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Technical Spotlight: NEAMS Structural Mechanics with Diablo

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Technical Spotlight: NEAMS Structural Mechanics with Diablo

The Diablo code being developed at Lawrence Livermore National Laboratory (LLNL) uses implicit, Lagrangian finite element methods for the simulation of solid mechanics and multi-physics events over moderate to long time frames. Its primary focus is nonlinear structural mechanics and heat transfer. The code provides a venue for parallel computation leveraging discretization technologies developed and user-tested in our previous codes. Diablo is architected around Fortran 95 data objects and a message-passing programming model.

A fundamental goal of the Reactor Product Line simulation system is to illuminate the behavior of advanced reactor designs through multi-physics simulation. Designs such as sodium fast reactors want to deploy well-characterized passive safety features. For SFRs, one of these features is utilizing core deformations arising during excessive thermal environments to moderate the neutronic behavior and thus safely throttle back the power.

The Diablo code now incorporates an interface to the SHARP data framework via the MOAB library. The current capability has been used to demonstrate taking temperature fields from coupled thermal-hydraulics (NEK5000) and neutronic (PROTEUS) simulations to determine the resulting structural deformations. Figure 1 shows a result from an end-of-FY13 milestone. A model of the EBR-II core was constructed to include one pin-resolved assembly (XX09) with the balance a set of homogenized assemblies. Temperature fields were written to a MOAB database representing the thermal-hydraulic model. This database was read by Diablo, the appropriate subset of data mapped to its structural mesh, and the distortions calculated. Figure 1 shows how asymmetries in the power and thus temperature creates lateral displacements.

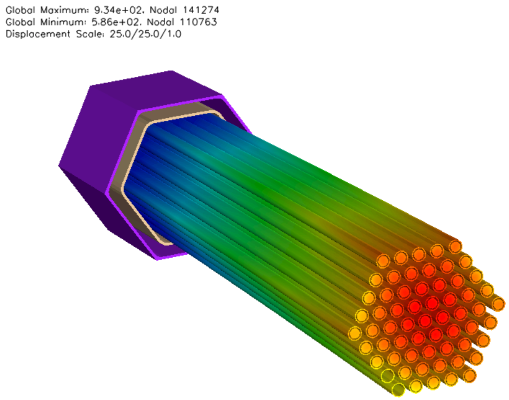

Fig. 1. Magnified (25x) distortions of the XX09 assembly model driven by the thermal response (color contours) from a coupled thermal-hydraulic / neutronic multi-physics simulation.

In addition to the effects of structural response within the reactor core, structural mechanics intersects with multiple issues in the balance of plant. Response under earthquake loadings is one broad class of interest. Providing adequate margins of structural performance is a significant driver of overall NPP capital costs. NEAMS investments are intended to create tools which capture response with greater fidelity, enabling design choices that minimize *excessive* margin and cost.

A recent effort examined technologies needed to extend Diablo for use in seismic response incorporating soil-structure interaction (SSI). This topic is of interest both because of recent events, but also the design trend toward subsurface placement of reactors.

The standard methodology for SSI relies upon a frequency-domain representation. This simplifies modeling far-field effects in layered geologic media, but at the price of limiting the ability to incorporate and thus evaluate nonlinear material response. The latter is important because nonlinear response is the most common means for structures and nearby soil to dissipate energy under extreme load events like earthquakes.

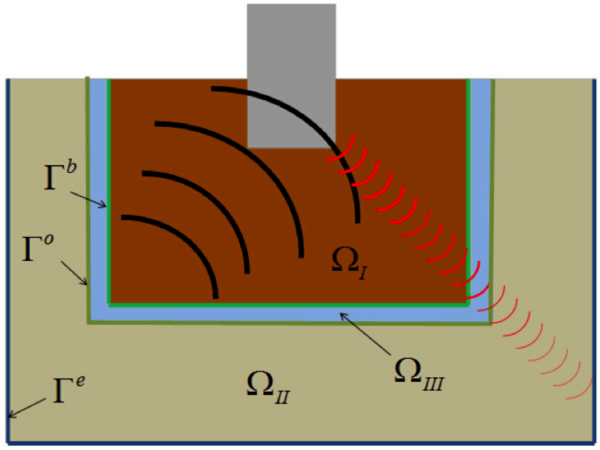

Fig. 2. Soil-structure interaction problems must apply the seismic excitation while also accommodating reflected waves escaping to the far field beyond the meshed domain.

The linear Bielak method for applying wave boundary conditions was extended to handle nonlinear soil models. This modified Bielak method applies the seismic loading upon a intermediate region within the model of the nearby geology. As shown in Figure 2, strong seismic waves are applied on Γ^b and in Ω_{III} to load the structure and adjoining soil. The outer domain Ω_{II} only needs to represent waves reflecting from the structure and are treated with absorbing boundary conditions on the outside boundary Γ^e to mimic their continued propagation to the far field.

Our SSI study was intended to illustrate how advanced time-domain simulation approaches compare with and complement the standard frequency-domain approach for SSI. Simulations were performed on a nominal buried SMR configuration defined by participants at ORNL. The geologic conditions were derived from available data for the Savannah River Site. SSI experts were retained by LBNL to exercise the standard frequency-domain tool on as identical a model as possible. The study showed the new time-domain approach provides comparable results for the excitation levels studied. This is a first step in establishing the method's credibility and can open the way to modeling more extreme structural response where nonlinear effects are key to quantifying margins without excessive conservatism.

Structural mechanics is a rich subject combining basic balance laws with a rich variety of material models and other phenomenon such as "contact" between different surfaces. The design and construction of the current NPP fleet drove many developments in computational structural mechanics. The community is in a position to leverage the intervening decades of research to help create next-generation solutions.

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