Performance-based uncertainty quantification of recover factors in concrete damage plasticity model for a squat shear wall

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1. Introduction

It is essential to consider explicitly all sources of uncertainties for an estimation of a fragility curve. With consideration of different levels of performance limit-state, careful characterization and quantification of the uncertainty in nonlinear model parameters in a concrete constitutive model are required. The Concrete Damage Plasticity (CDP) model has been used to capture the nonlinear behavior of concrete and is implemented in widely used software ABAQUS. The nonlinear response of concrete structures is represented by several parameters in the CDP model such as the nominal concrete compressive strength, modulus of elasticity of concrete, dilation angle, recovery factors, and damage variables. The recovery factor is one of the most important parameters among them [1]. In this study, a discussion on the characterization of the recovery factor, and the quantification of the uncertainty in this factor for a squat shear wall subjected to a monotonic lateral loading is presented.

2. Recovery factor in CDP model

Two recovery factors (w_c and w_t) in the CDP model are used to capture recovery the of degraded stiffness during uniaxial cyclic loading process from tension to compression or from compression to tension as shown in Figure 1. Factors w_c and w_t, referred to as compression recovery and tension recovery factors, affect the stiffness only after the occurrence of tensile and compressive damage, respectively. The compressive stiffness is recovered considerably under the cyclic loading from tension to compression because tensile cracks close by subsequent compression loading. On the other hand, the recovery of tensile stiffness is difficult to recover because the damage caused by compression loading increases due to the subsequent tension loading. Each of these recovery factor lies between 0 and 1. A zero indicates no recovery and a 1 indicates full recovery. In this sense, the CDP model is relatively robust continuum damage-plasticity model that has been used widely for modeling the post yield behavior of concrete particularly in nuclear structures.

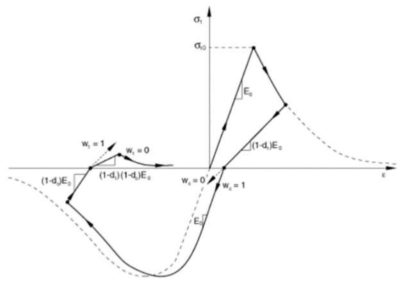
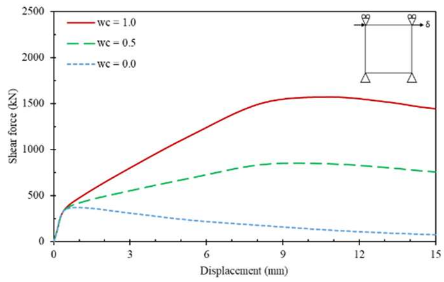


Fig. 1. Stress-strain curve under uniaxial cyclic loading in concrete damage plasticity model [2]

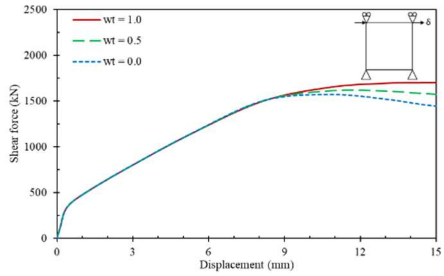
3. Characterization of the recovery factor

3.1 Concrete single element analysis

To characterize the effect of the recovery factors, a single 4-noded element subjected to monotonic lateral loading was analyzed as shown in Figure 2. While the effect of w_t is negligible except at very large displacements (near or beyond ultimate strength), the w_c has a significant effect on the overall nonlinear behavior. The w_c leads to a considerable change in ultimate strength and post elastic stiffness. In fact, the tensile cracks in concrete occur at relatively small deformation while the compressive damage occurs at large deformation. Thus, the effect of w_t is valid at large displacement although the effect of w_c is prominent throughout the nonlinear response.



(a) Compression recovery factor (w_c)



(b) Tension recovery factor (w_t)
Fig. 2. Concrete single element analysis subjected to monotonic lateral loading [3]

3.2 Concrete squat shear wall analysis

To estimate the effect of w_c on nonlinear responses of a squat shear wall, a Finite Element (FE) model of the squat shear wall tested by Palermo et al. [4] was developed as shown in Figure 3 and pushover analysis was conducted using ABAQUS. The results compared with those obtained experimentally as presented in Figure 4. The Figure 4 also shows load-deflection curves corresponding to the different values of w_c. It is found that the value of w_c gradually decreases with the increase in the damage (nonlinearity) to the shear wall. While the value of 1 for w_c represents similar response to the experimental one just beyond yielding region, the analytical response obtained from the value of 0.8 has a good agreement with the experimentally obtained one under before and after ultimate strength region. It shows that the recovery of the compressive stiffness is gradually degraded due to the accumulation of the tensile cracks in the shear wall.

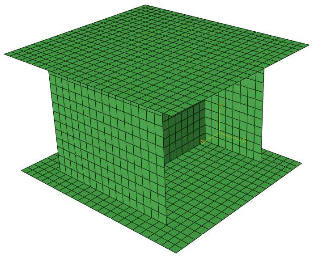


Fig. 3. FE model of the squat shear wall

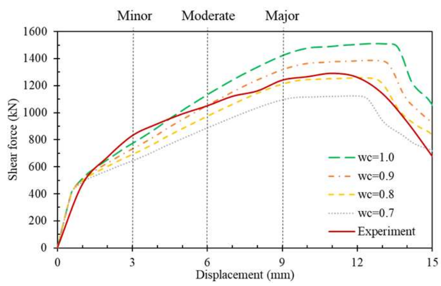


Fig. 4. Variation in load-deflection curves of the squat shear wall depending on w_c [3]

4. Performance based quantification of uncertainty in compression recovery factor for concrete squat shear wall subjected to monotonic lateral loading

To estimate a performance-based quantification of uncertainty in w_c, a $\pm$ 10% variability in the experimentally load-deflection curve from Palermo et al. was considered. Moreover, performance limit-states (minor, moderate, and major) of the shear wall are defined as shown in Figure 4. The FE analysis of the shear wall was repeated to determine the value of w_c satisfying $\pm$10% variation in experimental response at each performance limit-state. Figure 5 shows the values of w_c that satisfy the $\pm$10% variation in experimental responses and exact responses at the prescribed performance limit-states. While w_c lies near a value of 1 at minor limit-state, the values at the moderate and major limit-states are relatively less because much of compression strength can be recovered at the beginning of the nonlinear response and the recovery is less in degraded concrete with the accumulation of the damage. In addition, the range of w_c is relatively narrow as the damage increases in the shear wall. Thus, the uncertainty in w_c must be characterized and quantified differently based on the desired performance limit-state of the structures.

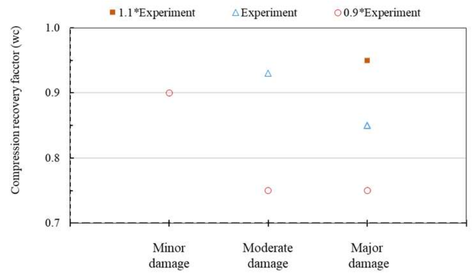


Fig. 5. Uncertainty in w_c depending on performance limit-state

5. Conclusions

In this study, the characterization of the recovery factor and the quantification of the uncertainty in the factor for a squat shear wall subjected to monotonic lateral loading case is presented based on performance limit-states. In the monotonic lateral loading, w_c represents the phenomenon on compression-softening of cracked reinforced concrete caused by transverse tensile cracks. The effect of w_c is much sensitive to responses of the structures with the accumulation of the damage. The uncertainty in w_c is quantified through the experimental data based on the desired performance limit-states and it was found that the uncertainty varies depending on limit-states of structures.

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