 9). It is clear from these plots by increasing of damping coefficient, have reduced the structural response.

Significantly damper damping coefficient equal to zero indicate that the structure response without any damper devices because as mentioned before in this case dampers force is zero. As seen in both plots (8 and 9) damper damping coefficient equal to 700, is most effective on reduction of structures stories displacement in X and Y direction subjected to earthquake load.

Hence it can be selected that C_d=700, it is the most suitable choice for designing of high performance passive energy dissipation system in order to protect of structure on earthquake excitation.

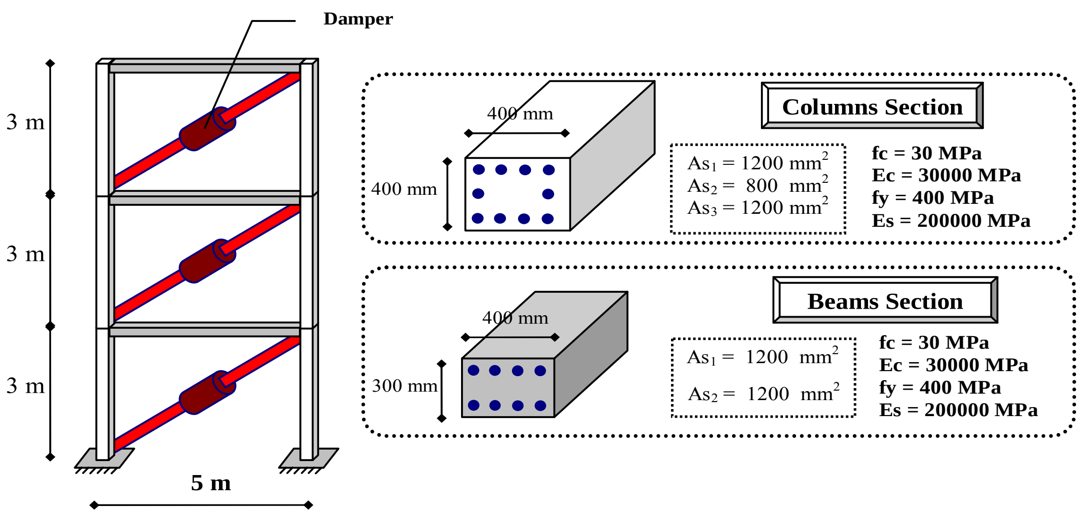

Fig. 4 Three storey frame example and beam column sections properties

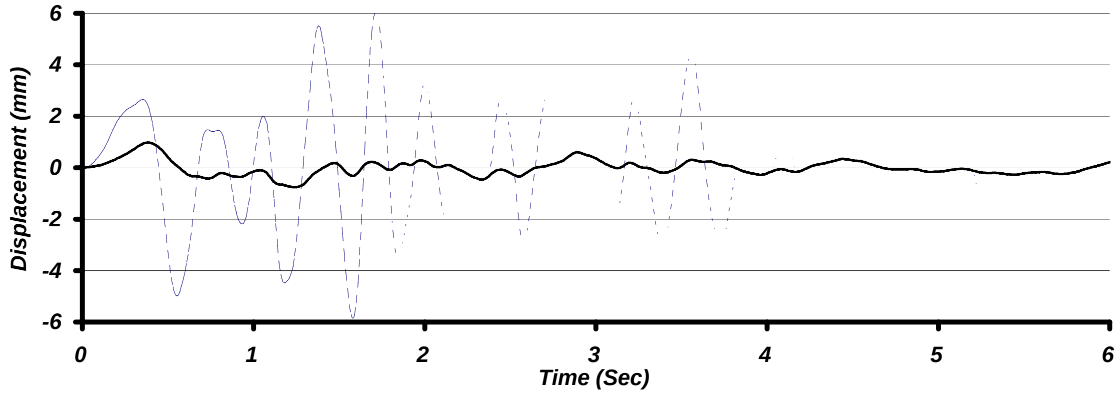

Fig. 6: Displacement of top roof node in X direction, ($\overline{C}_d$ =700)

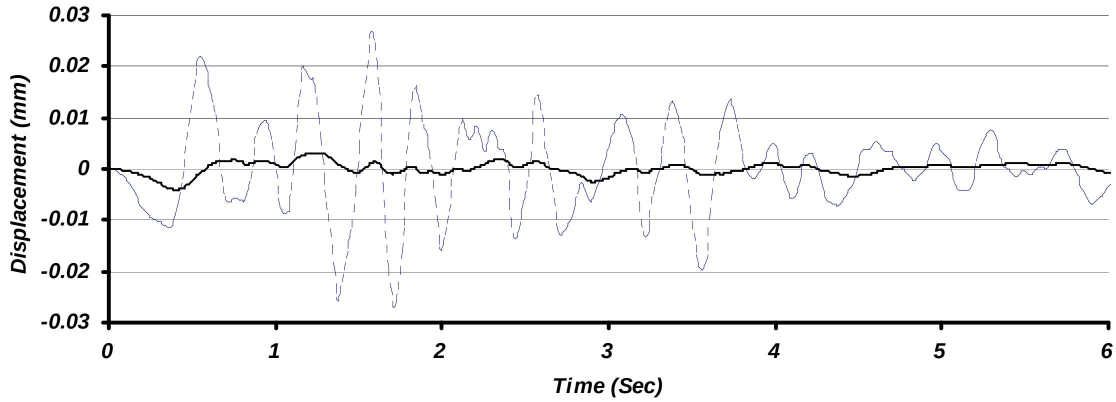

Fig. 7: Displacement of top roof node in Y direction, ($\overline{C}_d$ =700)

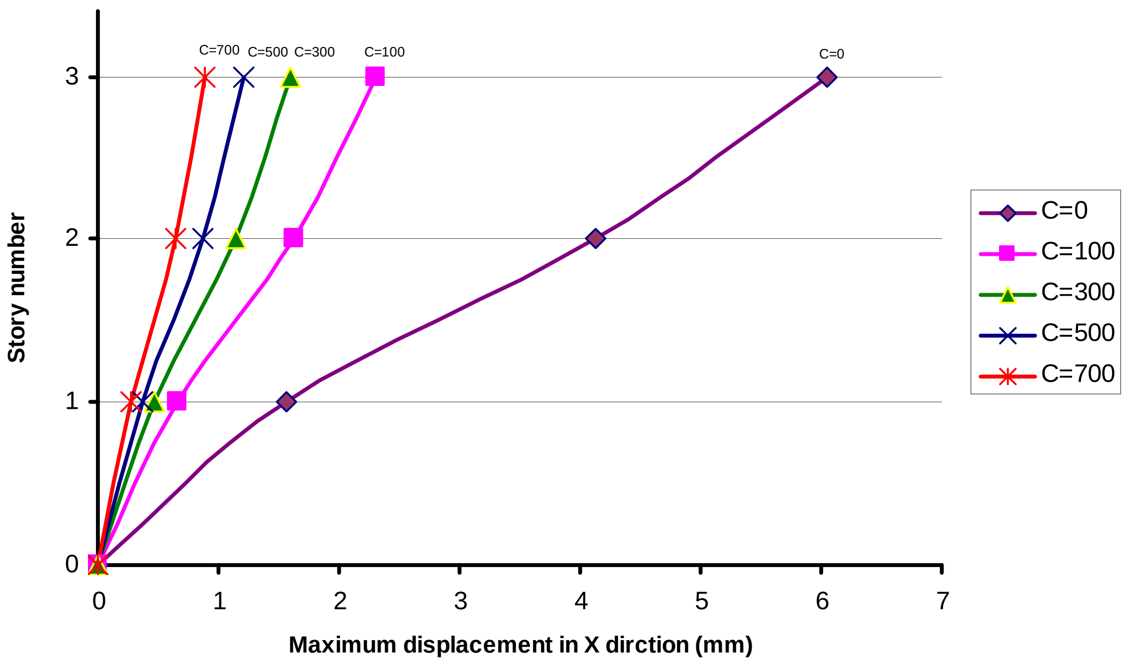

Fig. 8: Maximum displacement of each storey of three story example in X direction with various damper damping coefficient (η=1)

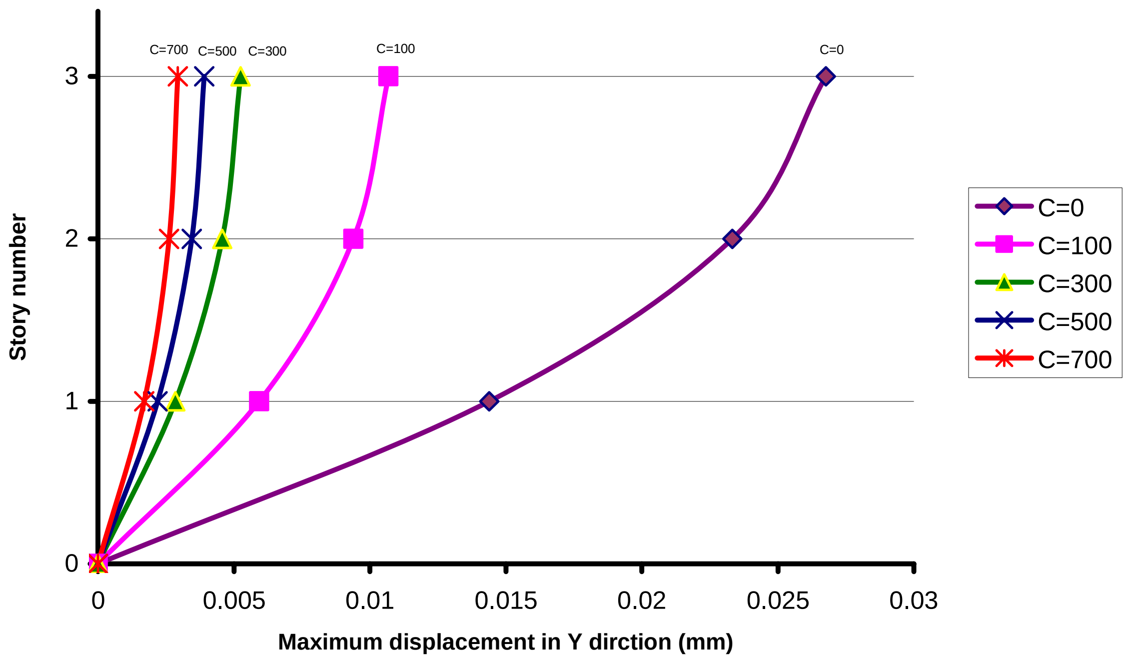

Fig. 9: Maximum displacement of each storey of three story example in Y direction with various damper damping coefficient (η=1)

VII. Conclusion

Based on the present study following conclusion can be drawn:

(i) A suitable computation tools for the analysis of reinforce concrete framed structures equipped viscous damper element have been proposed.

(ii) Compare on seismic responses of structures without energy dissipation system, and structures with proposed viscous damper elements show that using damper devices effectively reduced structural response subjected to earthquakes excitation. (80% decreasing for three story example)

(iii) The optimum design of damper parameters is eligible by evaluation of damper damping coefficient effect on the structures response, and chooses suitable damper properties for desire design of structure base on effect of damper devices to diminish the seismic load.

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