ASSESSMENT OF THE PARK & ANG DAMAGE INDEX FOR PERFORMANCE LEVELS OF RC MOMENT RESISTING FRAMES

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Keywords: Damage Index, Performance Levels, Reinforced Concrete Frames, Strength Damage, Collapse

The main goal in seismic design is havinglife safety while earthquake happens and controlling the damages of the structure which is repairable. In performance based design codes, the levels of performance are defined based on the inelastic deformation of the structural elements, so it is necessary to have an appropriate relation between the levels of performance and the damages of the elements. For estimatingthe damage in the elements, criterions are defined as damage indices.

Damage indices are functions which consist of some damage variables that show the effects of those variables on the element's damage. One of the most important damage models is the Park & Ang damage index (Park Ang, 1985). It shows the damage of reinforced concrete elements as a combination of maximum deformations and the absorbed cyclic energy as:

$$D_{PA} = \frac{\delta_m}{\delta_u} + \beta_{PA}\frac{\int dE}{Q_y\delta_u} \quad (1)$$

Where δ_m= maximum deformation; δ_u= ultimate deformation under monotonic loading; Q_y= yield strength; $\int dE$= incremental absorbed hysteretic energy; β_{PA}=non- negative coefficient. The analytical value of D_{PA} for the state without damageis zero and for the collapse of the element or structure should be equal to one. The β factor shows the reduction of element's resistance in cyclic loadingand specifies the energy dissipation and the strength damage of the elements. Park and Ang have used this factor for calibrating their damage index and they found the β_{PA} ratio which the damage index is merged to one in the failure point. Based on these results the following equation has been found as:

$$\beta_{PA} = \left(-0.447 + 0.073\frac{L}{d} + 0.24n. + 0.314\rho_t\right) * 0.7^{\rho_w} \quad (2)$$

Where $\frac{L}{d}$ = shear span ratio; $n.n.$= normalized axial stress; ρ_t= longitudinal steel ratio as a percentage; and ρ_w= confinement ratio. After some years Kunnathet al. (1992) modified the original index and represented their correctional equation as:

$$D_K = \frac{\theta_m - \theta_r}{\theta_u - \theta_r} + \beta_K\frac{\int dE}{M_y\theta_u} \quad (3)$$

Where θ_m= maximum rotation during load history; θ_u= ultimate rotation capacity of section;θ_r= recoverable rotation at unloading; and β_K= strength degrading parameter of hysteretic model. The most important difference in the Kunnath's correctional equation is representing this equation based on the moment-curvature diagram and eliminating the factor β_{PA} and replacing it with the strength deterioration factor in a hysteretic model. Taking this factor as a constant factor will increase the diversion of the damage index around the failure point and collapse prevention performance level.

Having a high dispersion of β_{PA} factor have coerced the researchers for having more research in this area. Rajabi and Barghi (2001) have considered the Kunnath index for various test pieces of reinforced concrete columns. Theydeveloped the following equation by using the results of the tests and the same variables of β_{PA} factor as:

$$\beta_{RB} = \left(-0.287 + 0.098\frac{L}{d} + 0.229n_{.} + 0.21\rho\right) * 0.687^{\rho w} \tag{4}$$

In this study the Park & Ang damage index and its revisory relations for the various performance levels which contain immediate occupancy level, life safety level and collapse prevention level has been evaluated and the values of damage index at these levels and the portion of deformation damage and strength damage in various elements have been considered.

For this purpose, three reinforced concrete frames with various number of stories have been designed for three levels of performance. Nonlinear dynamic analysis has been done with seven earthquake acceleration records and finally the damage analysis has been done for them. Three damage indices have been derived for all of these nine frames that you can see some of their results in the following.

The beam damage indices is directly related to the rotation which happens in the plastic hinges. In the components with the immediate occupancy level, this linear characteistic is more clear but with increasing the rotation in the componenets or in the collapse prevention level, damage indices is more diverged. At this level of performance the important share of damage is because of cyclic behavior and because of weakness of β factor, this damage would not be shown. In figure1 the damage indices of beams in six story frame versus the rotations in the plastic hinges has been shown.

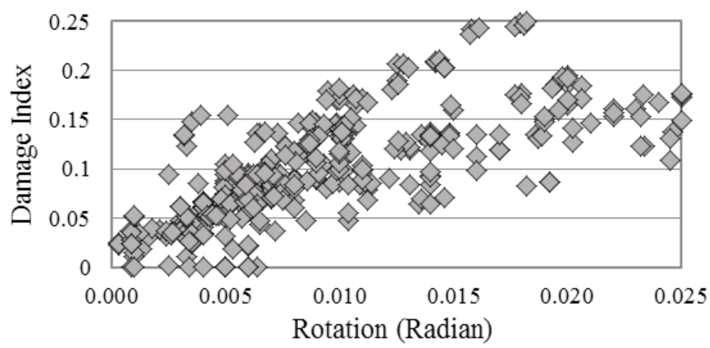

Figure 1. Damage indices versus the rotations

This frame is designed for the collapse prevention level in a specific way that the columns controlled the performance level or in another words the columns will reach the maximum values of their permited rotation in plastic hinges faster than beams. In this type of frames the capacity of dissipating energy of beams won't be used and their strength damage share will be reduced intensively.

The distribution of damage which caused by cyclic behavior (strength damage) in any elevation is proportional to the relative displacement of any story. We can result that the damage of beams and the distribution of strength damages are related to the relative displacement of stories.

The difference between three damage indices in the columns is so small and their values are so close to each other. In these three indices the quota of strength damage of columns is so small and is about 10%. It shows that these damage indices has a very weak relation with the cyclic damages or the strength damage of columns and can't evaluate the column damages.

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