DEFENSE NUCLEAR FACILITIES SAFETY BOARD

Staff Issue Report

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MEMORANDUM FOR: T. J. Dwyer, Technical Director

COPIES: Board Members

FROM: J. Blackman

SUBJECT: Geotechnical and Structural Engineering, Uranium Processing Facility, Y-12 National Security Complex

This report documents a review by the staff of the Defense Nuclear Facilities Safety Board (Board) of the geotechnical and structural engineering design activities for the Uranium Processing Facility (UPF) at the Y-12 National Security Complex. This review was conducted during the week of September 28, 2009, by staff members J. Blackman and J. Kimball, together with outside experts J. Stevenson and D. Ghiocel, and included meetings with representatives from the National Nuclear Security Administration's (NNSA) Y-12 Site Office (YSO) and Babcock & Wilcox Y-12 (B&W Y-12). Subsequent discussions with YSO and B&W Y-12 have been held to better understand the ongoing activities.

Background. The UPF main building is a two-story, rectangular reinforced concrete shear wall building extending from the foundation at grade to elevation 69 ft and subdivided by interior shear walls into individual modules forming a 4 x 3 grid. The first story (process level) rests on the foundation. The second story (utility level) consists of a reinforced concrete floor supported by a steel framing system; the reinforced concrete floor is designed to act compositely with the supporting steel beams. Several of the rooms contain a mezzanine level between the upper and lower floors.

B&W Y-12 is the project manager and integrator for the overall UPF engineering effort. The geotechnical and structural engineering effort is organized into three distinct areas: geotechnical characterization and seismic response evaluation, structural and seismic analysis, and structural design. The geotechnical characterization was performed by M & W Drilling, LLC and Professional Engineers, Inc., and the University of Texas, Austin. The site seismic response analysis was prepared by Carl J. Costantino and Associates, which is also performing the soil-structure interaction (SSI) analysis. CH2M Hill is preparing the structural design, and the structural and seismic analysis is being performed by Degenkolb and Associates (Degenkolb) under contract to CH2M Hill.

The project status at the time of the staff's review was as follows: the building structure layout to serve as a basis for modeling was being completed; the geotechnical characterization and site seismic response analysis had been completed; the structural design, structural and seismic analyses were in preparation; and the SSI analysis had been initiated.

Project Oversight and Review. Currently, YSO's technical review is being performed on a part-time basis by an individual located at another NNSA site. This individual is commenting on the same calculations reviewed by the UPF project peer review team, and the two reviews efforts are similar. The Board's staff observed that this oversight effort has not been planned and staffed with sufficient resources to identify and resolve the issues described below. Self-directed reviews are critical to the success of the project.

Given the importance of UPF to future operations at Y-12, it would be prudent for the review team to be chartered to review the overall technical strategy and approach, and implementation of the structural analysis and design, to provide a sound basis for improving safety and project execution. The primary review effort would best be performed by an NNSA-chartered team with the technical resources to provide adequate independent oversight of the development of the civil/structural engineering design of UPF.

The Board's staff observed that lack of a systematic plan and documented methodology to integrate the technical aspects of the geotechnical and structural engineering activities may be an underlying reason that some of the technical issues remain. This plan would identify technical interdependencies between the UPF project office and its engineering firms, the technical details of the structural and seismic analysis and design strategies, and the required content and scope of the project deliverables.

The project recently issued report RP-ES-801768-A007, Rev 0, *Seismic Analysis and Design Plan for Safety Related Structures (A007)*, to address this need. The Board's staff reviewed this document and concluded that it does not contain sufficient detail to assure proper integration and implementation of the structural analysis and design effort.

For example, sections of A007 appear to have been written as a tasking statement rather than as analysis plan. Section 8.0, *Use of Incoherent Ground Motions In The Soil-Structure Interaction Analysis*, acknowledges that consideration of incoherency introduces rocking and torsional components of motion that would otherwise not be predicted from conventional SSI analysis. It would be expected that if rocking and torsional affects were significant, an approach for incorporating these affects would be included. However, no approach is presented.

The Board's staff suggests that the usefulness of the plan would be improved if it were expanded to focus on specific tasking of the organizations involved and the development of specific technical guidance as to how results should be evaluated. Examples that might be considered are: *Seismic Analysis Plan For the Chemistry and Metallurgy Research Replacement (CMRR) Nuclear Facility Project*, Report No. 083330801-010, June 2009, and Chapter 5 and

Appendix A Part II of Chapter 5 of *Design Criteria for the Chemistry and Metallurgy Research Replacement (CMRR) Nuclear Facility Structural Design Criteria*, CMRR-109NF-DC-002-CH5, June 5, 2009.

Geotechnical Characterization and Site Seismic Response Analysis. The Board's staff developed the following observations with respect to the geotechnical characterization and site seismic response analysis.

Ground Motion Incoherency Effects and Impact on Soil-Structure Interaction Analysis—The UPF project team is exploring the possibility of incorporating ground motion incoherency effects directly into the SSI analysis for the UPF main building. This idea arose from the fact that the response spectrum for the bedrock design basis earthquake peaks at response frequencies near 30 Hz, and the initial SSI analysis of the UPF main building suggested that the building could amplify in-structure motions at these frequencies.

The assessment and incorporation of ground motion incoherency into the design of critical facilities has been the topic of much discussion in the commercial nuclear power industry. The United States Nuclear Regulatory Commission (NRC) recently published Interim Staff Guidance on this topic (*Interim Staff Guidance on Seismic Issues Associated with High Frequency Ground Motion in Design Certification and Combined License Applications*, DC/COL-ISG-01, May 19, 2009). Based on the NRC Interim Staff Guidance the incorporation of ground motion incoherence is most supportable at sites like UPF—Eastern United States rock sites with design earthquake ground motions that peak at high frequencies (~30 Hz).

The UPF project team provided general background information on ground motion incoherency effects, including reference to several documents that define the incoherency function and studies undertaken to establish validated approaches to SSI analysis. The NRC Interim Staff Guidance suggests that ground motions above about 20 Hz would be significantly reduced if incoherency effects were incorporated into the UPF SSI analysis. The UPF project team stated that they plan to complete the SSI analysis for the UPF main building with and without incorporation of incoherency effects. Such an approach is appropriate before a final decision is made regarding the formal incorporation of incoherency effects into the design. One issue warranting evaluation is whether the SSI analysis with incoherency effects incorporated would result in increased seismic loads because of torsion or rocking of the structure. If this is the case, the project team may need to adjust their fixed-base seismic analysis to account for these impacts on seismic loads. The Board's staff will review these results as they become available.

Site Seismic Response Analysis—The UPF project team summarized their updated site seismic response analysis (*Updated Site Response Analysis for Building 9226 Including Radiography Vault*, DAC-ES-801768-A034, Revision B, September 14, 2009). The analysis considers 22 base-case locations under the footprint of the main building where the project team obtained drilling data. The UPF site geology consists of weathered shale varying in thickness, overlying unweathered shale. The project team plans to remove portions of the weathered shale to reduce site ground motions, replacing it with mass fill concrete having a shear wave velocity near 8000 ft per second. Results from standard hammer tests performed under the building footprint will be used to define the weakest weathered shale for removal.

The site response analysis uses shear wave velocity (Vs) measurements that were collected at 2 of the 22 base-case locations. The Vs measurements were combined with other Vs measurements made in proximity to the UPF site to derive an average Vs profile as a function of depth, along with uncertainty estimates. Thirty Vs profiles were created for each base-case location to represent the uncertainty in Vs. Site response was calculated for each Vs profile, and the mean site response was then derived. The mean site response depends strongly on the presence and thickness of weathered shale between the mass fill concrete and the unweathered shale; the project team identified three response groups representing these conditions. For the response group that includes the thickest weathered shale, mean ground motions are significantly amplified—40 to 60 percent—compared with the response group that includes no weathered shale. The project team proposed deriving an overall mean free field ground motion for the UPF site based on a weighted average of the response groups, with weights linked to the footprint area associated with each group.

The Board's staff discussed several issues related to the site seismic response analysis with the project team, including the overall approach to the analysis and the sensitivity of site response to assumptions made, as well as how the project team derived the overall mean site response motion. These issues included the following:

- Whether the approach to the site response analysis is consistent with the intent of American Society of Civil Engineers Standard 43-05, *Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities*, regarding how statistical variation in soil properties is modeled.

- Whether the approach used to create the range of individual Vs profiles is appropriate, particularly for the two locations for which direct Vs measurements were made.

- Whether the approach used to combine response groups is appropriate.

The project team committed to addressing these issues by performing sensitivity studies of site response.

The Board's staff observed that removal of additional weathered shale would reduce high-frequency ground motions while also addressing some of the site response issues. While the project team has not planned to remove additional weathered shale, they do plan to quantify the effect of the removal of additional weathered shale on both site ground motions and SSI responses. If additional weathered shale is not removed, the project team will need to demonstrate that the SSI analysis model properly considers both the lateral variation in soil property stiffness and the lateral variation in foundation-level ground motions.

Structural and Seismic Analysis. The structural and seismic analysis performed by the project team is based on the requirements of the UPF *Structural Design and Analysis Criteria*, RP-ES-801768-A005, Rev. 0 (SDAC). The observations provided below are based on responses to questions raised by the Board's staff during this review, as well as a review of calculations in *UPF Main Building (9226-P) Lateral Seismic Analysis and Critical Concrete Sections Design*, DAC-ES-801768-A009 (A009), and *UPF Main Building (9226-P) Vertical Seismic Analysis and Critical Concrete Sections Design*, DAC-ES-801768-A010 (A010). Calculation A009 models the horizontal response of the UPF main building while calculation A010 models the vertical response; the calculations do not use the same structural model or assumptions.

UPF Finite Element Modeling—The finite element model (FEM) for the main building was developed to represent the behavior of external and internal shear walls and concrete floor slabs supported by a structural steel frame subjected to dead, live, equipment, and natural phenomena hazard loads. The external security wall is a reinforced concrete unit extending from the basemat to the utility level. The external shear wall from the utility level to the roof and the internal shear walls are conventional, reinforced concrete walls. The floor slab is constructed of reinforced concrete and is supported by composite steel beams. The steel beams in turn frame into girders and are supported by steel columns. The girders also support the floor slabs but do not act compositely with them.

The UPF FEM developed for structural and seismic analysis using GTSTRUDL (Georgia Tech Structural Design Language) software is also to be used for SSI analysis using SASSI (Structural Analysis of Soil–Structure Interaction) software. The results from SASSI will then be used to develop floor response spectra for seismic analysis and design of equipment and distribution systems in the building. The amplitude of the high frequency (20–30 Hz range) content of the input ground motion is large and is anticipated to be a concern for seismic qualification of safety-related equipment. The FEM developed for use in the structural and seismic (6–10 Hz range) analysis of the building may not adequately represent the high-frequency response of the structure, leading to improper characterization of the in-structure response spectra.

The SDAC requires that the finite element mesh refinement meet the intent of the provisions of the Hanford Waste Treatment and Immobilization Plant (WTP) modeling guidelines. These provisions were developed for static analysis of the High Level Waste Vitrification Facility (HLW). While UPF and HLW are both rigid shear wall buildings, several features unique to the UPF analysis and design are not addressed by the WTP modeling guidelines (e.g., UPF's security walls and consideration of internal blast effects). In addition, the seismic analysis of UPF uses response spectrum modal analysis, while the HLW seismic analysis uses a static equivalent analysis approach.

In addition, not all of the modeling provisions used in the HLW analyses are contained in the WTP guidelines. For example, composite construction, dynamic analysis, wall/slab eccentricity considerations, and shear wall/basemat modeling requirements are not formalized in the WTP guidelines, although they are addressed in the FEM developed for HLW. In light of these issues, it is unclear whether the FEM used in calculation A009 adequately represents the response of the main building to static and dynamic loads in the horizontal and vertical directions.

Calculation A010 was prepared with the understanding that the response of the main building in the vertical direction was not addressed by calculation A009. The vertical seismic analysis was limited to a "typical" interior bay and not the entire structure. Calculation A010 concluded that the building is adequately designed to resist vertical seismic loads since sufficient margin exists to compensate for inadequacies in the modeling of vertical response in calculation A009. However, a calculation has not been prepared in which an adequately refined FEM of the building is analyzed for static and dynamic loads in all three directions to demonstrate that the building response has been properly characterized and is within project acceptance limits specified in the SDAC.

Evaluation of the WTP guidelines for FEM refinement is warranted to determine the extent of their applicability to the UPF project, as is a determination as to what additional modeling provisions used at WTP should be required for UPF. Specific modeling requirements unique to UPF need to be developed. Systematic studies considering the above factors are necessary to ensure that all modeling requirements have been incorporated into the FEM.

Results of Composite Beam Evaluation—Composite construction is used extensively to support floor slabs in UPF. When steel studs are welded to the top flange of a beam and the supported concrete floor is cast in contact with the top flange, composite action develops between the floor slab and beam. Composite beam behavior is modeled in the analysis by adjusting the modulus of elasticity of the supporting beam by accounting for the increased stiffness properties of the composite cross section (beam plus adjoining concrete floor slab). For purposes of this analysis, it is assumed that the composite beam and floor slab act concurrently. The analysis does not consider the distance between the floor slab centroid and the beam centroid. This approximation was chosen to facilitate use of the same FEM for GTSTRUDL and SASSI analyses. The validity of this approximation and confirmation that it adequately represents the static and dynamic responses of the composite cross section in the model has not been established. The project should address this issue prior to development of floor response spectra.

Modeling of Exterior Walls—See Attachment for further discussion.

Structural Design. CH2M Hill and Degenkolb are working closely in their respective design and analysis roles and have developed an adequate building arrangement. The Board's staff reviewed calculation *UPF Main Bldg (9226-P) Structural Steel Design*, DAC-ES-801768-A015, and developed the following observations with respect to structural design.

Sizing of Structural Members—It is accepted practice during the design of Seismic Design Category 3 (or Performance Category 3) defense nuclear facilities to compare the results of the structural and seismic analysis for demand with the member capacities of all members to document the acceptability of the building structure and to quantify margin. The UPF structural design is not consistent with this practice. The CH2M Hill sizing of structural members (reinforced concrete walls, floors, and steel frame) is based on approximations of structural analysis results. In addition, while the calculations for the structural and seismic analysis address evaluation of the adequacy of major structural building members, not all building members are evaluated. The Board's staff discussed this issue with representatives of CH2M Hill and Degenkolb, including the need for the project team to confirm the adequacy of the size of all structural members by comparing member demands with member capacities. Based on this discussion, it did not appear that final reconciliation of the results of all analyses of structural members and their respective capacities would be completed during preliminary design.

Spacing between Buildings—The spacing between the UPF main building and adjoining structures is 2 inches. The Board's staff understands that this spacing was chosen based on traditional relative motion seismic analysis. However, a spacing of 2 inches may not be adequate to accommodate predicted horizontal seismic motion of the basemat resulting from high-frequency ground motion and the effects of the passage of seismic surface waves, due to shorter wavelengths, which may cause increased relative motion between adjacent buildings.

Accidental Blast Design—Internal accidental blasts are credible events, and the project team incorporated their effects into the design of the UPF main building by assuming that such blasts will result in the loss of one column. This assumption is unrealistic in that internal accidental blasts sufficient to negate the load-carrying capacity of a column would also have a much more detrimental effect on the integrity of adjacent walls and floors. Blast effects in confined spaces involve direct pressurization, as well as the amplified reflection of the blast wave off adjacent building surfaces. As a result, damage may be significantly greater than that resulting from unconfined blasts. Furthermore, the design of walls and floor slabs to resist blast pressure loading typically requires the incorporation of tension reinforcement through the addition of a third layer of steel reinforcement at the center of the wall or floor slab. Current designs do not include this feature. In addition, steam explosions or criticality-induced vessel explosions may produce missile fragments and involve pipe whip or pipe break effects commonly considered in commercial nuclear power plant design.

While the requisite computer software and technology are available to analyze blast effects, blast analysis is based on knowledge of the pressure and time duration characteristics of the event and the transient dynamic response of the affected structural members. This information is difficult to obtain, and the analysis involved is time-consuming and challenging to implement. If addressed at the later stages of project design, considerations related to blast effects could require significant structural redesign and reanalysis. The preferred approach is to develop engineered controls to prevent accidental blast events instead of designing the structure and equipment to mitigate blast effects. The project needs to demonstrate that the structural design, including walls and slabs, adequately addresses blast effects, if explosions cannot be eliminated as a design consideration.

Conclusions. The Board's staff concludes that several issues related to the geotechnical and structural analysis and design of UPF need to be evaluated to determine whether they affect the adequacy of the design:

- The incorporation of ground motion incoherence appears to be supportable at the UPF site. Experience at other Eastern United States rock sites suggests that high frequency accelerations (~30 Hz) are reduced when ground motion incoherency effects are incorporated into SSI. One issue that needs to be evaluated is whether the incorporation of ground motion incoherence would result in increased torsion or rocking of the structure.

- To reduce high-frequency amplification response and simplify analysis methodology, it is advisable to remove weathered shale below the entire building basemat.

- If the additional weathered shale is not removed, the project team will need to demonstrate that the SSI analysis model properly considers both the lateral variation in soil property stiffness and the lateral variation in foundation-level ground motions.

- The project team has not addressed finite element modeling requirements in a systematic manner. The team needs to address mesh refinement requirements, composite beam behavior, exterior wall static and dynamic responses, the use of the same model for structural and seismic analysis and SSI analysis, and other requirements determined to be necessary.

- The project team needs to confirm the adequacy of the size of all structural members by comparing member loads (demands) with member capacities.

- The spacing between buildings may have to be increased to accommodate the predicted horizontal seismic motion of the basemat resulting from high-frequency ground motion and the effects of the passage of seismic surface waves.

- Blast effects have not been addressed in a manner consistent with accepted practice. The project needs to demonstrate that the structural design, including walls and slabs, adequately addresses blast effects, if explosions cannot be eliminated as a design consideration.