An Integrated Platform for Validated Prediction of Collapse of Structures

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BACKGROUND

PROBLEM:

Due to the growing attention to accurate prediction of the collapse of structures, sophisticated models have been developed and validated for static and dynamic nonlinear constitutive modeling of such structures (Villaverde, 2007). These models incorporate critical effects such as multi-axial yielding; interaction between systems or members; local buckling; and energy-dissipating damping or fuse systems. However, accurate prediction of structural collapse with systematic incorporation of uncertainty still remains elusive, especially for structural evaluation and design of actual structures due to challenges in:

•modeling fracture on a scale sufficient to simulate dynamic instability (Krawinkler and Zareian, 2007)

•obtaining experimental test results that validate computational results (Suita et al., 2008), and

•identifying contributions of various damage measures to collapse despite significant uncertainties in loads and the chaotic nature of the dynamic instability of the structure (ATC-63, 2009).

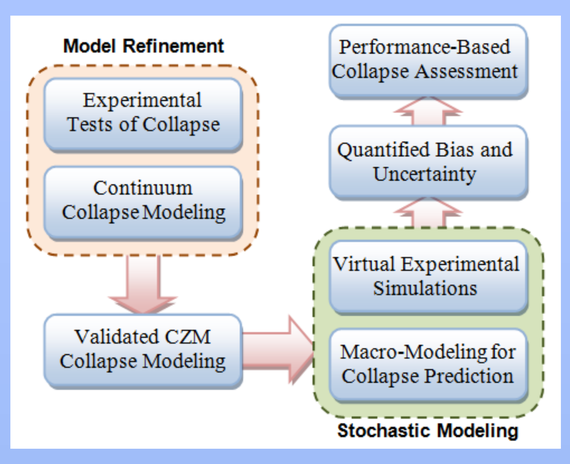
PROPOSED SOLUTION

This research seeks to establish a robust procedure for accurate assessment of the collapse of steel frame structures as follows.

•A cohesive zone method-based strategy is being developed as a standardized process for validating future finite element formulations of structural collapse.

•A stochastic framework is being developed to identify accurate collapse limit states and critical damage measures through incremental dynamic analysis.

PROJECT OVERVIEW



•First, a computational continuum modeling approach based on use of cohesive zone elements is developed to accurately predict collapse behavior and is calibrated and validated through comparison with available experimental test results.

•Second, using the continuum model validated by the test results, “virtual experimental simulations” are performed for a wide array of geometric, material, and loading parameters.

•Third, a macro-model incorporating fracture and disengagement of members for collapse analysis of structural systems is formulated and validated against both experiments and virtual experimental simulations.

•Fourth, the bias and uncertainty of macro-model predictions are quantified by developing a stochastic model of the collapse limit-state.

•Finally, factors correcting collapse capacity and demand are derived from the stochastic model for use in performance-based design and collapse assessment.

•The research aims to advance existing technologies related with state-of-the-art research so as to demonstrate the framework and to make broader and immediate impact across structural engineering research and practice constituencies.

CZM-BASED MACRO MODEL

COHESIVE ZONE MODEL (CZM)

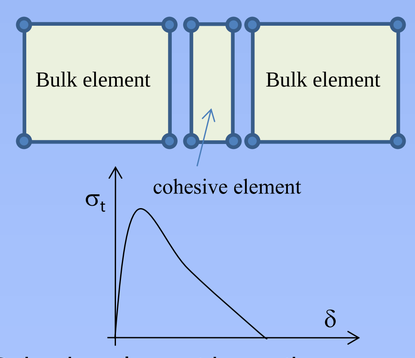
•CZM has been developed to efficiently model fracture processes in continuum mechanics (Elices et al, 2002).

•Interface elements (cohesive elements) having zero width are inserted between the interfaces of the bulk elements.

•The traction-separation relation is applied to cohesive element along the crack path

•CZM is generally developed for stress-space in continuum model simulating brittle materials.

•CZM is being extended in this work to explore ductile materials for both stress-space and stress-resultant-based formulations.



Cohesive element in continuum model

NONLINEAR DYNAMIC ANALYSIS

SIMULATION TOOL

In order to develop a stochastic platform for validation of new macro-models, The Open System for Earthquake Engineering (OpenSees) framework is adapted to perform nonlinear dynamic collapse analysis for several case studies. In brief, OpenSees:

•Is an object-oriented software framework developed by Pacific Earthquake Engineering Center.

•Can simulate the seismic behavior of structural and geotechnical systems including the reliability computation.

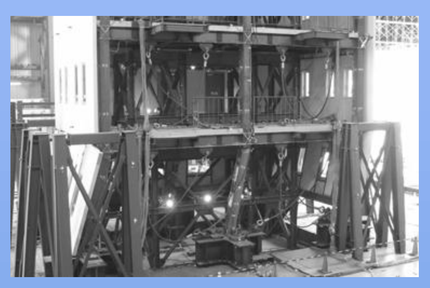
•Has been extensively employed in nonlinear earthquake engineering finite element applications because of its advanced capabilities in constitutive models, elements and solution algorithms.

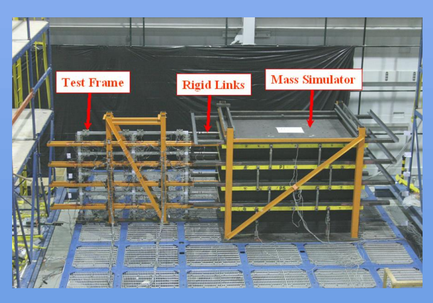
•Is open-source software providing researchers with the opportunity to contribute to the framework.

PROTOTYPE STRUCTURES

•There exist several experiments in the literature that assess dynamic performance of structures up to collapse.

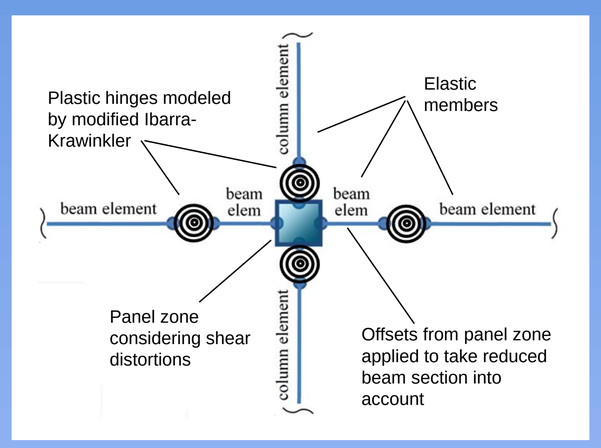
Collapse of a four-story steel moment frame at E-Defense (Suita et al., 2008)





Shake-table-test of a 1/8 scale 4-story, 2-bay steel frame with reduced beam sections (Lignos et al., 2009)

•An analytical model for the 1/8 scale 4-story test frame was developed in OpenSees based on the same deterioration parameters and mathematical model properties given by Lignos et al. (2008).

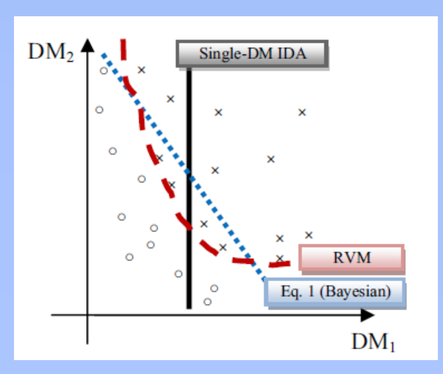


Mathematical model representing the interior subassemblage of the 1/8 test frame

FUTURE RESEARCH

•Using stochastic approaches such as a Bayesian parameter estimation method or relevant vector machine (RVM), critical damage measures will be identified for more accurate description of limit states and systematic treatment of uncertainties in seismic capacity, demand and model errors for collapse fragility models.

Limit-state surfaces by IDA, Bayesian model and RVM



•These research outcomes and the computational simulation results of the CZM strategy will be incorporated into the integrated platform for validated prediction of collapses.

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