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Cyclic deterioration parameters for shear-critical RC columns

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ABSTRACT

Existing reinforced concrete (RC) columns are susceptible to shear failure, and they are also known to experience significant strength and stiffness deterioration in force-deformation response. It is important to consider cyclic deteriorations when numerically simulating the force-deformation response of shear-critical RC columns. In this paper, the calibration procedure for three deteriorations (strength, unloading stiffness, and reloading stiffness) parameters is proposed. The numerical model is verified by comparing actual and simulated force-displacement responses of ten shear-critical RC columns.

1. INTRODUCTION

Reinforced concrete (RC) buildings built before modern seismic codes were adopted are referred to as existing RC buildings or older RC buildings. Columns in such buildings are likely to experience shear failure or even collapse during an earthquake. Shear failure can lead to a rapid reduction in the lateral strength of structures. This phenomenon is known to accelerate the side-sway instability of the entire buildings (Sezen and Moehle 2004; Lignos and Krawinkler 2011).

When it comes to predict the damage in existing RC buildings and establish an efficient retrofit scheme, accurate numerical model of shear-critical RC columns plays an important role. The numerical model should also properly account for cyclic deteriorations in strength and stiffness which are typically observed in the cyclic behavior of existing RC columns subjected to lateral loads.

For these analytical models, it is important to accurately estimate modeling parameters of cyclic deterioration (Ibarra et al. 2005). Unless cyclic deterioration parameters for strength, unloading stiffness and reloading stiffness are accurately estimated, the actual force-deformation response of existing RC columns cannot be reliably simulated using numerical models.

However, recently developed numerical models generally require more than one

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parameters per each mode (strength, unloading stiffness and reloading stiffness) of cyclic deterioration. If there are too many parameters to be determined, it is not easy to obtain unique sets of parameters that matches the deteriorated response of the actual RC columns. Moreover, it is difficult for field engineers to use such numerical models with too many input parameters.

Therefore, the purpose of this study is to (1) estimate the values for various mode of cyclic deteriorations (strength, unloading stiffness and reloading stiffness) in numerical models; (2) statistical evaluation of the estimated cyclic deterioration parameters. For this purpose, peak-oriented model (Ibarra et al. 2005), which has been widely used for simulating the force-deformation response of RC structural components, is considered. The input parameters for peak-oriented model is calibrated to ten rectangular RC column specimens.

2. CALIBRATION OF CYCLIC DETERIORATION PARAMETERS

The considered peak-oriented model proposed by Lowes and Altoontash (2003) is capable of simulating three different mode of cyclic deteriorations, that is, strength, unloading stiffness, and reloading stiffness. The rate of cyclic deterioration is controlled by α, as shown in Eq. (1).

$$\delta = \alpha\left(\Sigma E\right) \qquad (1)$$

where, α is the cyclic deterioration parameter that controls the rate of cyclic deterioration within each cycle; ΣE is the cumulative energy dissipation capacity; δ is the damage index which varies from 0 to unity. If δ reaches 1, this indicates that the numerical model has lost its entire lateral strength (or stiffness) capacity.

It is noted that the proper values for cyclic deterioration parameter (α) should be individually determined for strength (α_f), unloading stiffness (α_k) and reloading stiffness (α_r). The statistical comparison of α_f, α_k, and α_r is provided in the next section.

In order to estimate the cyclic deterioration parameters for numerical model, this study considered ten rectangular RC column specimens that have failed in shear. The required input parameters for peak-oriented model, such as, backbone, cyclic deterioration, and pinching is calibrated to force-deformation response of RC column specimens.

3. COMPARISON OF CYCLIC DETERIORATION PARAMETERS

The statistical comparison of α_f, α_k, and α_r is illustrated in Fig. 1. α_k/α_f and α_r/α_f for ten specimens collected in this study are compared.

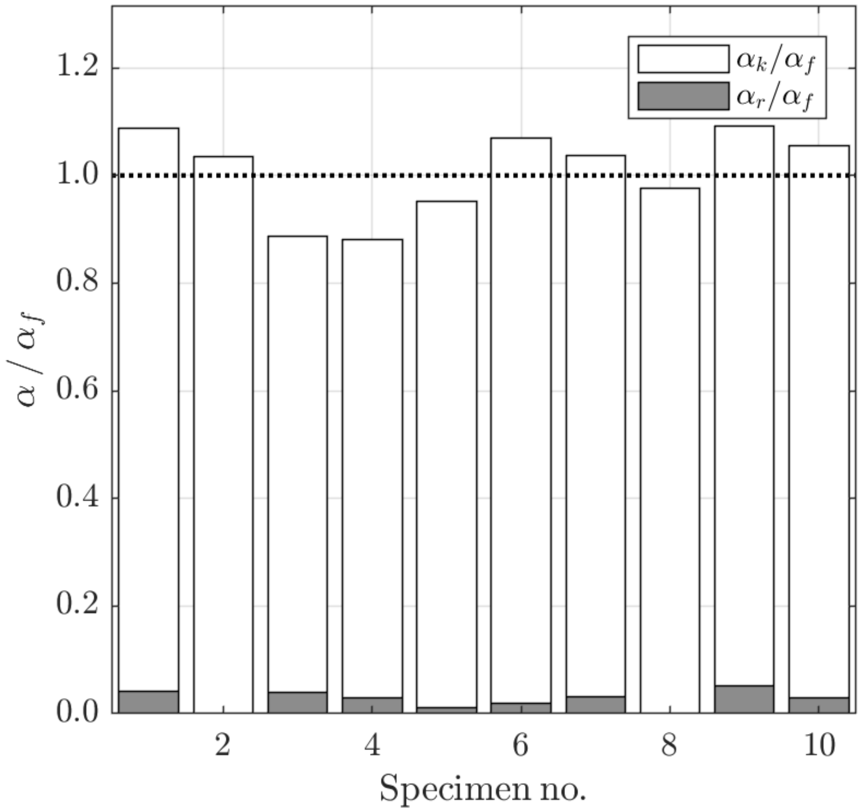

Fig. 1 Comparison of calibrated cyclic deterioration parameters

The median of $\alpha_{2,k}/\alpha_{2,f}$ is 1.00 and its standard deviation (σ) is 0.11, which indicates that similar α_2 values are obtained for strength and unloading stiffness for RC columns. Therefore, this study assigns the same value to $\alpha_{2,k}$ and $\alpha_{2,f}$. In contrast, the median value and standard deviation of $\alpha_{2,r}/\alpha_{2,f}$ is 0.03 and 0.01, respectively. which is insignificant to affect the simulated cyclic curves. Based on this observation, same value can be assigned for strength and unloading stiffness deterioration parameters. The reloading stiffness deterioration parameter, however, had negligible impact on the prediction of force-deformation response of RC column specimens.

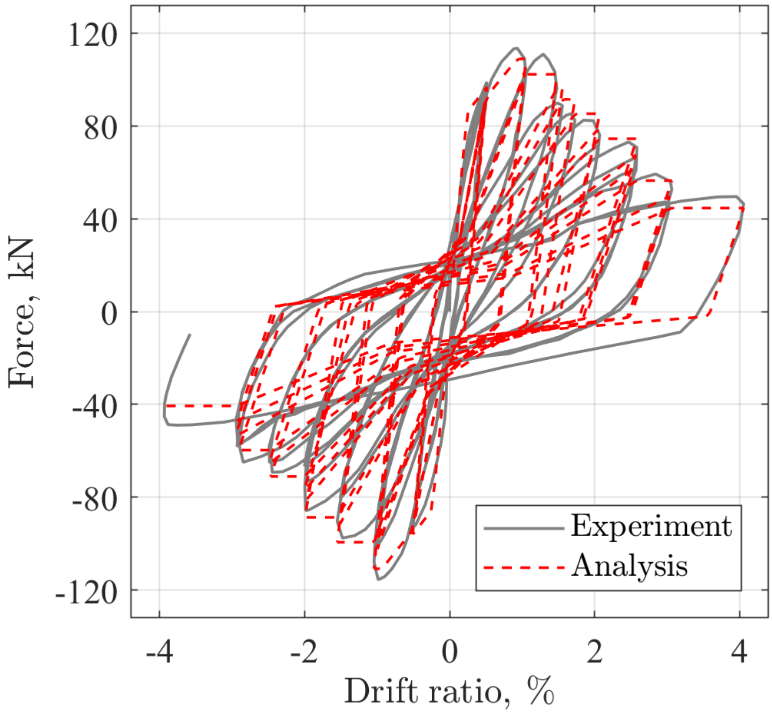

Fig. 2 Force-deformation response of experiment and analysis

Fig. 2 compares the force-deformation response obtained from RC column specimen and numerical analysis result using the simplifications assumed in the previous section. A good agreement between the generated cyclic curves of numerical model and the experiment can be found.

4. SUMMARY AND CONCLUSIONS

It is widely known that RC columns which were built before the development of modern seismic codes are susceptible to fail in shear. Such RC columns are generally referred to as existing RC columns. Shear failure in existing RC columns often causes sudden collapse of the entire building. In order to prevent the collapse of entire building, the engineer must determine whether the building must be retrofitted or not.

When performing seismic performance evaluation of existing RC buildings, accurate simulation of cyclic deterioration of RC column element is important. Although recently developed numerical models are known for its accuracy in simulating force-deformation response of actual RC structural components, they often require too many input parameters to be determined, making it harder for field engineers to use in performance evaluation study.

Therefore, this study estimated various modes of cyclic deterioration parameters and investigated for its possibility of simplification of input parameters. For this purpose, ten shear-critical RC column specimens are collected from former experimental research. The input parameters for peak-oriented model is calibrated to the force-deformation response of collected RC column specimens.

Statistical evaluation of estimated cyclic deterioration parameters showed that: (1) the median value of ratio of estimated unloading stiffness deterioration parameter to the strength deterioration parameter was 1.01 with low dispersion (0.11); (2) the median of estimated reloading stiffness deterioration parameter to the strength deterioration parameter ratio was 0.03 with almost negligible dispersion (0.01). Based on this observation, same value can be assigned for strength and unloading stiffness deteriorations, whereas reloading stiffness deterioration had negligible impact on the prediction of force-deformation response of RC column specimens.

A good agreement between the force-deformation response of experiment and the analysis result with proposed simplification of cyclic deterioration parameter was found.

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