Update to ANS/ANSI 2.29 Probabilistic Seismic Hazard Analysis

Abstract for the 2018 DOE-NRC NPH Meeting

Emily Gibson[1]
Lisa Schleicher[2]

American Nuclear Society/American National Standards Institute (ANS/ANSI) Standard 2.29 provides guidance for performing Probabilistic Seismic Hazard Analyses (PSHAs) for nuclear facilities defined as a facility that stores, processes, tests, or fabricates radioactive materials in such form and quantity that a nuclear risk to the workers, to the off-site public, or to the environment may exist. Currently, ANS/ANSI 2.29 is referenced by DOE-STD 1020-2016, *Natural Phenomena Hazards Analysis and Design Criteria for Department of Energy Nuclear Facilities,* and is used as a reference for other industries both in the U.S. and internationally. ANS/ANSI 2.29 was originally published in 2008 and was reaffirmed for use in 2016. The ANS/ANSI 2.29 working group is currently working to update the standard with the intent to provide the ANS Committee a final draft in early 2019. The update is also being performed in conjunction with the update to ANS/ANSI 2.27, *Criteria for Investigations of Nuclear Facility Sites for Seismic Hazard Assessments.*

Although the draft is still being developed, we would like to discuss some of the major updates to the standard that the working group is considering. This includes referencing and maintaining consistency with the newly developed NUREG-2213, *Updated Implementation Guidelines for SSHAC Hazard Studies,* ASCE 43, *Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities,* and ASME/ANS RA-Sb, *Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications*. Other proposed changes include replacing the table correlating Seismic Design Category (SDC) levels and PSHA levels with new guidance for updating existing PSHAs and the inclusion of a section on accounting for induced seismicity. Additionally, a new technical section discussing hazard integration will be added as well as details on Software Quality Assurance that is specific to PSHA. This presentation will also provide a valuable opportunity for stakeholders interested in providing input or reviewing the standard to reach out to the working group.

*The opinions findings, conclusions expressed herein are those of the authors and do not necessarily represent the views of the Defense Nuclear Facilities Safety Board.

---

[1] Senior Staff Engineer, Schnabel Engineering, LLC
[2] Geologist, Defense Nuclear Facilities Safety Board

PROCESS FOR ONGOING ASSESSMENT OF NATURAL HAZARDS INFORMATION AT U.S. NUCLEAR POWER PLANTS

Stephanie Devlin-Gill, Jon Ake, Laurel Bauer, Meredith Carr, Christopher Cook, Brad Harvey, Joseph Kanney, Michael Mazaika, Clifford Munson, Dogan Seber, Nebiyu Tiruneh, Brett Titus

U.S. Nuclear Regulatory Commission

The U.S. Nuclear Regulatory Commission's (NRC's) post-Fukushima Near-Term Task Force Recommendation 2.2 (R2.2) proposed a rulemaking to require licensees to confirm seismic and flooding hazards every 10 years. This would include addressing any new and significant information and, if necessary, taking actions that could include updating the design bases for structures, systems, and components important to safety to protect against the updated hazards. The NRC staff concluded that the agency can meet the intent of R2.2 using an approach other than rulemaking by enhancing existing NRC processes and developing associated staff procedures to ensure that the staff proactively and routinely aggregates and assesses new natural hazard information (ADAMS Accession No. ML15254A008 and ML16286A586). The Commission approved implementation of this approach (ADAMS Accession No. ML17123A453).

The NRC will present the status of implementing this approach through its Process for Ongoing Assessment of Natural Hazards Information (POANHI). The process framework has three main components: (1) knowledge base activities, (2) technical engagement and coordination activities, and (3) assessment activities.

The POANHI knowledge base activities leverage an existing platform developed by Idaho National Laboratory (INL) to support compiling and maintaining existing natural hazard information. The NRC has populated its Natural Hazard Information Digest (NHI Digest) on INL's platform with post-Fukushima seismic and flood hazard re-evaluation information, links to the individual plant examination of external events (IPEEE), and documentation of flooding significance determination processes. For the purpose of populating the digest with data for natural hazards other than flooding and seismic, the NRC incorporated the data used to support its post-Fukushima evaluation of natural hazards other than seismic and flooding (ADAMS Accession No. ML17123A453). The NRC is also developing the NHI Digest to potentially support the agency in its real-time responses to natural hazard related events by making the necessary NHI digest information readily available in the agency's Incident Response Center.

Through the POANHI technical engagement and coordination activities, the NRC is engaging with leading scientific organizations to maintain awareness of the latest developments in data, models, and methods related to natural hazards that may affect licensed sites. The staff is augmenting some of its existing technical coordination activities and partnerships and establishing new agreements, when necessary, to ensure appropriate interactions between the staff and other Federal partner agencies (e.g., USACE, USGS, NOAA, USBR, NIST), industry stakeholders (NEI, EPRI), professional societies, consensus standards organizations, and international counterparts (e.g., IRSN, CNS, IAEA).

With respect to the POANHI assessment activities, the NRC is developing an Office Instruction documenting its approach for assessing changes in data, models, and methods related to natural hazards. The approach will involve (1) information collection, (2) information aggregation, (3) significance assessment, and (4) referral to appropriate internal NRC programs. As an example, the NRC plans to use POANHI to assess the jointly sponsored research product "Next Generation Attenuation Relationships for Central & Eastern North-America" and the updated Tornado Hazard Maps in development by the National Institute of Standards and Technology as new natural hazards information that have the potential to affect nuclear plant safety.

Towards a Risk-Based, Cost-Optimized Design of Safety-Related Nuclear Structures and Facilities

Chandrakanth Bolisetti, William Hoffman, Justin Coleman and Andrew Slaughter

Nuclear power plants (NPPs) and other safety-related nuclear facilities are currently designed using deterministic approaches to calculate the seismic demands, or pseudo-probabilistic approaches that involve the simulation of lower-bound, upper-bound and best-estimate models such as those prescribed in ASCE-4. Such deterministic approaches account for model uncertainties (uncertainty in the soil properties, concrete properties, etc.) through the usage of large safety factors in the calculation of design capacities of structures, systems and components (SSCs). While this approach may produce a design that meets the performance goals prescribed by ASCE 43, it is often quite conservative resulting in an over-designed and very expensive structure.

This paper describes the development of a design philosophy that uses a probabilistic approach to optimize the design of safety-related nuclear structures, with the end goal of minimizing cost while meeting safety performance goals. This design philosophy is being developed by the Facility Risk Group (FRG) at Idaho National Laboratory and leverages the various advances in seismic probabilistic risk assessment (SPRA), including, (1) enhanced fragility calculation that enables explicit consideration of nonlinear behavior in the soil and the structure (unlike current procedures, which assume linear behavior across all ranges of ground motion intensity including beyond design basis), as well as energy dissipation mechanisms such as seismic isolation, (2) automation of intensity-based and time-based probabilistic risk assessment processes, including ground motion sampling, probabilistic simulation, fragility calculation and accident sequence analysis, that greatly simplifies the SPRA process, and (3) optimization of the facility SSC design using these capabilities to minimize total cost while meeting safety requirements. This procedure is implemented in the in-house finite-element seismic analysis code, MASTODON, being developed by the FRG. The procedure is applied to optimize the designs of two different NPPs at two sites of differing seismic hazards. The procedure is also used to demonstrate the effectiveness of seismic isolation in reducing the overall capital costs.

Interfacing Seismic Hazard Analysis with Structural Engineering Requirements

Jinsuo Nie, Jose Pires, and Dogan Seber
Division of Engineering, Office of Regulatory Research, Nuclear Regulatory Commission

In the current practice, structural engineers use input response spectra (IRS) obtained from seismic hazard analyses to perform seismic response analysis and design of safety-related structures, systems, and components (SSCs) of nuclear power plants. Subsequently, in-structure response spectra (ISRS) from the structural response analysis are used by mechanical engineers to perform analyses of equipment or equipment qualification. There has been a seldom practical need for seismologists to provide anything else to structural engineers or for structural engineers to pass on to mechanical engineers.

The response spectrum of an earthquake time history is smoother than its power spectrum, so the response spectrum has been preferred in representing the ground motion structural engineers need. However, a response spectrum is not a direct representation of an underlying ground motion. Instead, a response spectrum describes the maximum responses of a series of single degree-of-freedom oscillators subjected to a given input time history at a given damping ratio, typically 5% in probabilistic seismic hazard analysis. Therefore, a response spectrum by itself does not provide a precise description of the frequency content in the underlying time history and its strong motion duration. Our experience has shown that in analyses where synthetic time histories are generated to match the IRS, assumptions about the ground motion underlying the IRS made when generating the synthetic time-histories can affect the calculated structural responses and ISRS. In light of this experience, several questions arise: Is there other information required in addition to the IRS itself to fulfill its role of interfacing between seismologists and engineers? Are assumptions applied on one side of this interface equally applied on the other side? What are the potential consequences of differing assumptions and, if needed, what additional information can address potential differences? The presentation will attempt to address these questions, with an ultimate goal of establishing more coherent understanding of the design ground motions and related IRS, and help ensure consistent analyses and design of SSCs to resist seismic ground motions.

Impact Loading Due to Seismic Excitation

Nicholas D. Catella

SIMPSON GUMPERTZ & HEGER

Impact loading is an important consideration in the design and analysis of nuclear structures for seismic events. Impact can occur due to large seismic displacements between two adjacent structures. Impact may also occur when seismic motion causes a piece of equipment to become dislodged, fall, and strike another structure. Seismic impact may be prevented by ensuring that clearance between all adjacent structures and equipment is large enough to prevent contact. However, the efficient equipment layouts frequently used in nuclear facilities often make this impractical. Similarly, it is sometimes not possible to ensure that equipment is always secured to prevent it from falling. In these cases, it is necessary to design structures to withstand the effects of impact loading. The use of crude methods of impact analysis can produce unrealistic structural demands, which result in poor performance. When determining the best analysis methodology for impact analysis, it is necessary to consider such factors as the effective mass, velocity, and deformability of the impacting objects. This work presents methodology for analyzing impact due to seismic excitation in three phases. The first phase of impact analysis methodology presents hand calculations that can be used to determine structural demands due to impact. These hand calculations are based on principles of dynamics and structural mechanics. The second phase demonstrates how static finite element analysis can be used to compliment the hand calculations presented in phase one. The third and final phase presents the use of nonlinear dynamic finite element analysis performed in Abaqus/Explicit. The methodology is presented for a variety of impact configurations.

Walkdown Evaluations of Electrorefining Project at Y-12 National Security Complex

Michael W. Salmon[1], Glenn Cox[2]

Abstract for U.S. Department of Energy (DOE) Chief of Nuclear Safety/U.S. Nuclear Regulatory Commission 2018 Natural Phenomena Hazards Workshop, Washington D.C., Oct. 23-25, 2018.

This paper presents lessons learned during a seismic II/I interactions evaluation walkdown of a Major Modification to an existing NNSA facility.

DOE Order 420.1C, Facility Safety establishes requirements for DOE facility design, constructing and operations to protect the public, workers, and the environment from the impact of natural phenomena hazards including earthquakes. Design requirements are applicable to new facilities, major modifications and modifications that are warranted based on periodic NPH assessments. Section 3.c.(2) requires that the NPH analysis supporting design and construction of facilities and safety-class SSCs include evaluation of interactions of other SSCs in the same facility. DOE 420.1C references DOE-STD-1020-2012 as the NPH Design Criteria. DOE-STD-1020-2012 references American Nuclear Society (ANS-2.26-2004, *Categorization of Nuclear Facility Structures, Systems, and Components for Seismic Design*, and other ANS standards for NPH guidance.

It is well known that seismic induced failure of non-safety class components due to failing, proximity, fire, or flood may impact the safety functions of safety class components. This seismic class II/I issue is addressed in DOE Facilities in ANS 2.26-2004 and ASCE 43-05. ANS 2.26 requires that II/I interactions be addressed in SSC seismic categorization and in the facility safety analysis. ASCE 43-05 requires that the effect of seismic interaction of adjacent SSCS are part of the seismic qualification of the safety related item.

The evaluations for systems interaction effects in existing facilities for major modifications can be extremely expensive and time consuming if not done properly. DOE EH 0545, "*Seismic Evaluation Procedures for Equipment in U.S. Department of Energy Facilities*," provides a cost effective means to identify and screen potential seismic interaction sources based on the performance of components in actual earthquakes. DOE EH-0545 presents interaction criteria used to identify real (i.e. credible and significant) interaction concerns. The criteria on 0545 rely heavily on the use of engineering judgment in identifying interaction concerns that are realistic.

A walkdown using the criteria in 0545 was recently conducted by engineers at CNS/Y-12 for a new process to be installed in an existing facility. The walkdown process was then peer reviewed. This paper provides an overview of the methods used and conclusions drawn from the work. It highlights lessons learned from the II/I evaluations. These lessons will hopefully prove to be helpful for future DOE teams performing walk down evaluations for II/I interactions.

[1] Research and Development Engineer, Los Alamos National Laboratory, salmon@lanl.gov
[2] Design Engineer, Y-12 National Security Complex, Consolidated National Security, glenn.cox@cns.doe.gov

Consideration of Component Level vs. Element Level Stresses in Concrete Nuclear Safety-Related Structures Under High Seismic Loading

Authors: Lisa Anderson, Luis Moreschi

Most nuclear power plant buildings are complex structures consisting of box-type or labyrinthine structures comprised of intersecting reinforced concrete walls and slabs that are analyzed using refined 3D Finite Element Models (FEMs). The FEMs produce detailed nodal/element results that are most representative of stress conditions at the local level. In contrast, design codes have been primarily developed relying on experimental test data, mechanical models and empirical equations that are most representative of the component level or global structural responses. This leads to potential inconsistencies between the analysis using refined finite element results for demands and the design using component level for capacities. Lacking any guidance, practitioners have bridged this gap by developing alternative (and usually very conservative) design approaches. This presentation critically looks at the various code checks and the current practice in the nuclear industry. Using the relevant provisions of ACI 349 code for nuclear structures, the fundamental steps to perform reinforced concrete checks for walls and slabs under combined in-plane and out-of-plane demands are explained using a sample structure. Results are presented to compare rebar quantities produced by the different design methodologies.
Also discussed during the presentation is work being completed by the ACI 349 and Dynamic Analysis of Nuclear Structures working group, which publishes ASCE/SEI 4 and ASCE/SEI 43, to provide better guidance on use of stresses from seismic analysis and how to apply ACI 349 to the results.

Numerical Modeling of Concrete Building Pounding During Seismic Events-A Case Study

Asad Bassam, PhD, Ben Kosbab, PhD, and Payman Tehrani, PhD
SC Solutions, Inc

Review of existing literature on the topic of building pounding suggest that impact can not only result in potential structural damage, but can also result in large high frequency accelerations, that could cause malfunction of equipment installed within the buildings. The magnitude of impact effects caused by pounding is case-specific, and reliable methods to approximate impact effects are limited, due to the sensitivity of such predictions to both physical and numerical details. A rigorous analysis considering case-specific considerations is the preferred approach to investigate the effects of pounding with confidence.

In this study, the pounding caused by excessive seismic deformations of a fairly flexible structure to a relatively stiff concrete structure is investigated through a computational model. The type of structures investigated is representative of a typical design found in many power plants. The method used in the analysis couples interaction between two finite element structural models via a hybrid element in which nonlinear springs and dampers are activated during the approach period of impact. This process allows simulating the process of energy dissipation which takes place during the impact more accurately. Time history analysis is performed for various ground motions, and results are extracted in terms of impact force and acceleration response at various locations of the structures. The results from the detailed model are compared to a more simplified version of the model that represents the two buildings with single degree of freedom system, to evaluate the applicability of a simple model for use in initial screening assessment of the pounding effects. Additionally, the effect of uncertainties of local stiffness and damping of concrete in the impact zone are investigated to demonstrate the sensitivity of the results to variability of these parameters.

Based on the analyses performed, it is concluded that for this specific case study, pounding has negligible effects on the responses within the stiffer structure whereas it can have a pronounced effect on the response within the more flexible structure. More broadly, the case study provides a framework for assessing the effect of pounding that can be applied to other cases.

A Modern Computational Framework for the Nonlinear Seismic Analysis of Nuclear Facilities and Systems

David McCallen
Center for Civil Engineering Earthquake Research
University of Nevada, Reno
& Energy Geosciences Division,
Lawrence Berkeley National Laboratory

Boris Jeremic
Department of Civil and Environmental Engineering
University of California, Davis
& Energy Geosciences Division
Lawrence Berkeley National Laboratory

Patrick Laplace
Center for Civil Engineering Earthquake Research
Department of Civil and Environmental Engineering
University of Nevada, Reno

Ian Buckle
Center for Civil Engineering Earthquake Research
Department of Civil and Environmental Engineering
University of Nevada, Reno

Floriana Petrone
Energy Geosciences Division
Lawrence Berkeley National Laboratory

Dennis Istrati
Department of Civil and Environmental Engineering
University of Nevada, Reno

Sherif Elfass
Center for Civil Engineering Earthquake Research
Department of Civil and Environmental Engineering
University of Nevada, Reno

The U.S. Department of Energy (DOE) has ownership and operational responsibility for a large inventory of mission critical facilities including Office of Science (SC) discovery science experimental facilities, Office of Environmental Management (EM) sites and facilities, and National Nuclear Security Administration (NNSA) nuclear operations facilities. Ensuring an appropriate characterization of earthquake hazard and risk for the breadth of these mission critical facilities is essential to the economic and safe stewardship of the DOE enterprise. The DOE has been at the forefront in the advancement of design standards for natural hazards starting with the development of the cutting-edge, performance-based DOE standard 1020 in the 1980's. To fully realize the potential of standard 1020 for ensuring appropriate earthquake safety, it is essential to have a robust computational capability that can accurately assess seismic demands and perform reliable simulations of facility performance including nonlinear response and the predicted achievement of specified system limit states.

In support of the ability to execute performance-based analyses, a modern computational framework for nonlinear analysis, with a special focus on nuclear facilities and systems, has been under development with programmatic support from the DOE. The principal activities underway are focused in three main areas:

- The development of a modern, nonlinear, time domain finite element program for high performance computational simulations of the response of critical facilities including the effects of superstructure and soil nonlinearities and soil-structure interaction;
- The development of a large-scale laminar soil box experimental testbed for performing validation tests for nonlinear site response in soils and for validating computational simulations of dynamic soil-structure-interaction;
- Development of a systematic approach (procedures and technologies) for nonlinear, time domain modeling and simulation of facilities with a special focus on nuclear facility structures, systems and components.

Fully nonlinear treatment of soil, contact surfaces and structures using high fidelity models will permit engineers to optimize facility soil-structure systems for safety and economy, and provide an ability to execute risk-informed, performance-based design simulations as framed in DOE Standard 1020 and ASCE 43-05.

Recent developments and progress in this project will be summarized in this presentation. The ultimate objective is to make verified and validated computational tools for performance-based simulations widely available throughout the entire DOE complex for both DOE sites as well as DOE contractors.

Modeling and Simulation of Earthquake Soil Structure Interaction for Nuclear Installations

Boris Jeremic, UCD, LBNL; Yuan Feng, UCD; Han Yang, UCD; Hexiang Wang, UCD; Dragan Kovacevic, UCD; Floriana Petrone, LBNL; Francis McKenna, UCB, LBNL; David McCallen, UNR, LBNL

Presented here is a system for modeling and simulation of earthquake soil structure interaction of nuclear installations. The system, called MS-ESSI Simulator (http://ms-essi.info/), is developed for performing high performance, time domain, elastic and/or nonlinear/inelastic, finite element modeling and simulation of
(a) statics and dynamics of soil,
(b) statics and dynamics of rock,
(c) statics and dynamics of structures,
(d) statics of soil-structure systems, and
(e) dynamics of earthquake-soil-structure system interaction.

One of the goals of the MS-ESSI development is the understanding and reduction of modeling uncertainty. Modeling uncertainty is introduced in simulation results when simplifying modeling assumptions are made. A hierarchy of models, from simpler, with simplifying assumptions, to more sophisticated, higher fidelity models with less simplifying assumptions, is used to understand and control the influence of such simplifications on results. Focus is on using physics based methods and models that are used to predict and inform, rather than curve fit. Modeling and simulation of soil structure systems is used to follow flow of seismic energy through the system. Proper modeling of a flow of energy through the soil structure system can be used to optimize for safety and economy new systems designs and to improve existing systems.

A number of examples is presented to illustrate modeling and simulation of soil and structure nuclear installation systems. Examples presented, as well as a full documentation for the MS-ESSI is available at the http://ms-essi.info/ web site. In addition, MS-ESSI Simulator system is available for use by the government agencies through full on site install or at the Amazon Web Services Government Cloud (https://aws.amazon.com/govcloud-us/) with full compliance of U.S. government security and compliance requirements. Moreover, professional practice is able to fully utilize MS-ESSI Simulator system very efficiently and economically through Amazon Web Services marketplace.

Site response of the Atlantic Coastal Plain strata discerned from horizontal-to-vertical spectral ratios of earthquake and ambient noise ground motions

Abstract for the 2018 DOE-NRC NPH Meeting

Lisa S. Schleicher[1]
Thomas L. Pratt[2]

During the 2011 M_w 5.8 Mineral VA earthquake, many buildings in Washington, DC, sustained damage despite being 130 km from the epicenter. The surprisingly large amount of damage despite weak bedrock ground motions raises questions about how much ground motions are amplified by the Atlantic Coastal Plain (ACP) strata, which range from 0 to 270 m thick beneath the city but are thicker to the east, and highlights the need to estimate site responses for the ACP. The horizontal-to-vertical spectral ratio (HVSR) method, using either earthquake signals or ambient noise as input, is an appealing method for estimating site response because it only uses a single seismic station rather than requiring two or more seismometers traditionally used to compute a sediment-to-bedrock spectral ratio (SBSR). Here we test and quantify uncertainties associated with the HVSR (both on earthquake signals and ambient noise) versus the SBSR methods in the ACP. The ACP strata are composed of flat, unconsolidated sediment layers over bedrock, making it an ideal setting for evaluating the effectiveness of the HVSR method in an area lacking strong basin surface waves. Between November 2014 and August 2015, we used 27 seismometers to measure ground motions across the DC metropolitan area during teleseismic and regional earthquakes. In addition, the Southeastern Suture of the Appalachian Margin Experiment (SESAME) and the Eastern North American Margin (ENAM) seismic experiment provide ground motion recordings traversing the spatial extent of ACP strata to thicknesses of 1,800 m. Other studies have had mixed results when comparing the accuracy of the HVSR versus SBSR methods for identifying the frequencies and amplitudes of the primary resonance peaks. Our preliminary results show that at most sites we find a close match in the frequencies of the fundamental resonance peaks in the 0.7 to 5 Hz range between the HVSR (using either earthquake signals or ambient noise) and SBSR methods to a thickness of 200 m; amplitudes did not match as well between the two methods, but were generally within a factor of 2. In regions of thicker sediments (200 to 1,800 m), the HVSR method using teleseismic signals appears to identify the frequencies of the fundamental peaks estimated by the SBSR method, but consistently underestimates their amplitudes by a factor of about 5. These preliminary results calibrate the HVSR method in areas of sedimentary layers with a strong reflector at the underlying bedrock surface, and in particular for identifying the main amplitude peaks that are known to be important in the eastern U.S.

*The opinions, findings, conclusions expressed herein are those of the authors and do not necessarily represent the views of the Defense Nuclear Facilities Safety Board.

---

[1] Geophysicist, Defense Nuclear Facilities Safety Board
[2] Research Geophysicist, United States Geological Survey

A comparison of surface- and vertical seismic-derived shear- and *p*-wave velocities

Peter J. Hutchinson, PhD, PG[1]
Jana M. Bridwell, PhD[2]
Alex Balog[1]

[1]THG Geophysics, Ltd
Murrysville, Pennsylvania

[2]LeStat Associates
Atlanta, Georgia

Analog down-hole shear-wave velocities from vertical seismic profiles (VSP) from 2 sites in West Virginia compare favorably with shear-wave velocities derived from surface waves (Rayleigh waves). The VSP-derived shear- and *p*-wave velocities, collected with a surface source and down-hole tri-axial geophone, are consistent with velocities expected from boring log lithologies. Multichannel analysis of surface waves (MASW) data, derived from a 32-channel seismic acquisition system, were inverted through SurfSeis and statistically compared to VSP-derived shear wave velocities. Five statistical analyses between the VSP and the MASW data show an agreement of between 10 and 15%. Further, five statistical comparisons of digitally-derived *p*-wave velocities from the MASW data are consistent with the measured VSP-derived velocities, showing a 10% to 15% agreement. Subsequent analysis show little systematic differences between MASW and VSP data for both *p*- and shear-wave velocities.

An Updated approach for Seismic Vertical SSI Analysis

Farhang Ostadan[1], Nan Deng[1]

In recent years, development of vertical design motion follows the computation of horizontal design motion and applying the applicable vertical to horizontal spectral (V/H) ratio to obtain the vertical design motion. This approach is found to be consistent with the observation of recorded motions. Vertical motions are no longer developed from the assumption of vertically propagating waves due to anomalies associated with P-wave propagation.

In this paper, a summary of downhole array data in terms of V/H spectral ratios are presented and the trend with depth is discussed. In spite of the adoption of V/H ratio for development of vertical design motion in the ASCE 4-16 standard, SSI analysis in vertical direction is still performed using the vertically propagating waves. To maintain consistency between the free-field motion and SSI input motion for embedded structures, a new method is developed that maintains the V/H spectral ratio in the free-field motion for the vertical SSI analysis. The new method and the SSI results of two structures (one with shallow and one with deep embedment) using both the conventional P-wave propagation and the newly developed V/H ratio approach are presented and discussed.

1 Earthquake Engineering Center, Bechtel Corporation, San Francisco, California.

Implementation of FIRS for Deeply Embedded Structures

Tom Houston, Andrew Maham, Greg Mertz
Costantino and Associates

This presentation will discuss the additional conservatisms inherent in computed structural responses that result from defining the control motion for soil structure interaction analyses as the FIRS (foundation input spectra) as opposed to the implementation of the alternate approach for incorporating FIRS considerations permitted by ASCE 4-16. The discussion will focus on a deeply embedded structure sized to be representative of proposed SMR (small modular reactor) designs.

LIMITATION OF THE RVT APPROACH FOR ITS APPLICATION TO SEISMIC SSI ANALYSIS OF NUCLEAR STRUCTURES

D. M. Ghiocel, *Ghiocel Predictive Technologies, Inc., New York, USA*

The linear random vibration theory (RVT) is applicable to time-invariant dynamic systems excited by Gaussian processes. More generally, the classical linear RVT approach is usually limited to the multi-degree of freedom (MDOF) systems with classical or non-proportional damping for which the modal decomposition into real eigen-modes is possible (Der Kiureghian, 1980, 1981). For classical damping MDOF systems, the power spectral density (PSD) of the dynamic system response is a real, positive quantity. However, for the coupled MDOF systems, such as the dynamic SSI systems, a non-classical damping should be considered due to the significant differences in the vibration energy dissipation in the structure and soil media. For non-classical damping systems, the PSD of the system response should be a complex quantity with imaginary terms which arise due to the phase effects in the modal responses of the MDOF system. Der Kiureghian, the developer of the RVT approach that was recently implemented in SASSI (Deng and Ostadan, 2012), mentioned clearly that “the effect of non-classical damping can significant in soil-structure systems, where the difference of damping ratios is very large”. ”Numerical examples indicate significant errors with neglecting the effect of non-classical damping” (Igusa and Der Kiureghian, 1983).

Moreover, the RVT approach, as it was implemented recently in SASSI code, is theoretically limited to systems which behave close to the single degree of freedom (SDOF) systems. This is due to the fact that the RVT SASSI implementation uses only a single peak factor for computing the maximum seismic SSI responses (coming from a single mode of SDOF) instead of using multiple peak factors that is required for the MDOF systems with multiple mode contributions. Theoretically correct, multiple peak factors, with one peak factor for each modal response (with different frequency and damping) should be considered (Der Kiureghian, 1980, 1981). The RVT SASSI implementation based on a single peak factor could produce erroneous results when multiple modes have significant contributions, sometime even missing totally significant spectral peaks of the system response.

The paper investigates the accuracy of the RVT SSI approach as implemented in SASSI based on the RS-PSD or PSD-RS transformation in comparison to the traditional SASSI approach for SSI systems in the complex frequency domain which is capable of capturing correctly the non-classical damping and the MDOF system modeling aspects by using the complex Fourier transform approach applied to seismic time-history inputs. Three different analytical formulations for the PSD-RS transformation based on single peak factor were considered in paper (Ghiocel, 2015). Several case studies are presented including surface and deeply embedded nuclear buildings. As expected, the RVT SASSI approach provides crude results in many instances, especially when multiple SSI spectral peak responses are present. The differences could be large, up to 100% or sometime higher for multiple spectral peak responses. For the SSI responses that are dominated by a single peak spectral response, as it is typical for broad band responses, the RVT SASSI approach results are much more reasonable. *The paper is a warning on the application of the RVT SSI approach to nuclear projects without a proper understanding of its theoretical and practical limitations.*

References:

Deng, N. and Ostadan, F. (2012) “Random Vibration Theory-Based Soil Structure Interaction Analysis” The 15th World Conference on Earth. Eng., Lisboa.

Der Kiureghian, A. (1980).“Structural Response to Stationary Excitation”, J of EMD, Vol. 106, EM6

Der Kiureghian, A. (1981). “A Response Spectrum Method for Random Vibration Analysis of MDOF Systems”, J of Earth. Eng. & Struct. Dyn., Vol. 9, 419-435

Ghiocel, D.M. (2015). "Random Vibration Theory (RVT) Based SASSI Analysis for Nuclear Structures Founded on Soil and Rock Sites", *the SMiRT23 Conference*, August 14-19

Igusa. T. and Der Kiureghian, A. (1983). “Dynamic Analysis of Multiple Tuned and Arbitrarily Supported Systems”, University of California at Berkeley, EERC Report 83-07

Idaho National Laboratory Nuclear Safety Research Program

Justin Coleman, Idaho National Laboratory

INL in collaboration with universities and industry partners is developing the next generation of risk informed tools. The program initially started out to provide verified and validated numerical tools and methods for nonlinear soil-structure interaction analysis. The research focus has expanded to include development of risk informed tools and optimization algorithms. Risk informed tools use physics based modeling and simulation results in combination with real world data to highlight the most at risk components in a nuclear facility. This tool can be used for a new nuclear facility design to optimize the risk profile and limit excessive cost and conservatism. It can also be used as a deferred maintenance tool to highlight what pieces of equipment should be replaced given a limited budget.

The team is performing a number of experiments related to wave propagation in soil and gapping, sliding and uplift between concrete foundations and the adjacent soil. Experiments are being performed at both the INL's structural dynamics laboratory and at the University at Buffalo. Gathered data is being used to validate computer models.

Selection of Time Histories for Use in Nonlinear Response History Analysis

Nathan Yost[1], Richard Lee[2], Michael W. Salmon[3]

Abstract for U.S. Department of Energy (DOE) Chief of Nuclear Safety/U.S. Nuclear Regulatory Commission 2018 Natural Phenomena Hazards Workshop, Washington D.C., Oct. 23□25, 2018.

This paper presents background, methodology, and results of a study performed to investigate the potential conservatisms embodied in the traditional approach used for selection and conditioning time history analysis for dynamic analysis of nuclear structures.

DOE–STD□1020□2016 and ASCE 43□05 required that the seismic analysis of nuclear seismic design category 3, 4, and 5 structures be computed in accordance with ASCE□4. Seismic demand may be computed using linear equivalent static analysis, linear dynamic analysis, complex frequency response methods, or nonlinear analysis. Occasionally, time histories are needed as input to some of the dynamic analysis, depending on the method used. ASCE 43□05 section 2.4 provides criteria for developing synthetic or modified recorded time histories. The criteria in ASCE 43□05 are largely designed to produce an acceleration time history that produce a response spectrum that closely matches a target design spectrum. The target design spectra are based in uniform hazard response spectra with an annual frequency of exceedance of 4x10□4 for SDC□3 and SDC □4 structures.

Recent work by Baker and Cornell (2005a, b) and by Baker (2011) have shown that time histories designed to produce a response spectrum matching a uniform hazard spectrum (UHS) can be overly conservative. A UHS envelopes contributions from multiple magnitude/distance contributors to the hazard at a site, but enveloping over the deaggragated epsilons (εs) at a site can be more significant. Baker introduced the conditional mean spectrum (Baker 2005) and the conditional spectrum (Baker and Lee, 2018) as alternatives to the UHS for use in probabilistic dynamic analysis.

Researchers at LANL have recently looked at the potential conservatism introduced by using the traditional UHS matching technique to alternate techniques based on the conditional spectra approach. Thirty sets of ground motion at four different annual frequency of exceedance level were selected using the traditional approach described and above, and two other methods based on modification of the Baker Lee algorithm. A 2□dimensional structural model was then analyzed to each suite of ground motion records to extract distributions of demand. The differences in these distributions shed light into the conservatism associated with the traditional methods.

Procedure 1 is the traditional UHS spectrum matching approach presented in ASCE 43□05 and ASCE 4□16. Procedure 4 utilizes a modified Baker□Lee selection which uses a conditional mean spectrum as a target with a corresponding vertical target using the site specific V/H ratios. Procedure 2 is a hybrid approach that uses the modified Baker□Lee algorithm in selecting ground motions, but uses a UHS as a target spectrum. This approach was used as a sensitivity study only to see if there as significant differences in response due to the selectin algorithms only.

Results and recommendations are presented.

---

[1] Structural Engineer, Los Alamos National Laboratory, nyost@lanl.gov
[2] Chief Engineering Seismologist, Los Alamos National Laboratory, rclee@lanl.gov
[3] Research and Development Engineer, Los Alamos National Laboratory, salmon@lanl.gov

Scaling Acceleration Response Spectra from One Damping to Another

Farhang Ostadan[1], James Marrone[1]

When developing a suite of acceleration time histories for input to a structure for seismic response analyses, the "target" design response spectrum to which the input time histories must conform has primarily been based on one representing 5% spectral damping. For different structures, however, or particularly different components and systems within the structure, response analyses may require evaluations at different damping levels than 5%. To this purpose over the years investigations have evaluated various so-called *damping scaling factors* [DSF] to allow target 5% critically-damped seismic response spectra to be scaled to other required damping levels. While varying significantly, functions of DSF have had some consistent trends, though discriminating dependencies have attempted to bring application-specificity to the DSF functions. Some evaluated dependencies have been controlling earthquake magnitude and distance, site conditions, and tectonic environment.

The focus of DSF investigations, however, has been on recorded *free-field* earthquake time histories. In-Structure acceleration Response Spectra (ISRS) are required for seismic design/qualification of equipment for many critical facilities. As input acceleration time histories are, of course, modified by the structure response, this presentation considers the impact of in-structure response on the DSF of ISRS time histories *within* the structure as compared to DSF of the input acceleration time histories, as well as to the published DSF models based on recorded free-field time histories.

[1] Earthquake Engineering Center, Bechtel Corporation, San Francisco, California.

Impact of Topographic Effects on Site Response at Nuclear Facility Sites

Swetha Veeraraghavan[1], Justin L. Coleman[2] and Jacobo Bielak[3]

[1] Research Scientist, Seismic Research Group, Idaho National Laboratory, US

[2] Seismic Group Lead, Idaho National Laboratory, US

[3] Hamerschlag University Professor, Civil and Environmental Engineering, Carnegie Mellon University, US

Abstract

Mesas, which consist of an elevated area of land with a flat top and steep cliffs at the sides, are one of the common geological formations present in the western United States. Previous research has shown that geological formation such as sedimentary valleys can result in amplification of soil response during earthquakes. There have also been parametric studies to understand the response of an idealized and isolated mountain/valley under inclined plane waves. In the current study, a 2D linear elastic soil domain with topography taken from the western United States with many mesas and canyons is considered to understand site-specific topographic effects in the presence of non-isolated topographical features. Various earthquake fault configurations with varying rupture length and dip angles resulting in a M_w 6.5 earthquake are considered. 2D site response analyses of the soil domain under these earthquake ground motions are conducted using the soil structure interaction (SSI) tool MASTODON developed on Idaho National Laboratory's open source MOOSE finite element framework. These analyses show that the free field response of the soil can be amplified or de-amplified depending on the location of the station relative to the fault dip and location along the mesa. Amplification factors as high as 2 are mainly seen very close to the steep edge of the mesa directly above the fault dip. De-amplifications are also fairly common especially close to the valleys. Such site-specific studies can provide important insights into the topographic amplification factors for a region, which is an important parameter in the design of nuclear power plants at that location.

Three-dimensional Seismic Response of Large Embedded Structures

John Li, Kyungtae Kim, and Ahmed Elgamal

Dept. of Structural Engineering, University of California, San Diego, La Jolla, CA 92093-0085

ABSTRACT

For large embedded structures, soil structure interaction (SSI) plays a major role in determining the overall seismic response. In light of recent strong seismic excitation affecting such structures, three-dimensional (3D) response as well as nonlinear (NL) soil behavior are among the areas of increased interest. As such, a series of 3D NL numerical studies is conducted to shed more light on the involved SSI mechanisms. In this parametric study, consideration is given to factors such as the structure-ground interface properties, and the intensity of seismic excitation. For comparison, additional time domain simulations explored the use soil properties derived from an equivalent linear (EL) site-response analysis. Depending on the level of attained nonlinear response, influence of the following modeling considerations is discussed: i) employing the NL versus EL formulation, and ii) the soil-structure interface characteristics. Accelerations along the profile of the structure, as well as earth pressure on the walls and floor are among the main parameters of interest. From the conducted studies, it is observed that in the free-field, the EL representation adequately matches the NL acceleration response up to frequencies of about 10 Hz. In addition, both formulations generally resulted in remarkably close estimates of the structural response. Potential change in the soil stress-state due to seismic excitation is manifested only in the NL modeling scenarios.

Ahmed Elgamal, Professor and Associate Dean …. *elgamal@ucsd.edu* *858 822-1075*

Preliminary Investigation of Effects of Sliding and Gapping Phenomena in Soil-Structure Interaction Modelling

Efe G. Kurt[1] and Justin L. Coleman[2]

[1] Researcher, Idaho National Laboratory, ID, USA

[2] Seismic Team Lead, Idaho-National Laboratory, ID, USA

Abstract

Nonlinear Soil-Structure Interaction (NLSSI) analyses are used to capture best estimate nuclear facility and nuclear power plant (NPP) response during earthquake motions. These analyses typically include two nonlinear effects: 1) nonlinear soil, and 2) gapping and sliding between the foundation and the soil. It is important to benchmark and validate the numerical models for the two nonlinear effects to build confidence in the predictive capability. The focus of this paper is on experimental tests that will gather data used to benchmark and validate gapping and sliding.

A series of experiments have been conducted to investigate the effects of gaping and sliding on the local and overall behaviour of the structure and soil. The test specimens are composed of soils with different material properties, and model structures with different material and geometric properties. The model structures are loaded in compression, and compression-shear until gaping or sliding occurs. The pressure distribution under the model structures, the strain distribution around the interface between the model structures and soil samples, and displacements, and applied loads on the model structures are collected with the state-of-the art laboratory equipment.

2-D and 3-D models of the tested specimens are developed and compared with the results from the experiments. The compared local and global results from the experiments and different modelling approaches are used to benchmark and validate numerical constitutive gapping and sliding models. These models will be used to have better estimates of the effects of soil-structure interaction of NPPs under in-situ conditions.

Free-field displacements calculated with Green's Functions implemented in SC-SASSI

Julio GARCIA, Benjamin KOSBAB, and Huy TRAN

SC Solutions Inc.

A key step in the formulation and solution of the soil-structure interaction (SSI) problem is the calculation of the displacements of the soil without the presence of a structure, also known as free-field displacements. The free-field displacements are used as basis for the formulation of the compliance matrix or soil flexibility matrix. A new approach to calculate the soil flexibility matrix is presented and implemented as an option in SC-SASSI which uses Green's functions formulation for ring and disk loads to calculate free field displacements in the soil. This approach represents an improvement in the accuracy of the free field displacements, and also allows the simulation of soil-pile-structure interaction problems.

The new Green's function approach uses analytical (exact) solutions in the horizontal direction and discrete (approximate) solutions in the vertical direction, inside and outside of the loaded circle. This is in contrast to the traditional approach in SASSI which calculates the free field displacements in the soil based on a cylindrical core that uses a finite element (FE) approximation inside of the cylindrical core (discrete solution in horizontal and vertical direction) and transmitting boundaries (TB) outside of the cylindrical core (analytical solution in the horizontal direction and discrete solution in the vertical direction). The Green's functions formulation calculates displacements in the soil using Hankel Functions, Bessel Functions, as well as the eigenvalues and eigenvectors solution to the one-dimensional site response (wave propagation) problem.

This study demonstrates and compares the calculation of free field displacements due to forced vibration loads. First, the results of free field displacements using Green's functions' approach with SC-SASSI are presented and verified. Next, a comparison is presented for free-field displacements using different approaches: (1) Green's functions approach with SC-SASSI; (2) Finite Element-Transmitting Boundary approach with SC-SASSI; and (3) Results from DOE SASSI V&V Report. The results from different approaches are compared and evaluated, and the relative influence of key parameters is assessed.

ASCE 4-16 STANDARD-BASED PROBABILISTIC SSI ANALYSIS. PART 1: APPLICATION FOR DESIGN BASIS LEVEL (DBE)

D. M. Ghiocel, *Ghiocel Predictive Technologies, Inc., New York, United States of America*

ABSTRACT

Probabilistic soil-structure interaction (SSI) analysis is capable of capturing in much more detail the uncertainties related to the seismic motion, soil layering and structural behaviour than deterministic SSI analysis. In the introduction of the new ASCE 04-2016 standard (2017) it is stated that the purpose of the analytical methods included in the standard is to provide reasonable levels of conservatism to account for seismic analysis uncertainties. More specifically, the probabilistic responses defined with the 80% NEP are considered adequate.

The ASCE 4-16 standard Section 5.5 (ASCE, 2017) recommends for probabilistic SSI analysis the application of stochastic simulation using the Latin Hypercube Sampling (LHS). The ASCE 4-16 standard addresses both the probabilistic site response analysis (PSRA) and the probabilistic SSI analyses (PSSIA) in Sections 2 and 5.5, respectively.

Probabilistic modelling should include at least the random variations due to:
- Response spectral shape model for the seismic input
- Low-strain soil shear wave velocity Vs and hysteretic damping D profiles for each soil layer
- Soil layer shear modulus G and hysteretic damping D as random functions of soil shear strain
- Equivalent linear/effective stiffness and damping for concrete structural elements depending on stress/strain levels in different parts of the structure

For the probabilistic SSI response simulations, the input is represented as an ensemble of randomized seismic input motion sets. Each set consists of two horizontal components and one vertical component. The seismic motion response spectral amplitude for each direction is assumed to be a random variable or a 1D-1V random field with lognormal probability distribution. The low-strain Vs and D soil profiles are assumed to be statistically dependent 1D-2V random fields with normal or lognormal probability distribution. The statistical dependence is due to their joint dependence on the soil shear strain in each layer.

The paper illustrates the application of the new ASCE 04-16 standard recommendations for probabilistic SSI analysis applicable to the design-basis level (DBE) applications. Few case studies including a surface and a deeply embedded SMR-type structure are presented. Probabilistic and deterministic SSI analyses were comparatively performed for a surface and a deeply embedded SMR SSI model. The 80% NEP probabilistic-based and the deterministic-based ISRS are compared. The probabilistic SSI analyses assumed that the spectral shape of the site-specific ground response spectra, the soil stiffness and damping profiles were idealized as random fields. The structural stiffness and damping random variations were modelled as a pair of correlated random variables that depend on the computed structural stress levels. The comparative SSI results include in-structure response spectra (ISRS) at different locations.

The ACS SASSI software with Options PRO and NON is used for this paper.

ASCE 4-16 BASED PROBABILISTIC SEISMIC SSI ANALYSIS. PART 2: APPLICATION FOR BEYOND DESIGN BASIS LEVEL (BDBE)

D. M. Ghiocel, *Ghiocel Predictive Technologies, Inc., New York, United States of America*

ABSTRACT

Probabilistic soil-structure interaction (SSI) analysis is capable of capturing in much more detail the uncertainties related to the seismic motion, soil layering and structural behaviour than deterministic SSI analysis. In the introduction of the new ASCE 04-2016 standard (2017) it is stated that the purpose of the analytical methods included in the standard is to provide reasonable levels of conservatism to account for seismic analysis uncertainties. The ASCE 4-16 standard Section 5.5 (ASCE, 2017) recommends for probabilistic SSI analysis the application of stochastic simulation using the Latin Hypercube Sampling (LHS). The ASCE 4-16 standard addresses both the probabilistic site response analysis (PSRA) and the probabilistic SSI analyses (PSSIA) in Sections 2 and 5.5, respectively. Probabilistic modelling should include at least the random variations due to:
- Response spectral shape model for the seismic input
- Low-strain soil shear wave velocity Vs and hysteretic damping D profiles for each soil layer
- Soil layer shear modulus G and hysteretic damping D as random functions of soil shear strain
- Equivalent linear/effective stiffness and damping for concrete structural elements depending on stress/strain levels in different parts of the structure

For the probabilistic SSI response simulations, the input is represented as an ensemble of randomized seismic input motion sets. Each set consists of two horizontal components and one vertical component. The seismic motion response spectral amplitude for each direction is assumed to be a random variable or a 1D-1V random field with lognormal probability distribution. The low-strain Vs and D soil profiles are assumed to be statistically dependent 1D-2V random fields with normal or lognormal probability distribution. The statistical dependence is due to their joint dependence on the soil shear strain in each layer.

The paper illustrates the application of the new ASCE 04-16 standard recommendations for probabilistic SSI analysis applicable to the beyond design-basis level (BDBE) applications. Probabilistic SSI analyses for the beyond design-basis (BDBE) applications are typically performed for seismic input review levels that are much larger than the design-basis (DBE) seismic input, often by 2-3 times. For such much larger BDBE seismic inputs, the role of the nonlinear soil and structure behaviours become very important SSI modelling aspects for obtaining meaningful seismic margin results. Herein, the application of the probabilistic SSI analysis per the new ASCE 4-16 standard is presented in the context of the seismic fragility analysis of a typical concrete shearwall nuclear building.

For performing a pertinent probabilistic SSI analysis per the new ASCE 4-16 recommendations, probabilistic models for the seismic input motion, the soil profile and the structure are defined for several seismic hazard review levels. Structural and equipment fragility results are compared for several assumptions for selecting the review levels: i) 3 review hazard levels for annual probabilities of 1.e-4, 1.e-5 and 1.e-6, b) 7 review hazard levels for annual probabilities of 3.e-4,

1.e-4, 3.e-5, 1.e-5, 3.e-6, 1.e-6 and 5.e-7, iii) 1 review hazard level for annual probability of 1.e-4, and iv) 1 review hazard level for annual probability of 1.e-5. Also, the paper also shows a comparison between the probabilistic SSI analysis results based on the new ASCE 4-16 probabilistic-based methodology and based on the traditional EPRI deterministic-based methodology as applied in a number of seismic fragility analyses of nuclear utilities in US. The comparative analyses are performed for a single review level of 1.0g maximum ground acceleration that corresponds to the 1.e-5 annual probability. Comparative results include structural and equipment fragilities and total risk estimates.

The ACS SASSI software with Options PRO and NON is used for this paper.

Seismic fluid-structure-interaction in liquid metal nuclear reactors

Chingching Yu, Faizan Ul Haq, Michael Cohen, Justin Coleman, Philippe Bardet and Andrew Whittaker

Liquid-metal coolants enable thermal efficiencies not possible with the traditional pressurized water and boiling water reactors that make up the commercial nuclear fleet in the United States at this time. Thermal efficiency is achieved by minimizing the thicknesses of materials used in the construction of the reactor vessel and its internals, which may compromise seismic robustness. Design and seismic qualification of liquid metal reactor vessels and their internals will rely heavily on fluid-structure-interaction analysis, for which *verified* and *validated* computer models will be needed.

Results of a numerical study are presented that 1) verify numerical models for the seismic analysis of a ground-supported and head-supported cylindrical tanks using the ALE and ICFD formulations in LS-DYNA, and 2) characterize the seismic response of fixed and isolated head-supported reactor vessels to extreme ground motions. The first study supports the verification of numerical models for FSI analysis. The second study supports an experimental program on one of the 6DOF earthquake simulators at MCEER/University at Buffalo that will build a dataset to enable validation of numerical models. a numerical model of a generic liquid-metal reactor vessel to guide the design of a test article to be tested in late 2018 on an earthquake simulator at the University at Buffalo. ALE and ICFD models were used for the numerical studies to enable calculations for a wide range of seismic inputs for which nonlinear fluid response is possible. Information on the proposed testing program, and sample results, if available, will be presented.

Improvements in Frequency-Domain SSI Capabilities

Isabel Cuesta
Costantino and Associates

This presentation will discuss the state-of-the-art improvements and SSI capabilities that are fully applicable to nuclear facilities.

These improvements include:

1) Frequency-domain soil-structure-fluid interaction analysis.
2) Generation and export of SSI impedance and load vectors for different soil profiles into any commercial FEM Program (e.g., ANSYS, ABAQUS) used to model and design/analyze the structure.
3) Section cuts in frequency-domain analysis.
4) Cost-effective solutions of large models.

These significant improvements extend the analysis capabilities by (1) allowing the full suite of modern FEM elements, materials and constraints to be used in the analysis (e.g., acoustic elements); (2) reducing SSI analysis costs; and (3) streamline the analysis process by using the same model for both operation loads and seismic loads.

PROBABILISTIC SIMULATION PROCEDURE FOR DEVELOPING SITE-SPECIFIC PLANE-WAVE COHERENCE FUNCTIONS

D. M. Ghiocel, *Ghiocel Predictive Technologies, Inc., New York, USA*

ABSTRACT

This paper presents a probabilistic simulation approach for computing site-specific coherence functions based on 2D soil FE modeling and calibration of the "generic" Abrahamson analytical coherence models.

The paper shows that the site-specific coherence functions can deviate substantially from the "generic" Abrahamson coherence functions. At this time, about 10 years after the 2007 EPRI report on seismic wave incoherency (Abrahamson, 2007), there is a sufficient evidence from both dense array records and studies, that the deviation of the site-specific coherence functions from the "generic" EPRI Abrahamson coherence functions can substantial. The "generic" Abrahamson coherence functions also do not include the seismic motion directionality aspects which for particular sites could be significant. There are number of seismic experts who are aware that the "generic" Abrahamson coherency models might not be automatically applicable to any specific site project for licensing. However, this it was not translated yet in official USNRC or ASCE regulatory positions.

The specific incoherency effects produced by the existence of a nonuniform subgrade material under the nuclear building are considered by modeling the nonuniform subgrade zone as a separate 2D soil layering model. The SSI response of the nonuniform subgrade model at the structure foundation level was used as a seismic incoherent input for the structure. This physics-based incoherency modeling was required to capture the very specific incoherency effects on the structure, which were produced by the nonuniform subgrade material under the nuclear building. It should be also noted that the deviation of the site-specific coherence functions from the "generic" Abrahamson coherence functions was also recently discussed in the LOSSVAR workshop organized by the EDF Lab Saclay, Paris on August 2016. The workshop presentations are a good source of information on the subject.

The paper presents a straight forward computational approach based on using 2D soil layering probabilistic simulations. The paper explains the theoretical and implementation details of the proposed approach. The results of the proposed approach are in excellent agreement with the site-specific coherence functions provided by Abrahamson and other researchers.

Two validation cases are included: 1) the Pinyon Flat rock site investigated by Abrahamson and 2) the EDF "digital" site with uniform properties site investigated by EDF researchers.

Fluid-Soil-Structure Interaction Analysis of Tank for Seismic Evaluation of Nozzle Subjected to Differential Movement

Natalie DOULGERAKIS[1], Michael SALMON[2], Benjamin KOSBAB[1], and Payman TEHRANI[1]

[1] SC Solutions Inc.; [2] Los Alamos National Laboratory

This presentation summarizes the methodology and results from a recent seismic evaluation of a safety-class fire water storage tank. Tanks such as this are common at both DOE and NRC regulated nuclear facilities and their safety function following earthquake is relied upon for various design scenarios. The evaluation was initiated out of a concern for overstress and the potential loss of contents due to induced seismic anchor motions. Seismic-induced differential movement between a tank and its draw-off piping is a commonly overlooked failure mode but can introduce nozzle vulnerability that could challenge the pressure boundary of the tank and thus compromise tank inventory. Differential movement can be especially important in situations such as: (a) draw-off piping and tank supported by separate foundations; (b) soil site introducing soil-structure interaction effects; (c) inelastic response of the tank and/or its anchorage; and/or (d) fluid-structure interaction from tank contents. An analytical fluid-soil-structure interaction (FSSI) study is performed on an example configuration of tank /nozzle / draw-off piping to characterize the dynamic response behaviors which affect seismic demands on the tank nozzle.

The FSSI study utilizes a 3D finite element (FE) model, based on insights from hand calculations and simplified analyses. The tank itself is modeled with linear shell elements, and is supported on its concrete ring foundation and a continuum soil domain, both of which are modeled with solid elements. Soil is modeled with layers having equivalent-linear strain-compatible properties consistent with a design-level seismic hazard. The bearing support of the tank (in compression) is modeled using contact surfaces between the tank base and the ring foundation / soil. The tank anchorage to its ring foundation is modeled via non-linear spring elements representative of the elasto-plastic behavior of cast-in-place anchor bolts for realistic representation of tank rocking and uplift. Lagrangian fluid elements are used to represent the water contained in the tank, and coupled to the structural model. A viscoelasticity approach is utilized to model the nearly frequency-independent hysteretic response of the soil, concrete, and tank shell. Draw-off piping is modeled with shell elements at the tank connection, and with equivalent beam elements elsewhere. The 3D FE model is analyzed using dynamic response history analysis via explicit time domain integration, with ground motion time histories applied at the base of the soil profile. Sensitivity analyses are also performed to assess the relative significance of different configurations and details.

Three phenomena are found to drive the peak tank stresses around the nozzle and the maximum positive nozzle moment: fluid mass convection, pressure impulses within the fluid, and tank uplift. Fluid convection, fluid impulse, and tank uplift are interrelated behaviors, and peak demands occur when peaks in each of the contributing response behaviors coincide. Each of these behaviors contribute to differential movement between the tank and the supports for the draw-off piping, which is characterized by both a vertical uplift and a translational displacement (along the longitudinal axis of the pipe), both of which contribute to demands on the tank wall.

Blind Prediction of the Capacity of Unreinforced Concrete Column Capitals

Michael Salmon[1], Eric MacFarlane[2], Lawrence Goen[3]

Abstract for U.S. Department of Energy (DOE) Chief of Nuclear Safety/U.S. Nuclear Regulatory Commission 2018 Natural Phenomena Hazards Workshop, Washington D.C., Oct. 23–25, 2018.

LANL is initiating a collaborative experimental program with the University of Nevada, Reno investigating the nonlinear behavior and ultimate punching shear capacity of unreinforced column capitals. Results of the experimental program will be used to inform subsequent modeling of the columns in a nonlinear response history analysis of the columns at various loading levels. As part of the experimental work LANL is conducting an open source blind prediction contest open to any interested parties. This paper will introduce the objectives of the blind prediction contest, rules and submittal requirements. Results of the blind predictions along with the results of the experimental program may be used in quantifying modeling and response uncertainties in the prediction of the dynamic response of reinforced concrete systems for use in seismic fragility analysis.

Many Department of Energy and US NRC facilities were designed and constructed in the 1970s and 1980s to older reinforced concrete construction standards. Since the San Fernando earthquake of 1971 reinforced concrete detailing requirements have substantially improved. Much of the concrete research has been focused on enhancing the ductile response of concrete shear walls and beam column joints in moment frames. The ability of reinforced concrete structures to respond well into the nonlinear regime is desirable because of the large energy dissipation associated with hysteretic behavior. To date there has been little research into the nonlinear behavior of unreinforced column capitals on columns with 1970s vintage reinforcing.

LANL has initiated a test program for full-scale testing of typical 1970s vintage lightly reinforced columns with unreinforced capitals. This test program is part of the laboratory's commitment for continual reduction of the seismic risk from laboratory operations. A blind contest that predicts the behavior of the test specimens will be held in conjunction with the experimental program. Participants will predict the response of the test specimens using whatever methods they choose. The experimental program will be conducted in three phases. Phase 1 includes tests on the in-situ columns capital assembly subjected to increasing cyclic transverse and axial loading protocols. Phase 2 includes a similar series of tests, but will be conducted on columns with a portion of the column strengthened with carbon fiber polymer wraps. The column capitals remain unwrapped in Phase 2 testing. Phase 3 includes the same carbon fiber wrapped strengthening as Phase 2, but extends the strengthening to the column capitals.

Rules for the blind prediction contest with details on submission, loading protocols, specimen details, material properties, etc. will be presented. Participation will be encouraged.

[1] Research and Development Engineer, Los Alamos National Laboratory, salmon@lanl.gov
[2] Structural Engineer, Los Alamos National Laboratory, emac@lanl.gov
[3] Engineering Services Division Leader, Los Alamos National Laboratory, lgoen@lanl.gov

Evaluation of Cast Iron Fittings in a Hazard Category 2 Nuclear Facility

Michael W. Salmon[1], Eric MacFarlane[2], Maia Menefee[3], Rick Augustine[4]

Abstract for U.S. Department of Energy (DOE) Chief of Nuclear Safety/U.S. Nuclear Regulatory Commission 2018 Natural Phenomena Hazards Workshop, Washington D.C., Oct. 23□25, 2018.

This paper presents background, methodology, and results of a destructive test program performed on carbon steel fittings in an existing fire water suppression supply system. The fire water suppression system (FSS) was designed and installed in the early 1970s. The piping material was specified in the original design as ASTM A120, Schedule 40 carbon steel. Information on the material used in the fittings was not available. Recently the facility had envisioned upgrading the FSS to meet DOE□STD□1020□2004 seismic design criteria as a safety class component. Part of the safety basis strategy required the FSS to function following a PC□3 (SDC□3) event.

We performed a dynamic response spectrum analysis of a representative sample of the FSS using AutoPIPE and the provisions of ASCE□4□16 and using in□structure response spectra generated for evaluation of new systems in accordance with ASCE 4□16. Stresses in the piping system were checked against the allowables of ASME B31E. Preliminary results indicated that the stresses and displacements of the piping and supports were well within allowables. However, review of the stress analysis by others brought into question the validity of the assumption that the fittings were made of the same material as the pipe (ASTM A120). Because of this uncertainty, LANL undertook a limited destructive test program in which several small coupons of steel material were removed from fittings. Tensile tests were performed on a sample of these coupons. It was discovered that the likely material for the fittings was ASTM A48, Grade 20 gray cast iron. This material has a much lower stress allowable than what was previously assumed.

The use of gray cast iron for fittings per ASME B16.1 and B16.4 is allowed per NFPA 13 and may be more prevalent in existing fire water suppression systems than commonly assumed by structural engineers performing stress analysis of these systems. Caution should be used when making assumptions about the material and allowable stress properties for threaded fittings in existing fire water suppression system.

This paper will present the methods used in determining the allowable stress properties of the fittings. It will describe the analysis conducted and it will present a summary of the results. Strengthening plans for upgrading the system will also be summarized.

---

[1] Research and Development Engineer, Los Alamos National Laboratory, salmon@lanl.gov
[2] Structural Engineer, Los Alamos National Laboratory, emac@lanl.gov
[3] Student Intern, Los Alamos National Laboratory, mmenefee@lanl.gov
[4] Structural Engineer, ARES Corporation

An Optically-based Sensor System for Critical Facilities Post-Event Seismic Structural Assessment

Floriana Petrone[1] and David McCallen[1,2]

[1]Lawrence Berkeley National Laboratory, 1 Cyclotron Rd., Berkeley, CA (USA)
[2]University of Nevada, Reno, 1664 North Virginia St., Reno, Nevada (USA)

The infrastructure assets belonging to the U.S. Department of Energy (DOE) support agencies and offices that play a key role in promoting and advancing the research of a breadth of strategic fields including national security, discovery science and energy research. It becomes clear that the safety and integrity of this broad inventory of critical infrastructures, in addition to representing a massive resource investment, is tightly tied to the success of the DOE mission.

The DOE enterprise counts a remarkable number of critical facilities residing in areas of medium and high seismic hazard, which exposes them to the concrete risk of undergoing structural and nonstructural damage in response to earthquake events. This potentially translates into a significant economic loss and operational interruptions/delays for the DOE functions. Experience with past earthquakes in the western U.S. has demonstrated that post-event assessments of structural integrity is very challenging and can be costly and time consuming, mainly because of the lack of facility response data.

For enabling a fully efficient facility management system, the availability of active and passive structural monitoring systems is of primary importance, as it can allow prompt and effective detection of damage after any seismic event. In the design of ordinary and major structures, the interstory drift - defined as the measure of the relative displacement between two adjacent levels - is largely used as a key parameter for defining levels of *structural performance*. The same concept is then extended to the assessment of existing structures, in which the interstory drift is used as measure for defining *damage indexes*. The availability of robust and accurate systems for directly monitoring the structural permanent drift would provide an essential tool for rapid assessment of facility response and help enable informed response decisions.

In this context, this work presents recent DOE supported developments toward a new optically-based technique for measurement of both transient interstory drift (TID(t)) and residual interstory drift (RID). The ability of this newly designed laser-based optical sensor system to directly measure interstory drift is demonstrated through experimental and model-based evaluations. The scope is to extend the application of an innovative structural monitoring system based on optical sensors to the analysis of real three-dimensional structures and to define an optimization procedure for the monitoring systems design.

This monitoring system is rapidly approaching an application ready state and will be available for application at DOE sites and could help address recent recommendations related to DOE's emergency preparedness and response capability. This presentation will describe all aspects of this new sensor technology and illustrate the design and experimental testing results for the optical sensors.

High Performance Simulations for Regional Scale Seismic Hazard and Risk Assessments

David McCallen
Center for Civil Engineering Earthquake Research
University of Nevada, Reno
& Energy Geosciences Division,
Lawrence Berkeley National Laboratory

Anders Petersson
Center for Applied Scientific Computing
Lawrence Livermore National Laboratory

Arthur Rodgers
Atmospheric, Earth and Energy Division
Lawrence Livermore National Laboratory

Mamun Miah
Energy Geosciences Division
Lawrence Berkeley National Laboratory

Hans Johansen
Computational Research Division
Lawrence Berkeley National Laboratory

Estimation of the ground motion hazard due to future earthquakes continues to be a very challenging problem for the earthquake engineering and earth science communities. The current state-of-practice for hazard estimation for critical facilities includes an empirically based probabilistic seismic hazard assessment which homogenizes historical ground motion estimates from world-wide earthquake measurements based on an ergodic assumption of earthquake processes. Analysis of actual earthquake ground motion recordings has illustrated the complex distribution and strong site-dependency of observed motions. The complexities of motions are dictated by the fault rupture process (earthquake source), the modification of the earthquake generated waves as they propagate from source to site (path effects), and the interaction between incident waves and the site and facility of interest (site response and soil-structure-interaction). The limitations of utilizing ground motions from many other sites to estimate motions at a particular specific site has become clearer in recent years and there is an important opportunity for physics-based simulations to reduce the uncertainties associated with current ground motion estimates.

To this point in time, direct numerical simulation of ground motions has been a very challenging problem which has been constrained by the extreme computational demands of three-dimensional modeling of seismic wave propagation. With even the most advanced high-performance computers, regional-scale simulations have been limited to simulations on the order of 2-3Hz which creates significant restrictions for engineering applications.

In this presentation, recent developments in advancing physics-based simulations of earthquake hazard and risk will be described. This work is being executed in a DOE Exascale Computing Project (ECP) application development. The application development is creating a high-performance computing framework that will perform coupled simulations of ground motions and resulting infrastructure response. The overall objective is to advance the frequency resolution of ground motion simulations to the frequencies of interest for engineering evaluations of infrastructure. This will require utilization of leadership DOE computing and exploitation of the Exascale computers under DOE development.

The Role of Engineers in Society

By
Lawrence A. Salomone, P.E.
ceus_ssc@yahoo.com

Commercial corporate goals involved during the early days of my career in 1970 included: 1) Profit or Share Price, 2) Employee Welfare, 3) Retention of employees supporting a Company's core competence and 4) Community. I found that commercial corporate goals changed to focus primarily on Profit or Share Price as my career progressed. It then became important to learn to navigate in the commercial corporate world with this change in priorities.

I was trained to be a critical thinker as an engineer. My management skills and critical thinking allowed me to navigate through the commercial corporate world. An engineer has the skills to lead. An effective engineer should trust and respect his/her colleagues and should be generous giving credit to his/her colleagues. Each professional must decide to be a leader or a follower. An engineer will be retained to advance in the company as long as an engineer uses his/her critical thinking skills and ethics to provide value to a company. If one does not provide value, an engineer could be asked to leave. By adding value to the company and living the ethics which were part of engineering training will allow an engineer to navigate in the corporate world.

In 2008, utilities began responding to the Energy Policy Act of 2005 by planning the first nuclear power plants in 30 years. Because of the pause in the design and construction of nuclear power plants, the only model available to assess earthquake hazard was a 30-year old seismic hazard model. This need provided me an opportunity to develop a plan for updating the inputs used for Probabilistic Seismic Hazard Assessments. The updated source model for the Central and Eastern United (2012) resulted in a DOE award and the updated ground-motion model (2013) provided the basis for the Nuclear Regulatory Commission's response to the Congressional directive regarding the Fukushima Dai-Ichi Accident in 2011. The updated plan for assessing earthquakes was developed by forming an industry-government partnership to provide financial and technical support. An overview of the plan will be part of the presentation.

The 1994-1995 baseball Major League Baseball strike was the eighth work stoppage in baseball history, as well as the fourth in-season work stoppage in 22 years. The dispute was played out with a backdrop of years of hostility and mistrust between the owners and players. In response to a worsening financial situation in baseball, the owners of Major League Baseball teams collectively proposed a salary cap to their players which the players rejected. This impasse hurt many Americans and vendors and the image of Major League Baseball. This labor dispute provided me an opportunity to use my critical thinking skills to develop the strategic plan which addressed the problems facing Major League Baseball. The plan entitled, "Playing Baseball in the Twenty-First Century," was submitted to the Chairman of the Executive Council of Major League Baseball, Bud Selig, and it is now available in the Baseball Hall Of Fame and Museum. An overview of this strategic plan will be part of the presentation.

Periodic Review and Update of NPH Assessments

Sharon Jasim-Hanif, U.S. Department of Energy

Abstract

Department of Energy (DOE) Order 420.1C, *Facility Safety*, requires DOE nuclear facilities with safety SSCs classified as NDC-3 or higher, be reviewed at least once every ten years and whenever significant changes in NPH data, models, or analysis methods have been justified. DOE Standard (STD) 1020-2016, *Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities* contains criteria and guidance for performing these reviews. During 2013-2014, DOE Office of Nuclear Safety (AU-30) conducted a study of how these periodic NPH assessment reviews were being performed. The Report '*Implementation of Periodic Natural Phenomena Hazards (NPH) Assessment Reviews at DOE Sites*' was issued in April 2015.

This presentation will discuss the outcomes and lessons learned from the AU-30 review and discuss any further actions that should be taken to support effective implementation of the ten-year NPH review requirements stated in DOE STD 1020-2016.

Opportunities to Improve NPH Evaluations

Greg Mertz

Costantino and Associates

This presentation will discuss continuous improvement of NPH evaluation methodologies using several past NPH analyses in the DOE complex as examples. Lessons learned include professional development of engineering staff, development of engineering tools, the role of technical inquisitiveness, the importance of load path, interpretation of analysis results and the benefits of performance based acceptance criteria.

Defense Nuclear Facilities Safety Board GIS Natural Phenomena Hazard Database

Yong Li and Lisa Schleicher

Defense Nuclear Facilities Safety Board

Department of Energy (DOE) Order 420.1c requires that all DOE nuclear facility sites periodically review their Natural Phenomena Hazard (NPH), including earthquake, wind, flood and volcanic hazards, just list a few. Any significant changes to data, model and methodology related to a site NPH could lead to a site hazard reassessment and then potential design changes. The periodic review and possible following reassessment relies significantly on understanding site-specific NPH information and its changes. Therefore, establishing a NPH database and updating it continuously will ensure the availability of up-to-date NPH information for each nuclear facility site.

Defense Nuclear Facilities Safety Board (DNFSB) provides independent analysis, advice, and recommendations to DOE on adequate protection of public health and safety at defense nuclear facilities. Establishing a NPH database will enhance the Board's safety oversight of DOE nuclear facilities. Because NPH data are geospatial data, NPH database will be built upon a Geographic Information System (GIS) platform. Specifically, the GIS NPH database will allow the staff member understanding the hazard in an integrated manner. The database will also reduce future data requests to various DOE sites and their contractors and will ensue knowledge transfer among the Board staff members and also to prioritize site reviews based on estimated hazard change.

In sum, the GIS NPH database will enable the staff member's oversight of DOE's NPH periodic review more active, informative and effective. The database can also be an effective tool for assisting the staff's review of emergency preparation and hazard mitigation when NPH events or human related events occur.

Overview of NRC's Probabilistic Flood Hazard Assessment Research Program

Joseph Kanney, Meredith Carr, Elena Yegorova, Mark Fuhrmann Thomas Aird, Jacob Philip

U.S. Nuclear Regulatory Commission

This presentation will provide an overview of the probabilistic flood hazard assessment (PFHA) research program being carried out by the U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Regulatory Research (RES). This research program is designed to support development of tools and guidance to improve consideration of risks due to flooding in regulatory activities such as permitting new nuclear sites, licensing of new nuclear facilities, and licensing and oversight of operating facilities. Research progress and results are shared with various stakeholders and the public through the annual NRC PFHA Research Workshop, publication of NUREG series reports, presentations at the NRC Regulatory Information Conference, and other public meetings.

NRC's PFHA research is being conducted using a phased approach:

Phase 1 (Technical Basis): Focusing mainly on the probabilistic hazard assessment element of risk analysis (i.e., precipitation, riverine flooding, and coastal flooding processes), but including limited work on reliability of flood protection features and procedures, flood mitigation strategies, and initial work on quantitative assessment of plant response to a flooding event. Currently, RES is in the 4th year of a 5-year effort to complete Phase 1 research.

Phase 2 (Pilot Testing): Develop and perform pilot studies to gain real-world experience in applying the methods developed in Phase 1. This phase will include significant interactions with external stakeholders (e.g. one or more licensees, industry research organizations). This phase will also include work to fill in gaps or deficiencies identified during the pilot studies.

Phase 3 (Guidance): Finalize guidance on use of methods and tools developed previous phases. This phase will also include significant interactions with internal and external stakeholders.

Cooperation and collaboration with other federal agencies (e.g. USACE, USGS, USBR, DOE), domestic and international research organizations (e.g., Electric Power Research Institute, French Institute for Radiological and Nuclear Safety) is being pursued in order to leverage their research activities and experience to further common objectives. In addition to completing the final aspects of Phase 1 research, RES staff are currently in the planning stage for Phase 2 and Phase 3, and are actively seeking additional collaborations from other agencies and industry in these activities.

NUREG–2213: Updates to SSHAC Guidance

Miriam Juckett[1], John Stamatakos[1], Jon Ake[2], Cliff Munson[2], Kevin Coppersmith[3], and Julian Bommer[4]
[1]Center for Nuclear Waste Regulatory Analyses
Southwest Research Institute
San Antonio, Texas

[2]U.S. Nuclear Regulatory Commission
Rockville, Maryland

[3]Coppersmith Consulting
Walnut Creek, California

[4]Imperial College London
London, United Kingdom

The complexity of tectonic environments and the limited data available for seismic source and ground motion characterization make the use of a significant level of expert judgment in seismic hazard assessment studies unavoidable. The U.S. Nuclear Regulatory Commission (NRC) formulated guidance through the Senior Seismic Hazard Analysis Committee (SSHAC) regarding the way uncertainties in probabilistic seismic hazard analysis (PSHA) should be addressed using expert judgment. In 1997, the NRC issued its first guidance document on this topic, NUREG/CR-6372, “Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and the Use of Experts.” NUREG/CR-6372 describes a formal process for structuring and conducting expert assessments that came to be known as a “SSHAC process,” and the recommendations in the report are referred to as the SSHAC guidelines. The guidelines describe a series of study levels (1-4) with increasing scope, complexity and regulatory confidence.

Implementation of the SSHAC process in practical applications provided an accumulation of experience that led NRC to issue updated guidance in NUREG–2117, “Practical Implementation Guidelines for SSHAC Level 3 and 4 Studies,” in 2012. Since that time, numerous seismic hazard studies have been conducted worldwide utilizing SSHAC guidance, particularly after the Fukushima earthquake and tsunami. Based on the lessons learned from these studies, the need for further guidance, clarification, and elaboration became evident. Many of these recent SSHAC studies highlighted the importance of SSHAC Level 1 and Level 2 studies, especially when evaluating new information regarding the need for updating or replacing existing Level 3 and Level 4 studies or for application to other types of natural hazards.

To update SSHAC guidance with the most recent lessons learned and state-of-practice, the NRC has now issued NUREG–2213, “Updated Implementation Guidelines for SSHAC Hazard Studies.” This document builds on the framework described in the prior NUREGs while providing additional clarification and detail for certain parts of the SSHAC process. It preserves the key features and processes of previous guidance and, while it should be considered the most current standalone guidance, does not invalidate studies conducted under the earlier NUREGs.

Specifically, NUREG–2213: (i) clearly identifies the five key features that define a SSHAC study and allows an objective distinction to be made from non-SSHAC studies; (ii) strengthens the implementation framework for Level 3 studies, based on extensive recent experience; (iii) provides guidance on the attributes of Level 1 and 2 studies; and (iv) presents a revised, more rigorous framework for decision-making regarding the updating of existing SSHAC studies. To fulfill the objective of providing a consistent, structured framework for conducting hazard analyses, NUREG–2213 provides sufficient detail regarding implementation to ensure that various practitioners will interpret the guidelines in a reliable and consistent manner. Further, these guidelines describe an acceptable framework for nuclear facility licensees to implement the recommendations in Regulatory Guide 1.208 with respect to performing a probabilistic seismic hazard analysis study. In this presentation, we discuss some of the key updates in NUREG–2213 and the process and information that the NRC staff used to develop the document.

Next Generation Liquefaction Case History Database

P. Zimmaro[1], D.Y. Kwak[2], J.P. Stewart[1], Scott Brandenberg[1], John Stamatakos[3], Miriam Juckett[3], Thomas Weaver[4], S.L. Kramer[5]
[1]Department of Civil and Environmental Engineering
University of California at Los Angeles, Los Angeles, California

[2]Department of Civil and Environmental Engineering
Hanyang University, Ansan, Gyeonggi-do, South Korea

[3]Center for Nuclear Waste Regulatory Analyses
Southwest Research Institute
San Antonio, Texas

[4]U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Rockville, Maryland

[5]Civil and Environmental Engineering, University of Washington, Seattle, Washington

The Next Generation Liquefaction (NGL) Project was established by Pacific Earthquake Engineering Research Center (PEER) in 2013 to address significant shortcomings in the existing engineering practices used to evaluate liquefaction susceptibility, triggering, and consequences. NGL is a collaborative effort among research and government organizations interested in liquefaction risk. In 2016, the National Academy of Sciences (NAS) published a report highlighting key concerns about seismically induced liquefaction, describing the current state of engineering practice and emphasizing the shortcomings of existing methods and models. The NAS report recommended that the US establish a curated, publicly accessible database of relevant liquefaction triggering and consequence case-history data. The report also stated that the database should include case histories of events where soils have interacted with buildings and other structures; document relevant field, laboratory and physical model data; and establish strict protocols for data quality. Simultaneously, the U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Regulatory Research recognized the uncertainty in current liquefaction methods and models, citing specific concerns on how to develop and implement reliable, robust, performance-based and risk-informed nuclear safety regulations. The NRC has identified the need to update existing regulatory guidance on the methods used to evaluate seismic soil liquefaction [Regulatory Guide (RG) 1.198, "Procedures and Criteria for Assessing Seismic Soil Liquefaction at Nuclear Power Plant Sites"] and associated review guidance found in the Standard Review Plan (NUREG–0800). In 2016, NRC contracted with SwRI's CNWRA to support the objective of developing a liquefaction case-history database.

In this presentation, we describe the structure and format of the NGL database, including the formal relational database schema. The schema describes how data is organized into fields, structures, or tables and how these entities relate to each other. We will illustrate example data entries, explain the NGL database web interface, and describe the database interface, and lay out a vision for integration with the DesignSafe platform at the University of Texas Advanced

Computing Center. DesignSafe is the web-based research platform of the National Hazards Engineering Research Infrastructure Network that provides the computational tools needed to manage, analyze, and understand critical data for natural hazards research. Finally, we describe the administrative aspects of the NGL database, including the methods and protocols to manage, review, and document the quality of the data. These case histories documented in the database will form the basis for new liquefaction triggering and consequence models that are part of the larger NGL project.

This abstract is an independent product of the CNWRA and does not necessarily reflect the view or regulatory position of the NRC. The NRC staff views expressed herein are preliminary and do not constitute a final judgment or determination of the matters addressed, or of the acceptability of any licensing action that may be under consideration by the NRC.

Wind-borne missile impact on exterior walls and slabs in nuclear power plants

Brian Terranova, Len Schwer and Andrew Whittaker

Exterior walls and roofs in safety-related nuclear facilities in the United States, including nuclear power plants, must be designed to resist the loadings imposed by missiles borne by hurricanes and tornadoes. A parametric study was conducted to investigate the effects of panel thickness, Schedule 40 pipe size (mass and diameter), pipe velocity, and concrete uniaxial compressive and tensile strength on the resistance of reinforced concrete panels to impact by missiles borne by winds due to tornadoes and hurricanes. The axisymmetric SPH model used for the simulations was validated using data from tests at Sandia National Laboratory of four reinforced concrete panels impacted by Schedule 40 pipes. The values of panel thickness and concrete compressive strengths considered in this parametric study are typical of those in existing nuclear power plant structures in the United States. The Schedule 40 pipe is the missile used for simulations because it is referenced in the United States Nuclear Regulatory Commission (USNRC) Standard Review Plan and the Department of Energy (DOE) Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities that point to Regulatory Guide (RG) 1.76, RG 1.221, and ANSI/ANS 2.3-2011 for the definition of missiles and impact velocities. The impact velocities envelope the maximum velocities recommended in the USNRC and ANS documents for the design against the impact of Schedule 40 pipes. Impact resistance was evaluated using two metrics: 1) perforation (complete penetration of the panel by the missile), and 2) scabbing (ejection) of concrete from the back face. A considerable number of design parameters have a meaningful effect on the impact resistance of reinforced concrete panels. The most important parameter, aside from panel thickness, is tensile strength of concrete. The results from the parametric study enable the writing of guidance on the minimum thickness of reinforced concrete panels to resist the effects of wind-borne missile impact for 152 mm (6 in), 203 mm (8 in) and 254 mm (10 in) diameter Schedule 40 pipes.

Using a Graded Approach to the DOE STD 1020-12 Tornado Missile Criteria

Adeola Adediran[1], Jay Amin[2], Brent Gutierrez[3],

[1]Savannah River Remediation, 742-7G Savannah River Site, Aiken, SC 29808;
PH (803) 208-3520; email: adeola.adediran@srs.gov
[2]Savannah River Remediation, 742-2G Savannah River Site, Aiken, SC 29808;
PH (803) 208-8956; email: jayprakash.amin@srs.gov
[3]Department of Energy, 730-2B Savannah River Site, Aiken, SC 29808;
PH (803) 952-9284; email: brent.gutierrez@srs.gov

ABSTRACT

With the implementation of DOE-STD-1020-2012, a significant change in design tornado missiles has occurred for Department of Energy (DOE) facilities. Previously, DOE-STD-1020 specified a uniform set of tornado missiles (2x4 plank, 3" ∅ steel pipe, and a rolling and tumbling automobile) for all DOE facilities.

At the last NPH Workshop we warned that the new tornado missile criteria in DOE STD1020-12 & -16 may prove problematic to apply at the Savannah River Site and many other DOE sites because it included the requirement to check for the "flying automobile". At that time there wasn't a case study where the problem had yet been encountered. However, since then we have applied the flying automobile criteria to the Tank Closure Cesium Removal (TCCR) System enclosure design and we wanted to share the successful application of the graded approach to the criteria in STD-1020 to a steel framed structure for tornado missile impact or tornado wind. This may help other DOE sites and in their design for the "flying automobile" impact on their structures.

The steel framing of the new Metal Enclosure Structure with Ion Exchange Columns (IXC) installed inside as shown in Figure 1 is typical of many steel structures on SRS. Ordinarily a metal enclosure as shown in Figure 1 cannot be expected to survive an impact from an automobile. The graded approach was to evaluate the secondary effects of the impact of the tornado missile from the enclosure failure on the Ion Exchange columns. These columns are the critical systems in the structure that were not to fail. The failure mode of these IXC assemblies were distilled down to not rotating past 10.7° and preventing perforation of the outer skin of the assemblies. Therefore, by allowing the enclosure to fail thereby dissipating the energy at impact we were able to prevent the undesirable failure modes of the IXC assemblies themselves shown in Figure 2 recorded in the Design Safety Analysis document (DSA).

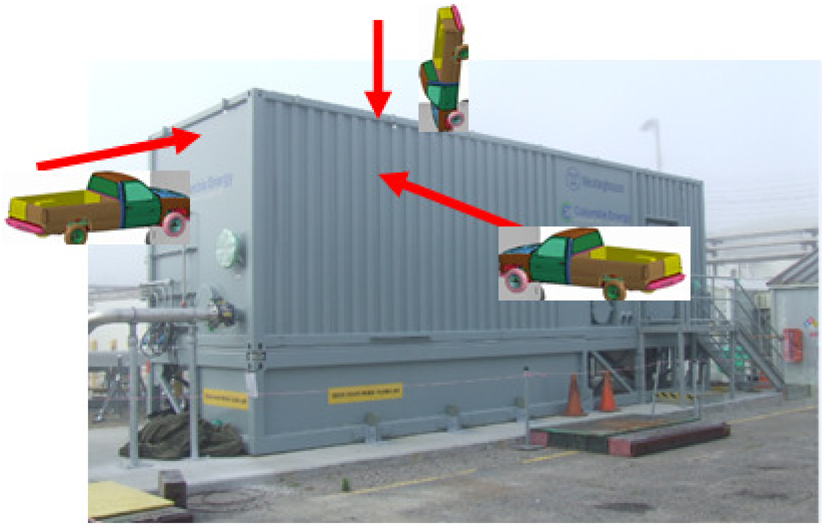

Figure 1

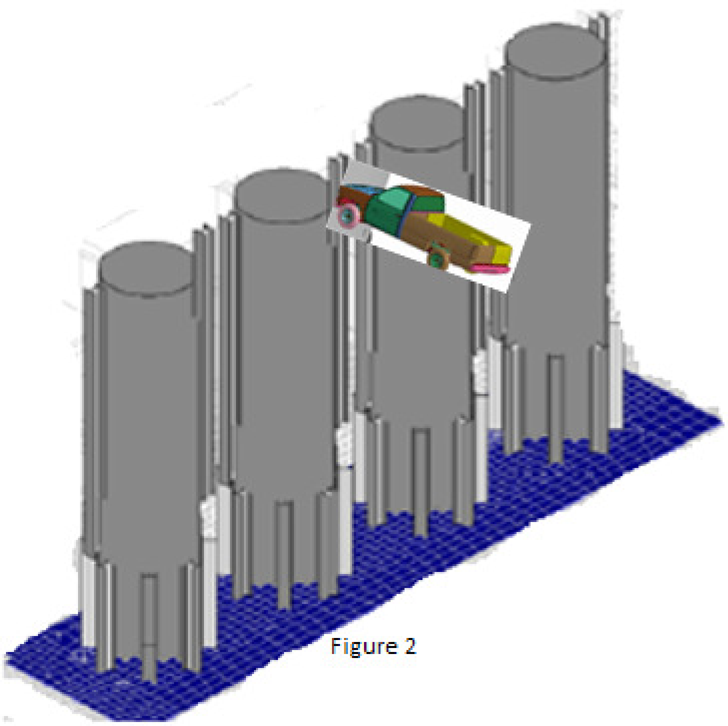

Figure 2

Comparison of Deterministic and Probabilistic Estimates of Liquefaction

Tom Houston, Andrew Maham, Greg Mertz

Costantino and Associates

This presentation will discuss the differences in approach and results from liquefaction evaluations based on deterministic and probabilistic approaches. The deterministic approaches use UHRS definitions of ground motions while the probabilistic approaches include deaggregation of the seismic hazard. Predictions of liquefaction triggering and associated vertical and lateral deformations will be discussed.

Determination of the Magnitude and Source Location of Paleoearthquakes from Paleoliquefaction Evidence

Russell A. Green
Department of Civil and Environmental Engineering, Virginia Tech

The probabilistic assessment of the seismic hazard of a region requires estimates of the magnitudes, source locations, and times of occurrence of past events that have impacted the region. However, information about these parameters is often limited in regions where the return period of moderate-to-large earthquakes is significantly longer than the historic earthquake record, such as in the Pacific Northwest (PNW) and the central/eastern United States (CEUS) -- we know moderate-to-large earthquakes occurred in these regions, we just do not know how large the events were or how often they occur. Paleoseismic techniques, particularly paleoliquefaction investigations, are plausible ways to extend the earthquake record into prehistoric times and allow both the recurrence time and characteristics of moderate-to-large earthquakes to be established. This presentation focuses on ongoing research being performed at Virginia Tech on determining the magnitudes and locations of pre-instrumental/prehistoric earthquakes from paleoliquefaction evidence, to include the quantification of uncertainty of these estimates. This research fills the gap between paleoliquefaction field studies which focus on identifying and dating features and the inputs required for probabilistic seismic hazard analyses (e.g., maximum magnitude and magnitude recurrence for the region). The approaches being developed take advantage of recent developments in ground motion predictive equations and liquefaction triggering procedures.

Oroville Dam Spillway - Engineering Geology Support Activities for Response and Recovery

Frank Syms

Lettis Consultants International, Inc.

Oroville Dam is the highest dam in the U.S. at some 770 feet and more than a mile across at the crest. The subject of much debate and scrutiny, there is nothing wrong with the dam itself. In February 2017, record rainfall across the region resulted in an emergency situation when the primary Flood Control Outlet (FCO) spillway was damaged. As inflow continued to exceed outflow capacity, the Emergency Spillway (ES) was used for the first time in the history of the reservoir. Continued destruction of the FCO and headward erosion threatening the ES resulted in the evacuation of nearly 200,000 people across two counties. The Department of Water Resources, Project Geology group played a significant role in the fast track response and subsequent recovery required to rebuild a functioning spillway to handle impending rainfall for the next winter. This talk will be an overview of the role that Project Geology played in the project and some of the specific activities that supported design, construction and long term maintenance of the new infrastructure.

Assessment of Potential Hazard from Tectonic Surface Deformation at New Nuclear Power Facilities by the U.S. Nuclear Regulatory Commission - A Case History

Gerry L. Stirewalt, U.S. Nuclear Regulatory Commission, Gerry.Stirewalt@nrc.gov

Prior to constructing and operating a new nuclear power facility in the United States, the U.S. Nuclear Regulatory Commission (NRC) requires an applicant to demonstrate that geologic characteristics of the proposed site are suitable for the intended facility design. NRC's regulatory requirements in Part 100.23 of Title 10 of the U.S. Code of Federal Regulations indicate the importance of geologic site characterization for a proposed new nuclear power facility and state that the potential for hazard specifically resulting from tectonic surface deformation (i.e., faulting) at a proposed site must be determined by an applicant to permit an adequate evaluation of the site. NRC geologists evaluate the applicant's conclusions and supporting data related to the presence of and potential hazard resulting from surface faulting at the site, including information constraining the age of faulting and the results of geologic mapping performed under the NRC's Geologic Mapping License Condition (GMLC). NRC considers faults that are 2.58 million years (Ma) or less in age (i.e., Quaternary) to be a primary focus for hazard assessment because Quaternary faults have a greater potential for creating a natural geologic hazard than do tectonic features that are pre-Quaternary in age. The GMLC requires an applicant to perform detailed geologic mapping of excavations for safety-related engineered structures at a new plant site, evaluate geologic features discovered, and notify the NRC once the excavations are open for examination by NRC staff.

This case history briefly summarizes investigations performed by the applicant for the Virgil C. Summer Nuclear Station (VCSNS) Combined License (COL) application to assess potential hazard related to surface faulting at the locations of two proposed new nuclear power reactors, Units 2 and 3, in South Carolina. These investigations included detailed geologic mapping of excavations for safety-related engineered structures for Units 2 and 3, as required by the GMLC. The two proposed units were located adjacent to existing VCSNS Unit 1 that began operation in January 1984. Faults with a documented minimum age greater than 66 Ma mapped in foundation rocks at Unit 1 enhanced the applicant's understanding of the need to assess the possible existence of faults at proposed Units 2 and 3. The case history focuses on explaining how NRC geologists independently confirmed the applicant's conclusions related to potential hazard due to surface faulting at the site and verified that field relationships and radiometric age dates constrained timing of displacement along minor faults and shear zones to be pre-Quaternary in age. By direct examination of field relationships of faults in the excavations for safety-related engineered structures at VCSNS Units 2 and 3, comparison of field observations with results of the geologic mapping of excavations for both units, and review of the radiometric age dates acquired by the applicant, NRC geologists verified that all available field and laboratory data documented the absence of faults and shear zones of Quaternary age in the excavations. Therefore, the NRC was able to confirm the applicant's conclusion that negligible potential existed for hazard related to surface faulting at the VCSNS site.

Updating On-Site Ground Motion Reporting and Simulation of Ground Motions from Nearby Earthquakes at Lawrence Livermore National Laboratory

Arthur Rodgers

Atmospheric, Earth and Energy Division, Lawrence Livermore National Laboratory

Lawrence Livermore National Laboratory (LLNL) is situated within the boundary of the Pacific and North American tectonic plates and is consequently exposed to significant seismic hazard. Ground motion hazard at LLNL is dominated by the Greenville Fault (GF), only 1-3 km of locations on the main site. The GF is capable of earthquakes up to magnitude 6.9 (Lienkaemper et al., 2013). The Hayward Fault (HF) is more likely to rupture (UCERF3, 2015) and is capable of similar magnitude ruptures, but is further away. Because LLNL is located within a seismic active region and relatively small (1 square mile), we can rely on permanent earthquake monitoring networks to report ground motions. These networks are operated by the United States Geological Survey, California Geological Survey and University of California Berkeley Seismology Laboratory. However, limited data are available for on-site recordings of ground motions. Recently, LLNL has performed a scoping study to record and rapidly report earthquake ground motions on site. The goal is to reduce latency in ground motion reporting and get reports to emergency management and facility operators as soon as possible. By recording and reporting ground motion intensities on site we can reduce the likelihood of communication breakdowns and power outages impacting data flow. We have also simulated ground motions for scenario earthquakes near LLNL in three-dimensional geologic/seismic models using high-performance computing. We report estimates of ground motions from GF and HF earthquakes from simulations and compare these to ground motion models used in hazard estimates.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. LLNL-ABS-752979

Technical Basis for Updating Seismic Hazard Analysis Guidance in NUREG-1520, Standard Review Plan for Fuel Cycle Facility License Applications

John Stamatakos[1], Jonathan Marcano[2], Cliff Munson[2], Jon Ake[2], Patrick Koch[2], and Miriam Juckett[1]
[1]Center for Nuclear Waste Regulatory Analyses
Southwest Research Institute
San Antonio, Texas

[2]U.S. Nuclear Regulatory Commission
Rockville, Maryland

In this technical presentation, we evaluated the currently acceptable approaches employed by licensees and license applicants to develop the seismic hazard analyses that are reviewed by the U.S. Nuclear Regulatory Commission (NRC) as part of licensing and safety evaluations of fuel fabrication facilities regulated under Title 10 of the *Code of Federal Regulation* (10 CFR) Part 70. As described in NUREG–1520, acceptable seismic hazard assessment methods for fuel cycle facilities include a range of options, such as U.S. Geological Survey (USGS) seismic hazard maps, the USGS seismic hazard mapping tool, or an approximated hazard by using the Regulatory Guide (RG) 1.60 spectra anchored at the Safe Shutdown Earthquake of the nearest nuclear power plant. In this report, we compare the results of these methods to site-specific fully probabilistic seismic hazard analyses at four sites in the central and eastern United States. These four sites were selected to represent a range in site conditions, from hard bedrock to thick soft soil, and relative hazard potential, from a high hazard area near the center of the New Madrid seismic zone to a low hazard site in eastern Pennsylvania. The results of the evaluation and associated recommendations described in this report are not intended to substitute for other important aspects of fuel cycle safety, nor are the results intended to challenge existing technical bases for seismic safety at NRC-regulated fuel cycle facilities. However, our results demonstrate the benefits of updating NRC's seismic hazard guidance for fuel cycle facilities to include fully probabilistic and site-specific seismic hazard analyses as a method for assessing seismic hazard. These updates will harmonize NRC's guidance on seismic hazard analyses with the current state of practice and across the agency, increase technical confidence and risk consistency, and support the NRC's goal of risk-informed, performance-based regulations.

Integration of Risk-informed Performance-based Approach to Seismic Safety of Nuclear Power Plants

Jose A. Pires[1], Jon P. Ake[1], J. Xu[2], H. Li[1] and R. Gascot-Lozada[1]
[1] U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research
[2]U.S. Nuclear Regulatory Commission, Office of New Reactors

In general, the seismic performance of nuclear power plants (NPPs) encompasses functional and physical design. The plant/system level functional design typically relies on a design basis accident analysis to identify safety-related systems, structures and components (SSCs) and the physical design of each SSC involves prescriptive and deterministic approaches. Integration of seismic probabilistic risk assessment (SPRA) with risk-informed performance-based (RIPB) approaches for the physical design of SSCs can be highly effective in advancing an interactive design process to produce optimal design outcomes. SPRA can provide the plant/system risk perspectives and clearly identify the role and performance expectations for the involved SSCs while the RIPB design approach facilitates the physical design of individual SSCs to meet the required performance goals established by the functional design. If appropriately implemented, this integration and further developments in the RIPB guidance for physical design of SSCs, can be a significant advance in the seismic design and safety reviews of nuclear power plants, which could provide options to achieve seismic safety goals and to focus NRC approaches on the most important safety-significant aspects of seismic issues.

The Office of Nuclear Regulatory Research (RES) of the U.S. NRC is starting a research effort to further RIPB approaches to the seismic safety of nuclear power plants. This research will align with broader staff efforts and initiatives to advance risk-informed approaches in various areas of safety reviews. The research will consider implications and applications not only for potential new reactor designs but also for the currently operating fleet. One thrust will evaluate the current NRC seismic regulatory framework with the goal of identifying potential pathways for implementation or enhancement of RIPB approaches to achieve seismic safety. This evaluation will consider plant and system level performance goals, as well as those related to individual SSCs. Based upon these evaluations, the work will prepare an assessment of potential changes to existing NRC guidance. The work will include evaluating methods for developing an SPRA for a design certification process as well as methods for addressing seismic risk in a generic Part 52 process. The work also will evaluate the potential application of RIPB approaches to performance goals other than those typically utilized in large light water reactors. The objective of the other thrust is to formulate technical bases for consolidated RIPB guidance for the physical seismic design of SSCs important to safety in a manner that leverages existing RIPB consensus standards for seismic analysis and design of SSCs to the extent practicable. The work will review the approach and provisions in the consensus standards for RIPB physical design published by the American Society of Civil Engineers (ASCE) and assess how those approaches and provisions, in conjunction with provisions in structural design and equipment qualification codes, achieve the intended SSC performance goals. A goal is to develop consolidated RIPB guidance that would provide an alternative to the current prescriptive and deterministic approaches for achieving or confirming SSC performance goals consistent with the intended plant or system level performance.