

STRUCTURAL INNOVATION AT THE HANFORD WASTE TREATMENT PLANT

Issue Date: December 2008

Abstract—Three innovative techniques have been used in meeting the structural challenges of designing and constructing the mammoth facilities constituting the first-of-a-kind Hanford Waste Treatment Plant. Addressing the areas of design production, nuclear safety assurance, and constructability, the first technique is a systematic approach to developing bounding loads considering dynamic response; the second is an advanced technique in soil-structure interaction (SSI) analysis, which provides confidence in the adequacy of the design; and the third approach is a construction tool that ensures the quality of concrete placement in highly congested areas.

Keywords—acceleration, bounding load, congestion, Hanford, high-level waste, high-slump concrete, incoherency, low-activity waste, nuclear waste, radioactive waste, response acceleration, seismic criteria, soil-structure interaction (SSI), structural innovation, structural steel

INTRODUCTION

Situated on the banks of the Columbia River in the shrub-steppe desert area of southeastern Washington state, the US Department of Energy's (DOE's) Hanford Site was where plutonium was produced for the Manhattan Project atomic bomb program that began in the early 1940s. Throughout the four-decade Cold War, the facility continued its national security mission to produce materials for nuclear weapons. The end of production at Hanford brought the task of cleanup and finding a long-term storage solution for the site's legacy: 53 million gallons of highly radioactive waste stored on site in underground steel tanks.

In December 2000, the DOE Office of River Protection awarded Bechtel National, Inc., the Hanford Waste Treatment Plant (WTP) project to build the world's largest such facility to solve the long-term storage problem. The \$12 billion facility will separate the waste into high-level and low-level streams, which when mixed with silica, heated to melting, and deposited in stainless-steel canisters will cool and harden into a stable glass safe for long-term storage.



Figure 1. Hanford Waste Treatment Plant Facilities, Washington State

The low-activity waste will be stored on site over the long term while the high-level waste is planned for shipment to Yucca Mountain in the Nevada desert.

As shown in **Figure 1**, WTP consists of three mammoth nuclear waste processing facilities—Pretreatment, Low-Activity Waste Vitrification, and High-Level Waste (HLW) Vitrification—each with reinforced concrete core structures surrounded by structural steel frames. A fourth facility, the large Analytical Laboratory, will contain a concrete “hot cell” where radioactive materials will be tested and categorized. The concrete cores will house process equipment, with support services located in the steel portion of the structures.

John Power
jrpower@bechtel.com

Mark Braccia
mrbraccia@bechtel.com

Farhang Ostadan,
PhD
fostadan@bechtel.com

ABBREVIATIONS, ACRONYMS, AND TERMS

ACI	American Concrete Institute	psi	pounds per square inch
ASCE	American Society of Civil Engineers	PTF	Pretreatment Facility
DOE	US Department of Energy	SASSI	System for Analysis of Soil-Structure Interaction
HLW	high-level waste	SSI	soil-structure interaction
ISRS	in-structure response spectra	WTP	Waste Treatment Plant
NRC	US Nuclear Regulatory Commission	ZPA	zero period acceleration

Determining adequate bounding loads is critical when design is “close-coupled” with construction.

The four facilities are designed to meet a combination of commercial and nuclear codes and regulations, and two of them, the Pretreatment Facility (PTF) and the HLW facility, are designed to the same rigor as nuclear power generating facilities, including full dynamic analyses using site-specific seismic criteria.

The sheer size and scope of these facilities present first-of-a-kind challenges. Due to schedule constraints, WTP is a “close-coupled” project in which the design of the upper floors was under way during construction of the foundation. This approach posed an enormous challenge in developing reasonably conservative design loads in the anticipation of structural design changes.

This paper describes three of the several innovative techniques used in designing and

constructing the facilities, addressing the areas of design production, nuclear safety assurance, and constructability. The first technique is a systematic approach to developing bounding loads considering dynamic response; the second is an advanced technique in soil-structure interaction (SSI) analysis, which provides confidence in the adequacy of the design; and the third approach is a construction tool that ensures the quality of concrete placement in highly congested areas.

DETERMINING BOUNDING LOADS [1]

The first of these innovative techniques is the two-step method for determining design bounding loads. Current codes and DOE regulations require consideration of

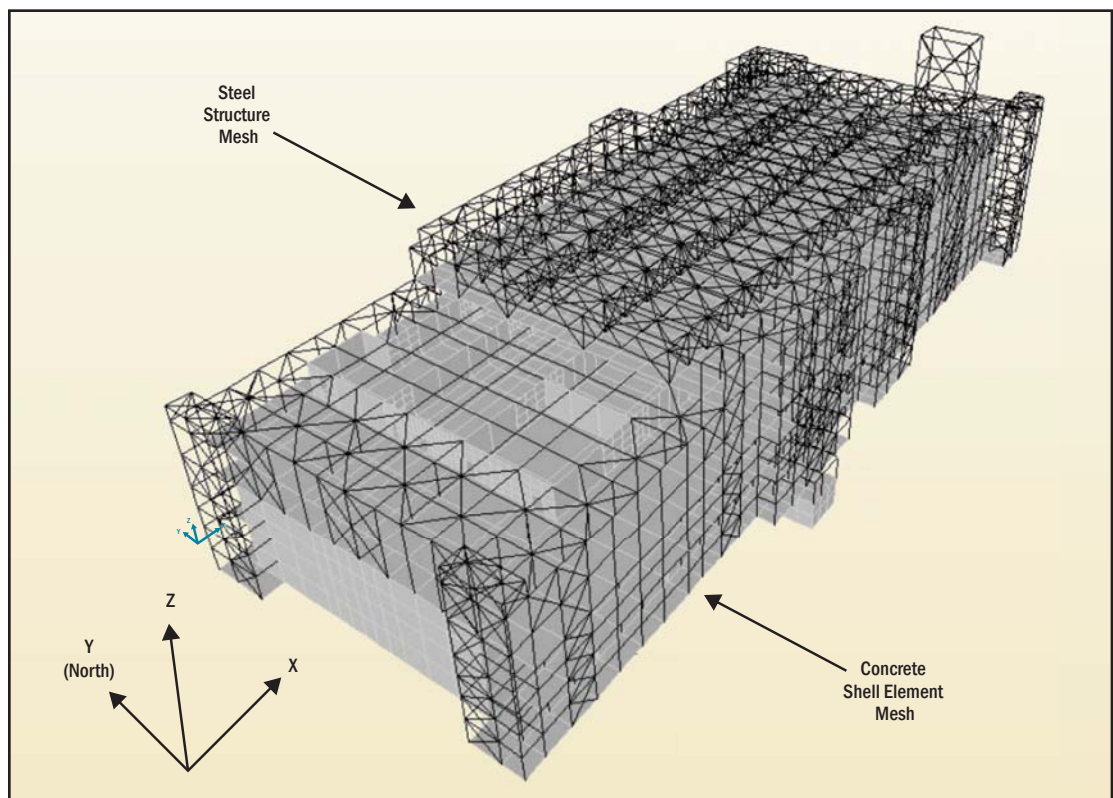


Figure 2. SAP2000 Static Model for Steel Comparison

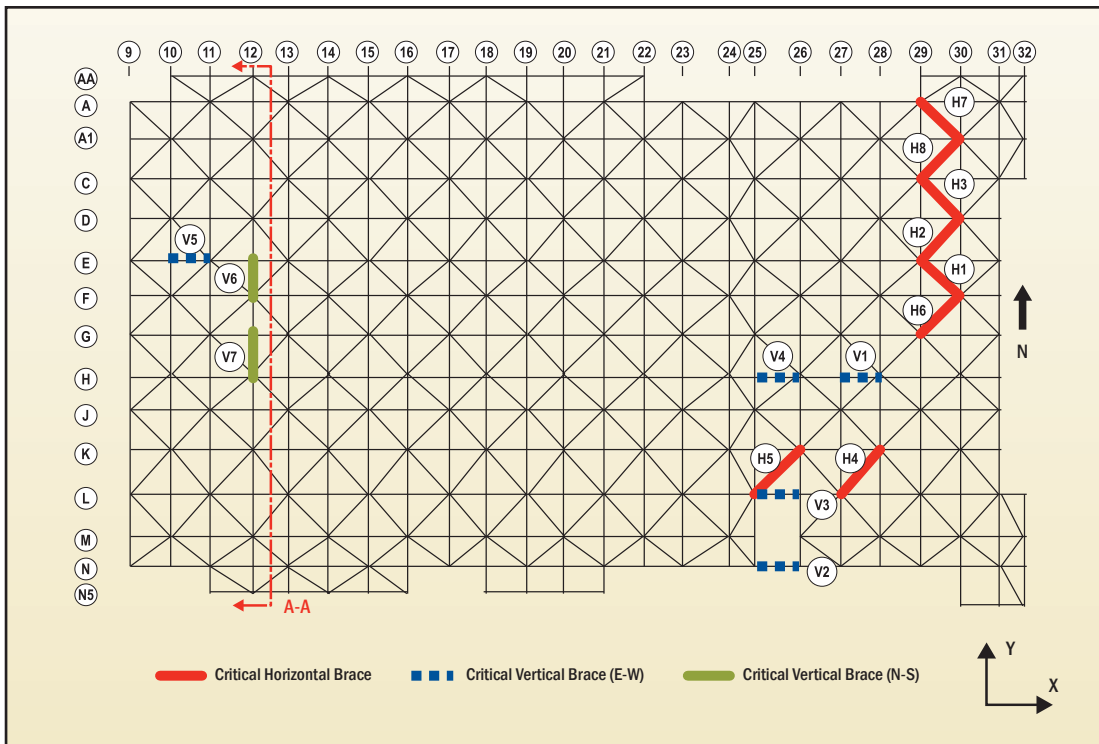


Figure 3. Plan View of Roof – Critical Bracing Members

SSI and dynamic response effects in the analysis of major nuclear facilities, such as the PTF and HLW facilities. However, current SSI software does not efficiently combine seismic responses with other loads required for design. Compounding this problem is the enormity of the structures and the analytical models that depict them (e.g., the finite element model for these structures exceeds 100,000 elements).

In addressing the challenge, WTP is one of the major nuclear projects using a detailed finite-element model for seismic SSI analysis. The state-of-the-art methodology and computer program SASSI (System for Analysis of Soil-Structure Interaction) was chosen for the SSI analysis. SASSI uses a complex frequency-response technique to simulate the time-history seismic analysis. Three separate SSI analyses are performed in which the seismic input motion—in terms of acceleration time history at grade—is applied in the X, Y, and Z directions, respectively. A range of soil cases is considered in the analysis to account for the variability of soil properties and the results are enveloped. Maximum acceleration profiles and in-structure response spectra (ISRS) are calculated taking into account the co-directional responses.

By reviewing the transfer functions obtained from the SASSI analyses, the response of the concrete structure and steel roof is adequately captured. Each steel member's maximum forces and moments are computed for validation purposes. These steel forces are spatially combined using the component factor method

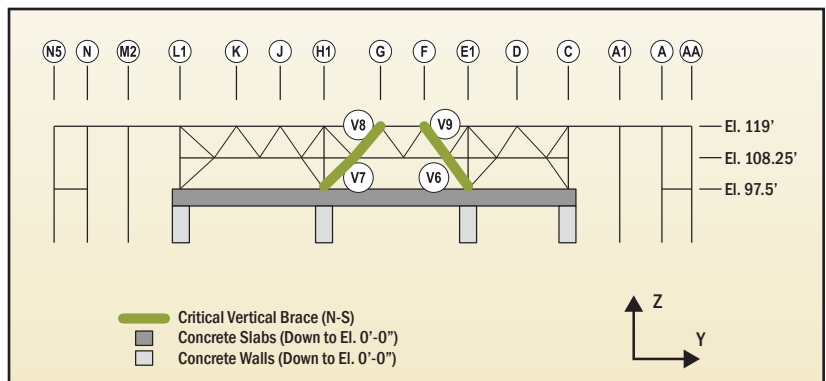


Figure 4. Section Cut AA

(100/40/40), which assumes that when the maximum response from one component occurs, the responses from the other two components are 40% of the maximum. [2] Also for validation purposes, shear stresses are calculated in the concrete shear walls.

In the second step, acceleration profiles derived from the first step are used, with an adjustment scale factor greater than or equal to 1.0, for the statistical analysis of the detailed finite-element model using SAP2000 computer code. [3] Figure 2 shows the finite-element model of the building studied in the steel member comparison. The Y-axis is in the N-S direction and the Z-axis is vertical upward. Figures 3 and 4 show the steel roof frame and identify the critical bracing members for which seismic force comparisons were made. The structure is supported by

The two-step method provides reasonable bounding loads to allow design and construction to progress.

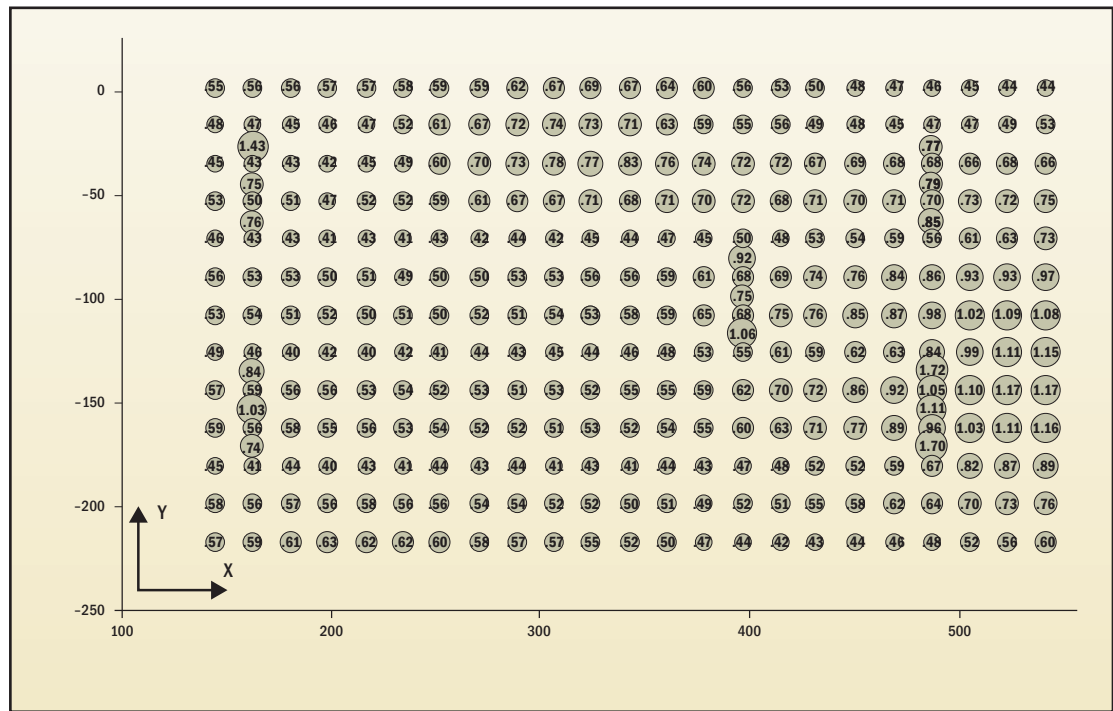


Figure 5. Roof Bubble Plot – X Acceleration (g) due to X-Direction Seismic Input

appropriate linear elastic soil springs. All steel member forces are extracted for design, and forces are combined using the component factor method.

The key to the two-step method is the use of conservative acceleration profiles derived from the SASSI analysis results, adjusted to ensure that calculated seismic stresses are conservative, even at local high-stress concentration areas. Establishing conservative acceleration profiles requires a good understanding of the dynamic responses of the structure from the first-step SSI analysis.

One of the tools used to show the dynamic behavior of the structure is the acceleration “bubble plot.” Available in Microsoft® Excel®, a bubble plot is simply a two-dimensional coordinate plan view of one elevation of the structure with a bubble plotted at every node within that elevation. The size of the bubble is proportional to the magnitude of the maximum acceleration at that node. Nine bubble plots are normally generated at each elevation, representing the response accelerations in the X, Y, and Z directions due to seismic input. In Figure 5, the bubble plot shows the maximum nodal response accelerations in the X direction due to seismic input in the X direction at the elevation of the steel roof.

Based on the nine bubble plots, a mass-weighted average maximum acceleration is determined for each story; then, if required, the story is divided into regions with similar accelerations and a conservative acceleration is assigned to

each region. (These adjusted acceleration profiles are applied to the static model in the second step of analysis.) The acceleration plots provide a clear picture of the dynamic response of the structure, floor by floor and wall by wall, so that timely decisions on design changes can be made to improve the seismic response. Such an iterative process would not have been possible following the commonly used practice of developing seismic shear and moment diagrams, and would not have enabled examination of the dynamic response of individual structural members.

ADVANCED SOIL-STRUCTURE INTERACTION ANALYSIS USING INCOHERENCY EFFECT [4]

The second innovation entails consideration of incoherency when determining seismic accelerations in the design of major nuclear facilities. The WTP facilities will contain and process highly radioactive materials, which if released would cause a serious threat. The facilities are just miles from the Columbia River, the largest North American river to flow into the Pacific Ocean. The public and regulators demand that appropriately conservative assumptions be made to bound the natural phenomena hazards the facility could experience. Earthquake is one of the primary design inputs, and although prescriptive techniques are available to define the potential seismic events, they require making assumptions that would directly influence the final spectra. With this situation in mind, the WTP design team took

on the task of showing that the development of conventional spectra is conservative because it does not consider that not all seismic waves impact the structure in unison.

When determining the SSI, a fully coherent model will lead the ground motion to transfer directly to the structure across the full range of frequencies. Introducing incoherency into the model reduces the structural response at high frequencies, thereby reducing the seismic forces used to qualify equipment. This approach can result in significant project savings by lowering the cost of major equipment.

The basic concept of incoherency is that high-frequency waves imposed on a large structure will not translate into the full building motion that would result in smaller structures. The best way to visualize this concept is to consider two vessels in an ocean: a 30-foot sailboat and an aircraft carrier. Four-foot swells would cause noticeable rocking and bouncing for the sailboat's passengers, but passengers on the aircraft carrier would barely perceive the motion. The same concept applies to the process equipment in the primary facilities of a major nuclear facility.

While the details of the incoherency model are beyond the scope of this paper, **Figure 6** demonstrates the resulting reduction in accelerations at high frequencies as compared to the results using a fully coherent model. The peak acceleration is approximately 11% lower and the zero period acceleration (ZPA) has been reduced by 25%. These reductions will translate into significant savings when

seismically qualifying equipment in the high-frequency range. Following this important development and its documentation, the US Nuclear Regulatory Commission (NRC) approved the incoherency model and its implementation in the SASSI program for SSI analysis. [5]

DEVELOPMENT OF CONCRETE MIX FOR HIGHLY CONGESTED AREAS

The third innovation is the use of high-slump concrete in congested concrete placements. The plant process areas will be located in multistory reinforced concrete structures. In addition to the heavy reinforcement, surface plates with embedded studs used throughout to support equipment and commodity attachments result in highly congested forms (see **Figures 7 and 8**). The danger in this situation is voids, which could require expensive repairs.

The proposed solution was to use a high-slump concrete mix that could work through the congestion without leaving voids. It was specified as a 5,000-psi (pounds per square inch) mix with a maximum water-cement ratio of 0.45. Additionally, maximum aggregate size was limited to 3/4 inch to prevent bridging or binding during placement. The construction team also sought a mix with 11-inch slump, which results in 1-inch final slump cone height, just slightly higher than the aggregate size. Finally, as the mix had to meet the criteria established in ACI 349, Bechtel worked with the project's concrete supplier to develop a mix that met the criteria.

The NRC has approved the use of incoherency in design of nuclear facilities.

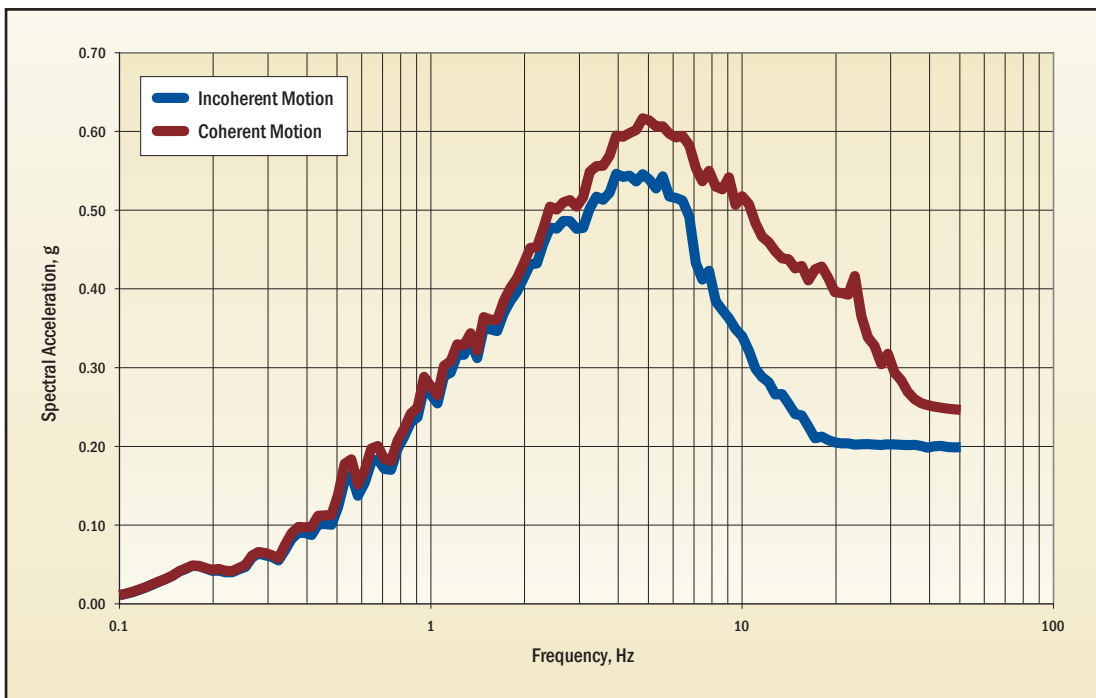


Figure 6. Foundation Motion in the Horizontal Direction (5% Damping, Rigid Massless Square Foundation)

Use of high-slump concrete mixes allows placement of concrete in congested forms without costly repairs due to voids.



Figure 7. Rebar at Shield Window
(Note Multiple Layers of Reinforcing)



Figure 8. Reinforcing Spacing

The concrete supplier designed two high-slump concrete mixtures. The F-6 high-slump mixture uses a 3/8 inch aggregate and the F-7 high-slump mixture uses both a 3/4 inch and a 3/8 inch aggregate. The high slump is achieved using Master Builders¹ Glenium[®] 3000NS high-range water-reducing admixture. As a precaution to prevent segregation and excessive bleed water, a viscosity-modifying admixture, Master Builders VMA 358, was introduced into the mix.

¹ Master Builders is the brand name of a line of products manufactured by the Admixture Systems business of BASF Construction Chemicals, Cleveland, Ohio, a division of BASF Aktiengesellschaft, which is headquartered in Ludwigshafen, Germany.

To prove that the mix was viable, testing demonstrated not only compressive strength, but also showed that it would not segregate. Four-inch-thick wall mock-ups were placed and allowed to cure for 24 hours. Once the forms were stripped, the concrete was broken and cross sections examined. Even with 11-inch slump, the aggregate remained evenly distributed throughout the matrix. Strength tests were also positive.

CONCLUSIONS

Using the high-slump mix in highly congested areas, WTP has avoided and will continue to avoid costly repairs associated with voids, saving DOE and taxpayers significant sums of money. ■

TRADEMARKS

Glenium is a registered trademark of Construction Research & Technology GmbH.

Microsoft and Excel are registered trademarks of the Microsoft group of companies.

REFERENCES

- [1] D. Watkins, O. Gurbuz, F. Ostadan, and T. Ma, "Two-Step Method of Seismic Analysis," First European Conference on Earthquake Engineering and Seismology, Geneva, Switzerland, September 4-6, 2006, Paper Number 1230.
- [2] ASCE 4-98, "Seismic Analysis of Safety-Related Nuclear Structures," American Society of Civil Engineers, 2000, access via <<https://www.asce.org/bookstore/book.cfm?book=3929>>.
- [3] SAP2000 User's Manual, Computers and Structures, Inc., Berkeley, California, 2005, access via <<http://orders.csiberkeley.com/ProductDetails.asp?ProductCode=SAP2KDOC-3>>.
- [4] F. Ostadan, N. Deng, and R. Kennedy, "Soil-Structure Interaction Analysis Including Ground Motion Incoherency Effects," 18th International Conference on Structural Mechanics in Reactor Technology (SMiRT 18), Beijing, China, August 7-12, 2005, Paper Number SMiRT18-K04-7 <http://www.iasmirt.org/iasmirt-2/SMiRT18/K04_7.pdf>.
- [5] Interim US NRC Staff Guidance (ISG) supplement to NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," Section 3.7.1, Seismic Design Parameters, regarding the review of seismic design information submitted to support design certification (DC) and combined license (COL) applications, May 2008.

BIOGRAPHIES



John Power, deputy discipline production manager, CSA, on the Waste Treatment Project in Richland, Washington, has 22 years of experience in structural and civil engineering. He assists in managing a staff of 100 structural and civil engineers, and architects.

John has a Bachelor of Civil Engineering from the Georgia Institute of Technology, Atlanta, Georgia, and is a certified Six Sigma Black Belt.



Mark Braccia, discipline production manager, CSA, on the Waste Treatment Project in Richland, Washington, has 30 years of experience in structural and civil engineering. Along with managing a staff of 100 structural, civil, and architectural engineers, he has been serving as

the structural technical interface with the Defense Nuclear Facilities Safety Board and the Department of Energy for the project.

Mark has a BS in Civil Engineering from the University of California, Berkeley.



Farhang Ostadan, a Bechtel Fellow, has more than 25 years of experience in geotechnical and geotechnical earthquake engineering and foundation design. As chief soils engineer for Bechtel, he has overall responsibility for this discipline and manages the efforts of a large and diverse

group of geotechnical specialists in locations across the US and around the globe. His project oversight responsibilities range from major transportation projects to petrochemical, nuclear, and power- and energy-related projects.

Dr. Ostadan has published more than 30 technical papers on topics relating to geotechnical earthquake engineering. He co-developed a method for dynamic soil-structure interaction analysis currently in use by the industry worldwide. Dr. Ostadan is a frequent lecturer at universities and research organizations.

Dr. Ostadan is currently a member of the American Society of Civil Engineers (ASCE), Geotechnical Division; the Earthquake Engineering Research Institute (EERI); and the National Earthquake Hazard Reduction Program (NEHRP) Foundation Committee, and is a past member of California's Seismic Safety Commission.

Dr. Ostadan received a PhD in Civil Engineering from the University of California, Berkeley; an MS in Civil Engineering from the University of Michigan, Ann Arbor; and a BS in Civil Engineering from the University of Tehran, Iran.

