

# Damage Indices

Employed primarily in the 1990s, a technique to quantify damage to a structure or an element is to use damage indices. Perhaps the most famous is the “Park and Ang” index (Park and Ang 1985), which is defined as

$$D = \frac{\delta_M}{\delta_u} + \frac{\beta}{Q_y \delta_u} \int dE \quad (1)$$

where  $\delta_M$ =maximum deformation,  $\delta_u$ =ultimate deformation in experiments with monotonic loading,  $\beta$ =model parameter,  $Q_y$ =yield strength, and  $E$ =absorbed hysteretic energy. Eq. (1) is formulated so that  $D > 1$  signifies “complete collapse or total damage” (Park and Ang 1985). The second term on the right-hand side of Eq. (1) accounts for cyclic loading but Park and Ang suggest that it may be insufficient to simply add up the hysteretic energy to predict damage, as that term does. To address that, they propose an extended version of Eq. (1), in which the displacement affects the damage accumulated by that term:

$$D = \frac{\delta_M}{\delta_u} + \beta \cdot \int \left( \frac{\delta}{\delta_u} \right)^\alpha \cdot \frac{1}{E_c(\delta)} dE \quad (2)$$

where  $\alpha$ =model parameter and  $E_c(\delta)$ =hysteretic energy in a cycle that is associated with the displacement  $\delta$ . A substantial portion of the paper by Park and Ang is devoted to the determination of the model parameters  $\delta_u$ ,  $Q_y$ , and  $\beta$  in Eq. (1). Williams and Sexsmith (1995) provide a didactic review of several damage indices applicable to reinforced concrete, categorizing the indices in the following manner:

- Local element/connection indices
  - Non-cumulative indices
  - Cumulative indices
    - Deformation-based
    - Energy-based
  - Combined non-cumulative and cumulative indices, such as Eq. (1) above
- Global structure-level indices
  - Weighted average indices

## References

- Park, Y. J., and Ang, A. H. S. (1985). “Mechanistic seismic damage model for reinforced concrete.” *ASCE Journal of Structural Engineering*, 111(4), 722–739.
- Williams, M. S., and Sexsmith, R. G. (1995). “Seismic Damage Indices for Concrete Structures: A State-of-the-Art Review.” *Earthquake Spectra*, 11(2), 319–349.