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Development of elasto-plastic viscous damper finite element model for reinforced concrete frames

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ABSTRACT

By advancing the technologies regarding seismic control of structures and development of earthquake resistance systems in the past decades application of different types of earthquake energy dissipation system has incredibly increased. Viscous damper device as a famous and the simplest earthquake energy dissipation system is implemented in many new structures and numerous number of researches have been done on the performance of viscous dampers in structures subjected to earthquake. The experience of recent severe earthquakes indicates that sometimes the earthquake energy dissipation devices are damaged during earthquakes and there is no function for structural control system. So, damage of earthquake energy dissipation systems such as viscous damper device must be considered during design of earthquake resistance structures.

This paper demonstrates the development of three-dimensional elasto-plastic viscous damper element consisting of elastic damper in the middle part and two plastic hinges at both ends of the element which are compatible with the constitutive model to reinforce concrete structures and are capable to detect failure and damage in viscous damper device connections during earthquake excitation. The finite element model consists of reinforced concrete frame element and viscous damper element is developed and special finite element algorithm using Newmark's direct step-by-step integration is developed for inelastic dynamic analysis of structure with supplementary elasto-plastic viscous damper element. So based on all the developed components an especial finite computer program has been codified for "Nonlinear Analysis of Reinforced Concrete Buildings with Earthquake Energy Dissipation System". The evaluation of seismic response of structure and damage detection in structural members and damper device was carried out by 3D modeling, of 3 story reinforced concrete frame building under earthquake multi-support excitation.

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1. Introduction

Generally, structure control subjected to seismic excitation has been among the most challenging tasks for civil engineers in recent decades. The traditional approach to design an earthquake resistance building is to provide adequate strength and stiffness against earthquake forces. As an alternative, studies have proposed the use of active and passive structural control systems, which have been enabled through technological and technical advancements, to decrease the effects of earthquakes and prevent seismic damage to buildings.

As part of these control systems, ordinary and simple passive control systems are used for two purposes, namely, to dissipate energy due to earthquakes and heighten the structure's ductile behavior to diminish earthquake load and prevent seismic damage to the structures. Because part of the seismic energy is dispersed by the supplementary energy absorber elements, the main parts of the structure are protected when powerful earthquakes occur. In particular, viscous dampers have been considered successful or efficient energy dissipation devices, which can be used to enhance the structural response against seismic excitation.

Constantinou and Symans [1] investigated on seismic response of structure equipped with linear fluid damper through mathematical modeling and experimental test. This study showed that damping force produced by the viscous damper is largely influenced by the physical properties of the fluid used in the device. The result proved that using damper device improved structural response in terms of story drift and shear force.

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Reinhorn and Constantinou [2] performed the experimental test using shaking table for reinforced concrete structures furnished with different damping devices such as viscous dampers to study the behavior and damage of structure and reach to physical or mathematical modeling. The result of experimental and analytical study has been reported in NCEER-95 which indicates that damper device decreases the inelastic deformation and reduces damage in structures. The analytical platform incorporated in IDARC software [3] was developed.

Lin et al. [4] also experimentally explored the seismic behavior of structures equipped with viscoelastic dampers. Result revealed that considerable improvement of structural performance under seismic loading can be realized via implementing viscoelastic dampers. Also it was apparent that effectiveness of damper is strongly dependent upon environmental temperature. The circumstance of damper positioning within the structure is also emphasized.

Ramirez et al. [5] carried out extensive research on analysis and design of structures with earthquake energy dissipation systems such as viscous dampers which is reported by MCEER-0010. The simplified method is proposed for elastic and bilinear elastic time history analysis of SDOF system with linear and nonlinear damper devices. Also displacement ductility demand for retrofitted structure by damper device is evaluated to determine equivalent earthquake forces and to perform modal analysis. The analysis procedure and result are verified through 3 and 6 story steel moment frames which were designed based on NEHRP (1997). Ramirez et al. [6] extended their work and the numerical simulations have been done via 20 earthquake records that were scaled to match on average the NEHRP (2000) spectrum. So the damping coefficient which used to calculate spectral accelerations for damping was proposed and new relationship for the ratio of peak inelastic displacement to the peak elastic displacement was formulated for structure furnished with viscous damper device.

Pavlou and Constantinou [7] analytically studied nonlinear response of steel moment frame structure which was designed based on NEHRP (2000) with and without supplementary damping systems under far-field, near-field, and soft-soil earthquake excitation using IDARC 2D program [8]. The analysis result showed that using of viscous damper devices significantly reduced peak accelerations and velocities in structural stories.

Rodrigo and Romero [9] investigated the dynamic response of a multi-story steel moment resisting frame equipped with fluid viscous dampers and subjected to seismic load numerically. Providing a simple methodology leading to an optimum retrofitting option with nonlinear fluid vs dampers subjected to seismic loads was the main objective of this numerical research. The seismic response of a six-story steel building was evaluated and it was reported that the maximum force experienced by the dampers in the nonlinear case can be decreased more than 35% in comparison with the linear retrofitting case with a similar structural seismic performance. Min et al. [10] presented a design process for viscoelastic dampers and experimental test results of a 5-storey single bay steel structure equipped with viscoelastic dampers. The location of designed viscoelastic dampers was in the first and the second stories of the building. The results indicated that by installation of the dampers, the dynamic response of the full-scale model structure decreased appropriately.

As an alternative, numerical simulation was used to extensively examine the role of viscous damping in preventing buildings from collapsing from massive earthquake ground motions by Soda [11]. Tezcan and Uluca [12] evaluated the viscous dampers performance through analyses of a number of structures equipped with energy dissipation devices, and results revealed both their advantages and disadvantages. Yang and Agarwal [13] investigated the influence of the passive control device on the structural response produced by strong ground motions in near field. The findings showed that near-fault ground motions with large velocity pulses could lead to the use of seismic energy dissipation devices that are critical for structure performance [14]. Wanitkorkul and Filiatrault [15] assessed the effect of structural passive systems on the structural and non-structural seismic fragilities of buildings. Also Guneyisi and Altay [16] compared the fragility of buildings equipped with and without passive control systems and concluded that viscous dampers were particularly effective in assuaging seismic structural response when different earthquake ground motions were applied.

Lee et al. [17] compared the accuracy and efficiency of different conventional analysis techniques for building structures with added viscous dampers that include the methods of direct integration, complex mode superposition, the modal strain energy method and matrix condensation technique. The eigenvalue analysis showed that the matrix condensation technique which is applied to dynamic analysis provided quite accurate results in significantly reducing analysis time, regardless of the plan shape and the location of the viscoelastic dampers. Also the most important advantage of direct integration method in comparison to other methods was accuracy in the process of time history analysis [18]. Nonetheless, Pong et al. [19] used direct integration which is one of the most extensive techniques in computer simulation and analyzed the structures supplemented with damper devices, which are subjected to steady-state excitation. Also direct integration is generally applied in the finite element method.

Lu et al. [20] verified the generalized Maxwell model in order to accurately simulate the hysteretic behavior of damper. It was reported that this model was able to predict the amount of energy dissipation by the damper more accurately. Pawlak and Lewandowski [21] presented the determination of the dynamic characteristics of structures with visco-elastic dampers. The dynamic characteristics of a structure with visco-elastic dampers have been determined as a solution to the appropriately defined eigenvalue problem. Also the problem of existence of real eigenvalues was discussed when the fractional model is used.

Hejazi et al. [22] developed constitutive model for damper devices which was applicable in reinforced concrete structures. The nonlinear performance of damper device was considered and finite element model was proposed. Application of developed system in some structural models indicated that using damper devices effectively diminish earthquake effect on reinforced concrete buildings and reduce seismic response of structure [23,24].

Although in all studies which are available in the literature, the damper devices are depicted as a structural member but the effect of damper damping is just considered as a single value of damping parameters while solving the general equation of motion; and never the damper devices are modeled and they contribute as a structural member and element with boundary condition and failure criteria which must be completely compatible with the structural analytical model such as reinforced concrete structure's model.

Then, the most commercial software are able to model damper device function in the structure but not consider it as a structural element and hence just damping effect is considered during dynamic analysis of structures. Therefore it is not possible to model the structure which includes all structural members such as damper devices and to detect the damage of dampers (failures identify) during earthquake excitation which is the most challenging issue on safety of retrofitted structures subjected to earthquakes. Thus, efforts to enhance both the physical and constitutive modeling of reinforced concrete framed buildings equipped with earthquake energy dissipation system with the possibility of damage detection in damper devices are crucial and necessary.

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