The NRC ESSI Simulator

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ABSTRACT

The NRC ESSI (Earthquake-Soil-Structure Interaction) Simulator is a software, hardware and documentation system for high fidelity, high performance, time domain, nonlinear, 3D, finite element modeling and simulation of earthquake-soil/rock-structure interaction of Nuclear Power Plants (NPPs). The NRC ESSI Simulator consists of three components, namely the NRC ESSI Simulator Program (software, aka ESSI-Program), the NRC ESSI Simulator Computer (hardware, aka ESSI-Computer), and the NRC ESSI Simulator Notes (documentation, aka ESSI-Notes)

Presented in this short paper is a brief description of the NRC ESSI Simulator System, together with the modeling and simulation philosophy that underlies the development.

The NRC ESSI Simulator System

The NRC ESSI Simulator System is designed to provide regulators and designers with a tool for high fidelity numerical prediction of seismic response of Nuclear Power Plants (NPPs). Users (regulators, designers, etc.) use the ESSI-Program, using computational resources provided by the ESSI-Computer to investigate seismic (and dynamic in general) behavior of NPPs. In addition to providing modeling and simulation capabilities, available through the ESSI-Program and ESSI-Computer, significant effort is undertaken to develop documentation material, with special emphasis on user education.

The NRC ESSI Simulator System is available in public domain (using various public domain licenses) and can be obtained from `http://sokocalo.engr.ucdavis.edu/~jeremic/NRC_ESSI_Simulator/`. Each of the three components of the NRC ESSI Simulator System is briefly described below.

The NRC ESSI Simulator Program. The ESSI-Program is a 3D, (material) nonlinear, dynamic finite element program specifically developed for high fidelity modeling and simulation of Earthquake Soil/Rock Structure Interaction problems for NPPs on ESSI-Computer. The NRC ESSI Program is based on a number of public domain numerical libraries that are compiled and linked together to form the executable program. Significant effort is devoted to development of verification and validation procedures (described briefly below), as well as on development of extensive documentation (ESSI-Notes). ESSI-Program is in the public domain and is licensed through the GNU Lesser General Public License (Free Software Foundation, Inc., 2007).

The ESSI-Program uses 3D solid, structural, contact and special purpose finite elements, to model the the soil/rock-structure system. Earthquake loading is applied through the Domain Reduction Method (DRM)

(Bielak et al., 2003; Yoshimura et al., 2003; Jeremić et al., 2011). Use of DRM allows application of real 3D, inclined seismic motions that feature both body (P and S) and surface (Rayleigh and Love) waves into material nonlinear soil/rock-structure NPP finite element models. Dynamic input waves can represent seismic (real earthquakes) and/or synthetic (constructed frequency sweeps) waves propagating through the soil/rock-structure system. Displacement proportional energy dissipation, resulting from material nonlinear effects is accurately taken into account by using a number of realistic elastic-plastic models for solids and structures. Accurate modeling of energy dissipation (resulting from soil/rock, structural and component inelastic behavior, damage) allows analysts (regulators, designers, etc.) to gain detailed understanding of the dynamic (seismic or synthetic) response of an NPP soil/rock-structure system. The ESSI-Program uses Plastic Domain Decomposition (PDD) method (Jeremić and Jie, 2007, 2008; Jeremić et al., 2009) for high performance, parallel computations on heterogeneous parallel computers, such as the ESSI-Computer, described below.

The NRC ESSI Simulator Computer. The ESSI-Computer is a distributed memory parallel computer, based in part on a Beowulf concept (Sterling et al., 1995; Ridge et al., 1997) and more recent developments of heterogeneous clusters of clusters and Graphical Processing Units (GPUs). Compute nodes are Shared Memory Parallel (SMP) computers (of multiple generations), that are connected, using high speed network(s), into a Distributed Memory Parallel (DMP) computer. Such heterogeneous parallel computers do impose additional burden on program development. However, complexity imposed by designing and maintaining a heterogeneous system, permitting multiple generation (performance) computer nodes, and multiple generation (bandwidth and latency) networks, pays off by longevity of investment in hardware (Sterling et al., 1998). Expanding the system based on needs and funding situation benefits from heterogeneity of the system as new compute nodes (off-the-shelf PC component and network(s)) can be chosen by their performance and price and not restricted by homogeneous hardware requirements.

It is important to note that while the ESSI-Computer is specially developed and is optimized for ESSI-Program, a wide range of DMP and/or SMP computers can be used for this purpose as well, although ESSI-Program runs most efficiently on the ESSI-Computer and its clones.

The NRC ESSI Simulator Notes. The ESSI-Notes are a set of (a) lecture notes on theory and formulation background, verification, validation and practical examples for modeling and simulations of NPP ESSI problems. In addition to that, ESSI-Notes incorporate detailed ESSI-Program API (Application Programming Interface). Format of ESSI-Notes will be similar to to that of current lecture notes developed at UCD by Jeremić et al. (2011). Education of users (analysts, regulators, designers, decision makers, etc.) is of utmost importance for proper modeling and simulations, resulting in dedication of a significant effort to the development of ESSI-Notes and accompanying educational material and activities (lectures, short courses, etc.). ESSI-Notes are in public domain and are licensed under a Creative Commons Attribution-ShareAlike 3.0 Unported License. Publication and distribution of ESSI-Notes relies on electronic media (on-line), and will incorporate wiki-like features (Cunningham, 1994) in near future.

Verification and Validation.

Developing a strong assurance of fidelity of numerical predictions of the seismic response of NPP soil/rock-structure systems relies heavily on **Verification and Validation** (V&V) procedures. Verification and validation procedures are the primary means of assessing accuracy in modeling and computational simulations (Roache, 1998; Oberkampf et al., 2002; Oberkampf, 2003; Oden et al., 2005; Babuška and Oden, 2004; Oden et al., 2010a,b). Verification is the process of determining that a model implementation accurately represents the developer's conceptual description and specification. Verification provides evidence that the model is solved correctly. It is essentially a mathematics issue. Validation, on the other hand, is the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model. Validation provides evidence that the correct model is solved. It is essentially a physics issue. V&V procedures are the tools with which we build confidence and credibility in numerical predictions resulting from modeling and computational simulations. Figure 1 shows role of verification and validation in modeling and simulating real world NPPSSSs. It is very important to note that

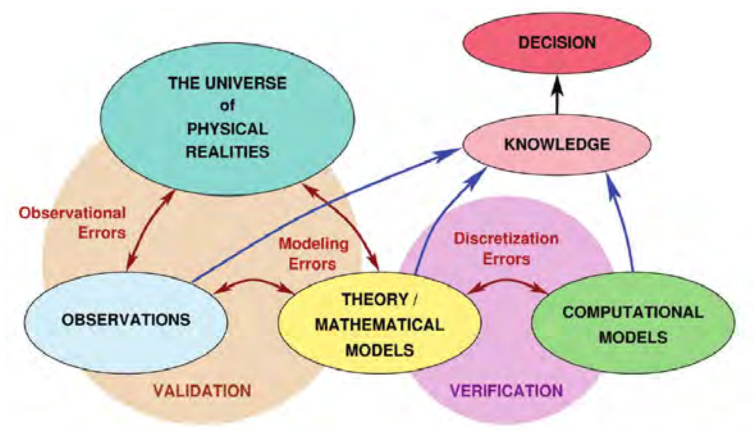

Figure 1: Schematic representation of role of verification and validation in relation to the real behavior and decision making process (after Oden et al. (2010a,b)).

a tight coupling exists between each of the phases of modeling and simulation process shown in Figure 1. Figure 2 shows a more detailed view of relationship of verification and validation to the developed computational solution. It is also important to note that verification procedures include software quality assurance practices, which are based on an extensive (fully and semi–) automatic test suite (eg. regression testing, white and gray box testing, static and dynamic testing, etc.).

The main motivation for performing verification stems from the simple question: "how much can you trust model implementations?" Validation, on the other hand can be motivated by the question: "how much can your trust numerical simulations?" Both questions can be summarized by the question: "how good are our numerical predictions in simulating dynamic behavior of soil/rock-structure NPPs?". The NRC ESSI Simulator system will feature an extensive set, currently under development, of Verification and Validation procedures.

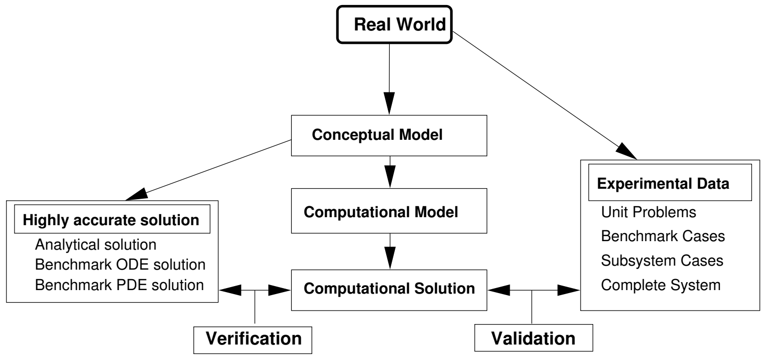

Figure 2: Schematic representation of relationship between verification and validation (based on Oberkampf et al. (2002)).

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