SIMULATION PLATFORM FOR THE EARTHQUAKE RESPONSE OF REINFORCED CONCRETE STRUCTURES

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Motivation:
Reinforced concrete structures, RCS, are strongly heterogeneous composites, the performance of which depends on the subtle interaction of the brittle concrete and the ductile reinforcement. Under extreme seismic events, the interplay between the two components is critical for the safety and survival of RCS as demonstrated by dramatic failures during recent earthquake disasters in Turkey, Taiwan, Japan, and the USA.

Objectives:
It is proposed to develop a 3-dim simulation platform for the earthquake response, SPER, to model progressive failure of RCS subjected to seismic events. The parallel finite element architecture of FEMS-FETI, which was developed by the team of Dr. Farhat for the solution of large fluid-structure interaction problems, provides the basic platform for the proposed earthquake simulation environment. SPER will feature a novel nonlinear solver using incomplete elimination, and an innovative interface model to capture localized cracking and shear failure in concrete. For proof of concepts, a RC column will be examined in which quasi-static failure takes place in the form of a cascade of events, such as spalling of the concrete cover, progressive debonding of the reinforcement, yielding and rupturing of the transverse stirrups, and subsequent buckling of the axial reinforcement. As an illustrative example on system analysis, a two-span RC bridge structure will be selected to highlight the 3-dim interaction between the bridge super-and the pier and to showcase the scalability of SPER. The long-term objective envisions multilevel substructure models of elevated transportation systems exemplified by the Hanshin Express Way, which exhibited dramatic multiple segment failure during the 1995 Kobe earthquake.

Methodology:
The proposed SPER software will be based on a combination of multilevel/multigrid, domain decomposition and incomplete nonlinear elimination methods. Roughly speaking, in these algorithms, (i) domain decomposition provides the parallelism, (ii) multilevel provides a scalable computing environment with respect to problem size and the number of processors on parallel computers, while (iii) incomplete elimination removes the sensitivity of the nonlinear solver to localized singularities.

Relevance:
Progressive degradation of RCS is a matter of great importance in earthquake engineering. The current design philosophy has moved to a performance-based approach which requires reliable assessment of the structural behavior beyond the elastic range. SPER is designed to simulate the seismic performance of existing RCS which have been built according to older and often non-conservative earthquake provisions, and to assist the development of rapid and cost-effective rehabilitation procedures.

Outreach:
SPER will be disseminated through a web site which will document the progress and outcome of the model-based earthquake simulation software for RCS. In the long haul, the intention is to eventually incorporate the 3-dim capabilities of SPER into the forthcoming NSF Network for Earthquake Engineering Simulation (NEES), and to develop therein an internet-based capability for earthquake simulations which may be used by colleagues in academia and the earthquake engineering community.

Human Resources and Education:
The exploratory research will involve three graduate research assistants from the Civil Engineering, Computer Science and Aerospace Engineering, respectively, which will be guided and supervised by the four Co-PI's in three departments. They will work in an interdisciplinary environment that encompasses civil infrastructure systems, parallel computing technologies, and numerical solution schemes. The simulation platform SPER will be used as an education tool in a number of undergraduate and graduate courses that are being offered in the Civil Engineering Program at the University of Colorado, such as the Design of Reinforced Concrete Structures, Earthquake Engineering, and Computational Mechanics. SPER will also serve as a demonstration tool for public outreach, especially to high school teachers and K-12 students, on earthquake disaster awareness. This effort will take advantage of the new Integrated Teaching and Learning Laboratory (ITLL) at the University of Colorado which has received national attention because of its novel approach to learning through discovery.