**DEFENSE NUCLEAR FACILITIES SAFETY BOARD**

# Staff Issue Report

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**MEMORANDUM FOR:** J. K. Fortenberry, Technical Director

**COPIES:** Board Members

**FROM:** C. Shuffler

**SUBJECT:** Summary of Structural Design Reviews for Integrated Waste Treatment Unit

This report summarizes a series of reviews by the staff of the Defense Nuclear Facilities Safety Board (Board) of the development of the design basis ground motion, seismic structural analysis and structural design of the Integrated Waste Treatment Unit (IWTU).

**Background.** The IWTU will convert approximately 900,000 gallons of acidic sodium-bearing tank waste at Idaho National Laboratory (INL) to a solid carbonate product suitable for off-site disposal. The core of the process, including steam reforming waste treatment equipment and product packaging capability, is surrounded by reinforced concrete cells. These cells provide both confinement and shielding functions for the hazardous waste operations. The approved preliminary safety basis for the IWTU requires that the process and packaging cells (PPC) be designed to meet Performance Category (PC)-2 criteria, but the Department of Energy's (DOE) Office of Environmental Management has mandated that a PC-3 design be adopted to accommodate potential future missions. One potential future mission is the preparation of approximately 4,400 cubic meters of calcined high-level waste for off-site disposal at a national geologic repository. The calcined waste is currently stored in six bin sets at Idaho Nuclear Technology and Engineering Center (INTEC).

The original site-specific PC-3 design basis earthquake (DBE) for the IWTU was an area-wide DBE developed for the Reactor Technology Complex and INTEC. When the decision was made in early 2006 to design the PPC to PC-3 criteria, the project convened an independent panel of industry experts to review the appropriateness of the design spectrum for application to the IWTU design. This Blue Ribbon Panel (BRP) issued a report in August 2006 confirming the adequacy of both the rock uniform hazard spectrum and the soil 5% damped response spectrum for the PC-3 design. This conclusion, however, was contingent on a recommendation for additional site-specific geotechnical work to confirm that the soil profiles and properties at the IWTU site were bounded by those incorporated into the development of the area-wide DBE spectrum. This geotechnical investigation was completed in early 2007. Results demonstrated that the soil properties at the IWTU had a smaller range of shear wave velocity compared with those at INTEC; as a result, a revised site-specific ground motion was needed. A new spectrum developed in accordance with BRP recommendations resulted in a peak response about 40 percent higher than that used in the initial design. To help mitigate the impact of the increased spectrum on structural demands in the soil-structure interaction (SSI) analysis and to eliminate debris uncovered during site excavation work, the project replaced the top 11 feet of low-velocity natural soil with 7 feet of compacted engineered backfill.

**Site Characteristics and Response.** The Board's staff reviewed in detail the development of the site-specific response spectrum and spectrum-compatible time histories, as well as the geotechnical inputs to the SSI analysis. The staff identified a number of significant issues in these areas, which were formally transmitted to the IWTU federal project director in September 2007. The manager of DOE's Idaho Operations Office (DOE-ID) responded in a October 1, 2007, memorandum to the Board, committing the IWTU project to addressing the issues raised by the Board's staff. The issues and their resolution are discussed below.

*Site-Specific Horizontal Design Response Spectrum*—To assess site response, 30 randomized soil profiles based on the new geotechnical data were generated for the IWTU site. Horizontal time histories derived from the PC-3 rock response spectrum were input to the SHAKE computer program for the base of each random soil column to produce individual horizontal response spectra at the free field. The BRP recommended that these individual spectra be averaged and broadened for use in the SSI analysis. The staff reviewed this development effort and raised issues related to (1) the absence of clear criteria with which to generate and judge the acceptability of the random soil profiles, and (2) the averaging of randomly generated spectra to derive the design response spectrum for a shallow soil site.

The generation of randomized soil profiles was based on statistical assumptions without consideration of geologic control. The staff's concern regarding the review criteria stemmed from several randomized soil profiles with properties unrealistic for the IWTU site, or in excess of reasonable upper and lower bounds given the geotechnical data. For example, 3 of the 30 profiles contained an upper alluvial soil layer with a higher shear wave velocity than that of the lower alluvial soil layer, a condition not observed in the geotechnical data. The shear wave velocity range for the randomized soil layers also extended well beyond the range of velocities measured during site borehole testing. Many soil profiles incorporated into the development of the horizontal design response spectrum were therefore beyond the ranges observed for the IWTU site.

Averaging randomized spectra to obtain the design response spectrum is an accepted practice. The staff, however, disagreed with the use of this approach for the shallow-soil IWTU site (soil thickness of approximately 43 feet). With thin soil layers, changes in soil properties from the randomization process cause the individual spectra to peak at significantly different frequencies. The site, however, is likely to respond within a narrow frequency range given that soil thickness does not vary greatly under the PPC site. Averaging the individual spectra therefore reduced the peak that would likely be observed during a seismic event. Members of the BRP acknowledged that DOE standards and Nuclear Regulatory Commission (NRC) guidance do not address this issue adequately. The staff encouraged the project to document this issue for

DOE's Chief of Nuclear Safety so it can be addressed by the recently formed DOE Seismic Advisory Panel.

To address both of the above issues, and at the staff's suggestion, the IWTU project adopted the $84^{th}$ percentile horizontal free field spectrum for design purposes. The staff believes that this approach adequately accounts for the uncertainty in the soil profile randomization process and the artificially low average spectrum.

*Geotechnical Inputs to the Soil-Structure Interaction Analysis*—The staff reviewed the geotechnical inputs to the SSI analysis. The original IWTU design and SSI analysis were based on soil properties (i.e., strain and stiffness) obtained from a one-dimensional SHAKE analysis without consideration of the building weight. This approach is widely accepted for the design of nuclear facilities. To help mitigate the impacts of the increased seismic demands attributed to the site-specific geotechnical investigation, the design agent, Simpson, Gumpertz & Heger (SGH), developed a two-dimensional computer model using a computer program (System for Analysis of Soil-Structure Interaction (SASSI)) to account for the building weight in deriving the strain-compatible properties of the engineered fill. In addition, the initial low strain properties of the engineered fill in the SASSI model included the bearing pressure of the PPC structure, derived using a methodology developed in a recent University of Texas doctoral dissertation.[1] The compacted nature of the fill, however, was not considered.

Upon further investigation, the staff discovered that the SGH two-dimensional soil model fixed the properties of the natural soils beneath the engineered fill in accordance with the original SHAKE output, which accounted for neither the engineered fill nor the building weight. The staff concluded that this model was inappropriate. Given the thin soil layer at the IWTU site, the properties of both the engineered fill and natural soils would be influenced by the structure. The staff also questioned the applicability of the methodology developed in the doctoral dissertation to the IWTU soils and the impact of fill compaction.

In response to the issues raised by the Board's staff, the BRP recommended that the soil property inputs for the final confirmatory SSI analysis revert to the best-estimate iterated soil properties supporting the original facility design, i.e., using SHAKE without the engineered fill layer or the building. Uncertainty in the soil properties was accounted for by broadening the lower- and upper-bound shear moduli used in the SSI analysis cases beyond the minimum requirements of American Society of Civil Engineers 4 (ASCE-4), *Seismic Analysis of Safety-Related Nuclear Structures*. Specifically, the lower-bound was decreased and the upper-bound was increased by a 1.6 constant instead of the 1.5 constant provided by ASCE-4. To account for the compacted engineered fill and the confining pressure of the building, an additional extended upper bound case was introduced. This case increased the best-estimate shear modulus by a factor of 2.25. The staff agreed that adopting this more conventional approach for deriving

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[1] Farn-Yah Menq, *Dynamic Properties of Sandy and Gravely Soils*, Dissertation, University of Texas at Austin, May 2003.

strain-compatible soil properties for the SSI analysis and extending the upper bound case adequately addressed the issues originally raised.

*Time History Development*—The original SSI analysis demonstrated that the PPC structure would respond at damping values greater than 12%. In accordance with DOE and ASCE-4 guidance, the horizontal time histories supporting the analysis matched the 5% damped design response spectrum. The staff expressed concern, however, that the IWTU time histories were not compatible with empirically derived response spectra at the higher damping values that would be mobilized according to the SSI analysis. As a result, the original time histories substantially underpredicted the response of the structure at the most significant damping values. In addition, the staff pointed out that the energy developed during the strong ground motion phase of the DBE for the one of the two time history motions (H2) was substantially lower than that developed for the orthogonal time history motion (H1). The lower ground motion was considered inadequate.

To address the damping issue, SGH developed new free field time history input motions for the SSI analysis from revised 84$^{th}$ percentile free field response spectra. These spectra were obtained by propagating a revised rock time history input motion through the randomized IWTU soil columns with the SHAKE computer program. The revised rock time history motion matched the empirically derived rock response spectrum at 11% damping, determined to be the damping of the soil-structure system for the best-estimate soil properties. The rock motion input to the free field response spectrum analysis was therefore based on 11% damping, instead of the 5% damped spectrum output from the probabilistic seismic hazards analysis. To explore the potential impacts on the PPC design of a potentially deficient time history motion, SGH applied the two ground motions in the SSI analysis individually in both the north-south and east-west directions. The PPC demonstrated little sensitivity to the different ground motions, resolving the issues raised by the Board's staff.

**Probabilistic Seismic Hazard Assessment.** The INL probabilistic seismic hazard assessment (PSHA) supporting the site-specific design response spectrum is unchanged from its original 1996 version, with the exception of a recomputation in 2000 to include improved ground motion attenuation relationships resulting from work supporting the Yucca Mountain project. The Board's staff noted that the PSHA had been reviewed by both the state of Idaho and the NRC, but those reviews did not adhere to the Senior Seismic Hazard Analysis Committee (SSHAC) process outlined by modern seismic technical standards. The INL PSHA is scheduled for a review and potential update in 2010 in accordance with DOE requirements. If updated, the SSHAC process would apply. Ultimately, any revised ground motion that might result from future PSHA updates would have to be reviewed for its impact on the IWTU PC-3 structure. The staff believes, however, that this impact would be minor.

**Two-over-One Criteria.** The process building and two cranes that span the PPC must meet a two-over-one (II/I) design requirement to prevent interference with the PC-3 cells. SGH adopted an approach recommended by Dr. Robert Kennedy of RPK Structural Mechanics

Consulting Inc., for meeting the II/I requirement to prevent structural collapse at the PC-3 failure probability (i.e., $<10^{-4}$/yr). To achieve this, the International Building Code (IBC) 2003 design response spectrum for PC-2 structures was replaced by the site-specific PC-3 spectrum. The importance factor and all other IBC provisions were maintained. The staff questioned this criterion, particularly for the maintenance crane, because it allowed large permanent distortions. To resolve this issue, SGH reevaluated both the process building and cranes to PC-3 criteria, noting that acceptable demand-to-capacity ratios were maintained. Only a few modifications were required.

**Mechanical Anchors for Reinforcing Bar.** The Board's staff reviewed the detailed design drawings for the IWTU PPC and noted the wide use of Lenton® Terminator anchors, in lieu of traditional L-bends, to anchor the ends of reinforcing bars. Mechanical heads allow shorter development lengths and enhance constructibility in congested areas of reinforcing bars. The staff raised concern about the absence of clear design criteria and test data supporting the use of mechanical anchors. The American Concrete Institute (ACI) codes adopted by the IWTU project do not provide specific requirements (e.g., for development length) for mechanical anchors. Instead, the codes include a general statement that appropriate testing should be done to demonstrate the adequacy of the design.

In response to these issues, SGH prepared a design guide outlining how the general requirements of applicable ACI codes were met for mechanical anchors, including provisions for concrete breakout, pullout, and side-face blowout. SGH also included a description of the more explicit criteria for developing mechanically anchored reinforcing bars in tension, based on a draft of the 2008 revision of ACI-318, *Building Code Requirements for Structural Concrete*, that addresses the use of mechanical anchors. The final design met all new requirements in draft ACI-318 with one exception: the maximum bar size allowed by the code (#11) for mechanical anchors was exceeded by the #14 diagonal reinforcement of the coupling beams in the south wall of the packaging cells. SGH believes that use of the larger #14 bars in this application is justified by their significant embedment within the wall, which moved the anchors well beyond the critical sections of the coupling beams; the absence of edge effects; adequate confining steel; and manufacturer testing of the bars. The staff agreed with this conclusion.

The SGH design guide also summarized available research and testing data on the adequacy of mechanical anchors. The staff reviewed the data and concluded that sufficient experimental evidence was available to support the use of mechanical anchors in safety-related concrete structures. Appropriate changes were made to the IWTU drawings to incorporate this additional understanding of mechanically anchored reinforcement. The revision to ACI-318 was recently issued and remained consistent with the draft revision.

The staff reviewed examples of field reports to SGH's head office documenting construction issues. Such field reports will help the design agent ensure that a quality structure is built. DOE-ID agreed to notify the staff of any significant future field changes that impact the design.

**Conclusions.** The staff's seismic and structural reviews of the IWTU raised several issues related to the development of the design basis ground motion, geotechnical inputs to the SSI analysis, criteria for meeting the II/I design requirement, and the use of mechanically anchored reinforcing bar. Commitments made by DOE-ID and SGH resolved each issue to the staff's satisfaction. It is worth noting that because of the large degree of conservatism SGH incorporated into the original design of the PC-3 PPC, the increased demands resulting from both the geotechnical investigation and resolution of the issues raised by the staff required no significant changes to the structural design. Construction of the IWTU is currently under way, with concrete placement for the PPC walls expected to begin in April 2008.