A DAMAGE MODEL FOR STRUCTURES WITH DEGRADING RESPONSE

Principal Investigator: Filip C. Filippou, UC Berkeley
Student Investigator: Thanh N. Do, UC Berkeley

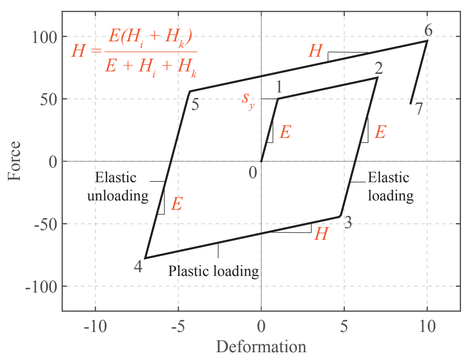
PEER Annual Meeting, January 28-29, 2016

Objectives

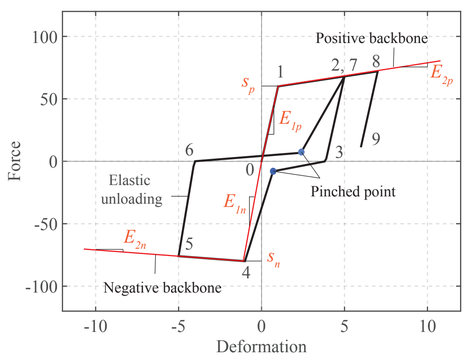
- To present a new damage model for the simulation and assessment of existing and new structures under extreme loading conditions
- To formulate the model from rational rules of mechanical behavior with as few ad-hoc assumptions as possible
- To obtain adequate accuracy, consistency, numerical robustness, and computational efficiency to meet the challenge of large-scale simulations in performance-based earthquake engineering

Formulation

- The model defines the force-deformation relation *s*-*e* and the damage index *d*.
- The formulation is based on continuum damage mechanics: undamaged effective space $\bar{s}$-*e* and damaged physical configuration *s*-*e*.
- The effective response is based on 2 models: plasticity model and hysteretic model.



(a) Plasticity model



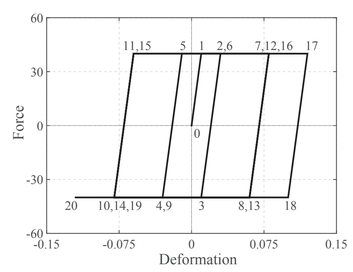
(b) Hysteretic model

Effect of Damage Parameters

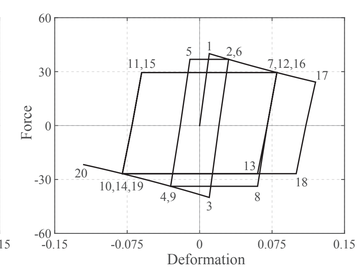
- 6 damage parameters

Parameter	Description	Feature
C_{d0}	Threshold coefficient	Initation of damage
C_{d1}	Ductility coefficient	Ductility or complete strength loss
d_{p1}	Damage scale parameter	Intensity of damage
d_{p2}	Damage shape parameter	Rate of damage
C_{cd}	Damage coupling coefficient	Strength loss interaction in +ive and -ive
C_{wc}	Cyclic degradation coefficient	Cyclic degradation from repeated cycles

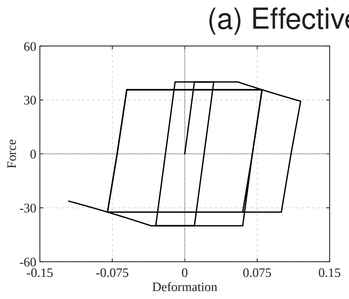
- Can specify unequal parameters to simulate asymmetry in +ive and -ive
- Effect of parameters on force-deformation relation



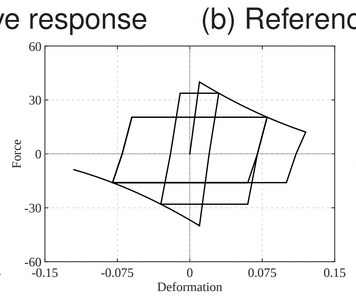
(a) Effective response



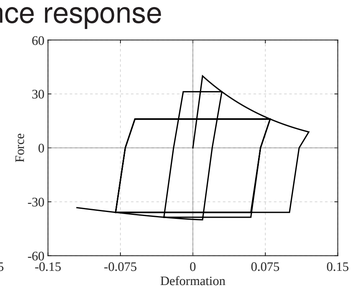
(b) Reference response



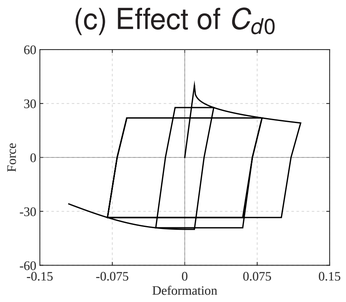
(c) Effect of C_{d0}



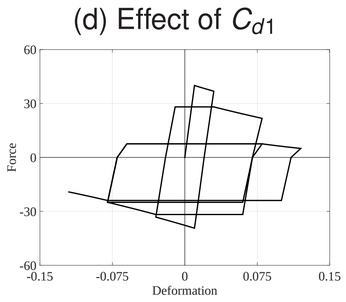
(d) Effect of C_{d1}



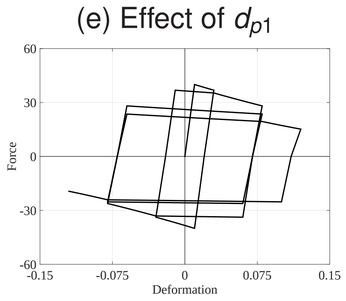
(e) Effect of d_{p1}



(f) Effect of d_{p2}

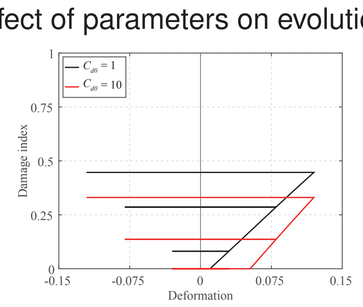


(g) Effect of C_{cd}

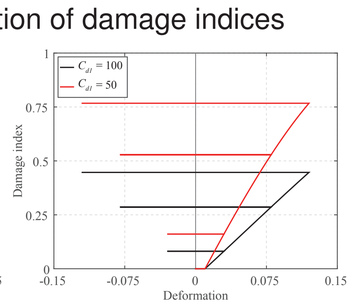


(h) Effect of C_{wc}

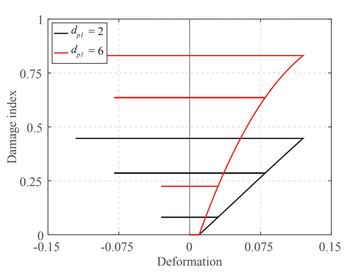
- Effect of parameters on evolution of damage indices



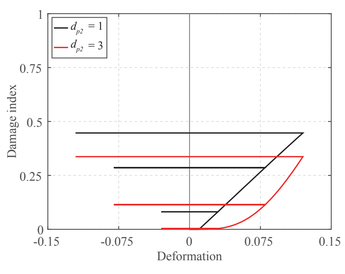
(a) Effect of C_{d0}



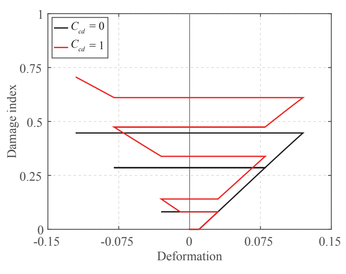
(b) Effect of C_{d1}



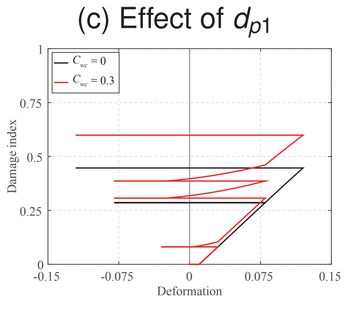
(c) Effect of d_{p1}



(d) Effect of d_{p2}



(e) Effect of C_{cd}



(f) Effect of C_{wc}

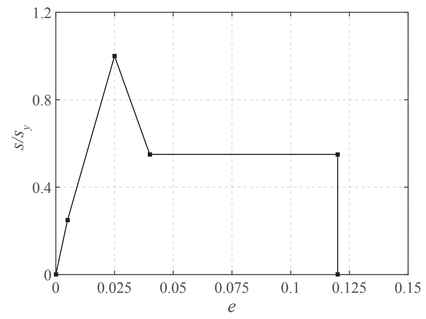
Summary of Features

The proposed model is able to capture the following:

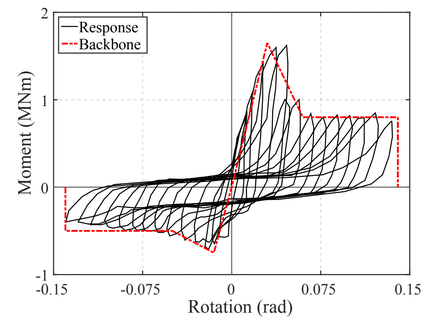
- Hysteretic behaviors and failure mechanisms of structural components
- Progressive strength and stiffness degradation in the response
- Cyclic and in-cycle degradation
- Dependency of damage on cumulative energy and deformation
- Continuously updated damage profile given by the damage indices
- Nonlinear softening behavior
- Strength degradation interaction between the response in +ive and -ive
- Asymmetrical hysteretic behavior in +ive and -ive

Damage Correction Procedure

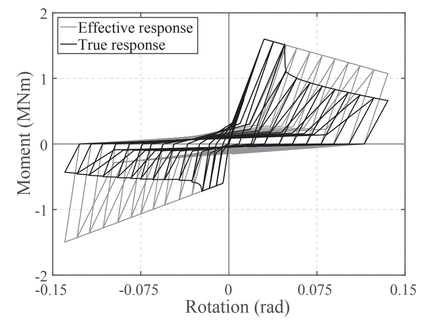
- The model simulates the response of a typical gravity frame system with shear tab connections (Liu et al. 2004).
- The monotonic backbone curve and experimental data in Fig. a-b are highlighted in FEMA P440A (ATC 2009)
- The damage correction procedure introduces strength and stiffness degradation to the undamaged effective response (Fig. c)



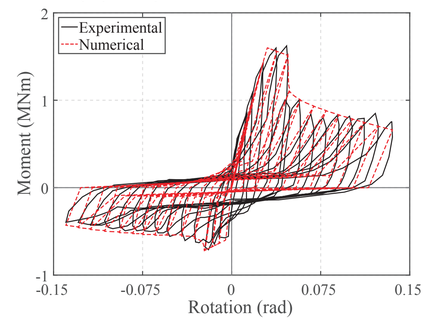
(a) Monotonic backbone curve



(b) Experimental result



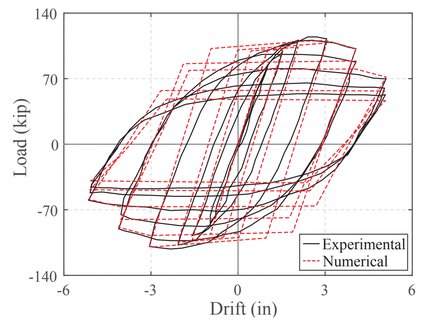
(c) Damage correction



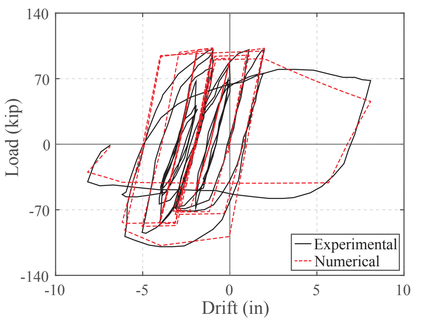
(d) Response comparison

Simulations of Structural Components with Degrading Response

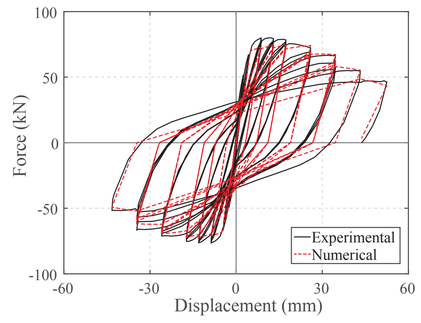
- Simulations of steel and reinforced concrete structural components
- Steel beam-to-column subassemblages (Uang et al. 2000): use the plasticity model in the effective space
  - Specimen LS1: subject to quasi-static cyclic loading (Fig. a)
  - Specimen LS2: identical to LS1 and subject to near-fault excitation (Fig. b)
- Reinforced concrete (RC) columns: use the hysteretic model in the effective space
  - Specimen STC2 (Kanda et al. 1988): flexural-critical column (Fig. c)
  - Specimen CUW (Umehara 1982): shear-critical column (Fig. d)



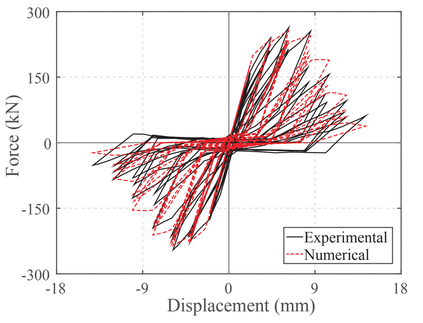
(a) Steel specimen LS1



(b) Steel specimen LS2



(c) RC specimen STC2



(d) RC specimen CUW

On-going and Future Development

- Further assessment of the model accuracy and efficiency in large-scale simulations
- Extensive calibration of the model parameters against available experimental database of structural components
- Implementation of the damage model in formulation of beam and column elements with degrading response
- Study of the response of multi-story buildings with degrading element behavior under static and dynamic loadings
- Extension of the 1d model to 3d with implementation in material constitutive modeling
- Application of the model in resilience assessment and damage evaluation of new and existing structural systems