Seismic Performance of RC Column Using Fiber Hinge Concept with Time Integration Method

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Abstract
Recent seismic events showed the importance of understanding the structural performance of RC column that can be predicted numerically. The accuracy of column performance depends on type of the analysis and representation of seismic effect. Therefore, in this paper a nonlinear time history analysis has been performed to assess the seismic performance of bridge column using fiber hinge concept with time integration method using sap2000 software. A long bridge RC column is utilized and subjected to seismic excitation. The column has been divided into different size and numbers of fiber to assess the accuracy of the analysis and time consuming to analyze each case of fiber hinges. In addition, this paper used three-time integration methods, Newmark, Hilber-Hughes-Taylor, and Chung & Hulbert to predict the most suitable method to be used in column seismic analysis. The time history displacement and base shear in addition to moment rotation of the column are the most important factors to evaluate the column seismic performance. The analysis results demonstrated that the most suitable time integration method is Hilber-Hughes-Taylor for such type of the analysis since it gives more stable base shear result than other two methods. Furthermore, the results indicated that the accuracy of seismic performance increased by number of fibers incremental. Moreover, the number of steel fibers should be equal to the number of bars with same area and location. The unconfined and confined concrete should be divided into small areas to get accurate prediction of column seismic performance.

Keywords: Fiber hinge, time integration method, seismic, nonlinear analysis, comparison

1. Introduction
The ground motion effect on structures has been observed during recent seismic events [1-3]. In general, the column is the most critical structural element that highly affected by earthquake and demonstrates plasticity and failure. The column inelastic behavior has studied to assess the column capability and understand the way of failure[4]. Some of the researchers conducted experimental tests on RC and steel columns [5]. Yeh et al. (2002) performed experimental tests on two hollow RC columns to evaluate the static and dynamic responses of the columns. The results indicated the adequacy of the column to overcome the applied loading and the failure shown in the steel rebars. Moreover, the prototype with high ductility showed less axial forces [6]. Lehman et al. (2004) conducted experimental testing to predict the seismic impact on the RC circular cross-section column. Different factors have been assessed such as longitudinal...
and shear reinforcement, aspect ratio and confined region length. The outputs approved the importance of these factors to improve the column seismic response [7]. However, experimental testing required time, cost, equipments, and other factors. Thus, many numerical researches were performed to predict the column seismic performance.

The inelastic performance of the column can be represented by different numerical methods. There are two ways to show column plasticity, concentrated and distributed plasticity. In concentrated plasticity, a plastic hinge will be provided at each ends of the column, either rigid plastic hinge or inelastic spring with hysteresis characteristics. The finite hinge length is the first distributed plasticity model. The column section in the plastic hinge zone is represented by nonlinear moment curvature or fiber section integration. The most accurate plasticity models are the distributed fiber hinge model and finite element model. However, finite element is the most complex one and required long process and time [8]. The fiber element plasticity model has been proposed by Taucer et al., (1991). The model assumed that deformation is small and plane section remain plane during applying dynamic loadings [9]. After that, the fiber element model has been approved by different studies and they conclude the accuracy of this model to simulate the nonlinear behavior of the structural elements like the RC column [10, 11].

One of the most famous numerical dynamic methods is the time integration and there are number of time integration methods. Each of these methods comes out with dynamic numerical solution to represent the structure performance against dynamic loadings. Houbolt (1950) developed a procedure to assess the dynamic behavior of aircraft. This method is the earliest time integration method [12]. Then, Newmark (1959) proposed time integration method to solve any dynamic analysis with multi-degree of freedom from elastic to inelastic behavior. The method used for nonlinear analysis and the possibility to get plastic hinges [13]. The recent researches approved the accuracy of this method. After Newmark, Wilson introduced a time integration method in (1968). The researcher proposed a comprehensive integration procedure to assess the dynamic performance of 2D linear elastic. This method is suitable for underground structures and stable in blast and earthquake loadings [14]. Bathe and Wilson (1972) presented a new method and compared the accuracy and stability of time integration methods. The procedure approved the adequacy of all methods in certain issues [15]. Hilber et al. (1977) developed an unconditionally stable time integration method. This method called Hilber-Hughes-Taylor method and found to be more stable with controllable damping properties and easier to be implemented than the previous methods [16]. In (1978), Hilber and Hughes followed the collocation concept that introduced by Wilson (1968) and proposed the optimum scheme. This method called α-method that assesses the dissipation and dispersion [17]. Chung and Hulbert (1993) introduced a time integration algorithm called generalized α-method. This method showed accuracy and have ideal high and low frequency dissipation [18]. Figure 1 shows the historical sequence of time integration methods.

![Figure 1 Historical sequence of time integration methods](image-url)
However, the recent methods either same concept or modify of the mentioned methods. Based on the abovementioned information, this study assessed the seismic performance of RC bridge column using fiber hinge concept. The study compared the efficiency of the major three-time integration methods (Newmark, Hilber-Hughes-Taylor, and Chung& Hulbert) and the effect of number of fibers on the column seismic behavior.

2. RC column and applied earthquake

Figure 2 shows the RC column and the selected ground motion. The column dimensions are 6m height and 1.5*1.5m cross section. The longitudinal reinforcements are 28 bars with 25mm diameter and the transverse reinforcements are 12mm bars with 150mm spacing. The column is subjected to ground motion and the target response spectrum is 0.85 g. The target spectrum has been added to PEER ground motion and seven records has been selected [19]. For column plasticity, the unconfined and confined concrete and steel have divided into fibers. Four models of fibers were considered with different number of fibers as illustrated in Figure 3. In the first model, the steel reinforcement is considered as two columns and two rows with rectangular cross section. The unconfined concrete is as similar as the reinforcement, two rows, and columns. However, the confined concrete is simulated as one fiber with the area of all the confined concrete. In the second model, the concrete has simulated as same the first model. However, the reinforcement fibers are as same as number, areas, and locations of the longitudinal bars. The fibers in the third model are same the second model except the confined concrete has divided into four equal fibers. In the last model, the steel fiber is same the previous model but the confined and unconfined concrete are divided into small areas and the total number of fibers is 168. The column nonlinear analysis has been done using Sap2000 software. Three-time integration methods were selected and compared, Newmark, Hilber-Hughes-Taylor, and Chung& Hulbert.

![Figure 2 The RC column and the selected ground motion](image-url)
3. Results and discussions

The aim of this paper is to compare the time integration methods that simulate the column seismic performance in addition to assessment of number of fibers impact on the column performance. Thus, the column performance has been assessed in terms of time history base shear, displacement and plastic hinges using the mentioned time integration methods. To perform the comparison, the column with 36 fibers has been selected and the results of one ground motion have been clarified. Figure 4 demonstrates the base shear and displacement of the column using the three methods. The time history displacement of the column is almost same in all methods and the maximum displacement reached to more than 300mm. However, the column positive and negative base shear using Hilber-Hughes-Taylor method is lower than other two methods with around 1100KN and 1400KN positive and negative. However, the other two method showed more than 1500KN indicating the similarity in these two methods. Furthermore, Hilber-Hughes-Taylor method exhibited more stability than other methods since the base shear has stabilized in the last seven seconds of applying the ground motion. Unlike the other methods that demonstrated base shear instability by the end of the analysis since the base shear did not reach back to zero.
The second order column moment rotation with different methods is shown in Figure 5. In all methods, the moment rotation is almost same with moment around 3000 KN.m and the rotation 0.05 rad indicating that any time integration method will come out with same column response in terms of plastic hinge formation.
Figure 6 shows the time history base shear and displacement for RC column using different number of fibers. The figure explained that the accuracy of column responses will be increased by number of fiber incremental. The column time history base shear is stable for all fiber cases in positive and negative directions. However, the slight instability has been observed using 9 fibers due to inaccurate prediction of reinforcement behavior. The displacement time history results demonstrated the importance of using small fibers with large number. By using 9 fibers and assuming the reinforcement as rectangular rows and columns, the column displacement response showed instable performance and considerably large displacement. Furthermore, a large variation is shown between positive and negative displacement indicating that the column has deformed in one direction due to ground motion. However, considering the reinforcement as individual fibers resulted in displacement reduction and stabilized the column performance. Also, the positive and negative displacement variation has decreased using small fibers. The results also indicated that there is slightly different in displacement response between 36 and 168 fibers showing the importance of dividing the confined and unconfined concrete into fibers but small and extremely small fibers have slight impact on the results. However, smaller fibers required longer analysis duration. Figure 7 illustrates the maximum base shear and displacement, there is slight variation in maximum base shear in all cases showing the minor effect of number of fibers on base shear response. However, number of fibers importance has appeared in maximum column displacement due to the large variation in displacement response.
Figure 6 Time history base shear and displacement using different number of fibers
Figure 7 Maximum base shear and displacement using different number of fibers

The column moment rotation of all fiber cases is shown in Figure 8. The column with 9 fibers showed not proper column response and it's not recommended to divide the column into fibers in such similar way. Furthermore, the second column division (33 fibers) also not recommended since the confined concrete used as one full area. The other two cases (36 and 168 fibers), showed stable performance. There is a slight difference in moment since the 36 fibers case resulted in 3157 KN.m maximum moment and the 168 fibers case showed 3383 KN.m maximum moment. The maximum rotation in 36 and 168 fibers cases are 0.055 and 0.042 Rad respectively. However, the column with 168 fibers is more reliable and able to predict the real RC column response (moment-rotation).

Figure 8 column moment rotation using different number of fibers
4. Conclusion

This research evaluated the seismic performance of long RC column using nonlinear time history analysis in sap2000 software. The fiber hinge concept with different time integration methods is utilized in the numerical analysis. The results concluded that all time integration methods (Newmark, Hilber-Hughes-Taylor, and Chung& Hulbert) are able to simulate the column seismic performance. The nonlinear time integration method selection is based on column base shear, displacement, and second order moment-rotation. The column time history base shear using Hilber-Hughes-Taylor is more stable than other two methods. Therefore, it's recommended to use Hilber-Hughes-Taylor method in such type of the analysis. The column plasticity based on fiber hinge concept showed that the way of column fibers division and number of fibers have a considerable impact on predicting the column performance. It's essential to use steel fibers with exact number and area of the reinforcement rather than other divisions such as rectangular rows and column. The confined and unconfined concrete should be divided into small fibers to predict the accurate column plasticity. Moreover, the extremely small fibers are required long computational process.

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