DEFENSE NUCLEAR FACILITIES SAFETY BOARD

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January 4, 2005

The Honorable Linton Brooks
Administrator
National Nuclear Security Administration
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585-0701

Dear Ambassador Brooks:

The Defense Nuclear Facilities Safety Board (Board) encloses for your information and use a report on the structural design of the Pit Disassembly and Conversion Facility. The report indicates that, as a general matter, the design is progressing well and the approach is sound. The Board is particularly encouraged by the design team's technical competence and its willingness to respond to questions about the design raised by the Board's staff.

As noted in the enclosed report, several ideas and suggestions have been made by the Board's staff regarding analysis and design. We will continue to follow the implementation of these ideas and suggestions.

Sincerely,

John T. Conway
Chairman

c: Mr. Mark B. Whitaker, Jr.

Enclosure

DEFENSE NUCLEAR FACILITIES SAFETY BOARD

Staff Issue Report

November 23, 2004

MEMORANDUM FOR: J. K. Fortenberry, Technical Director

FROM: B. Jones

SUBJECT: Structural Design of Pit Disassembly and Conversion Facility

This report documents the results of a series of structural design reviews of the Pit Disassembly and Conversion Facility (PDCF) conducted from June 2003 to October 2004. Members of the staff of the Defense Nuclear Facilities Safety Board (Board) A. Hadjian, B. Jones, and H. Massie conducted the reviews with support from outside experts J. Stevenson and P. Rizzo.

Background. The primary mission of the PDCF is to (1) receive surplus weapons plutonium in the form of pits and other plutonium metals, (2) convert the plutonium metal to plutonium oxide, and (3) remove any residual classified attributes through blending of the converted plutonium oxide. Safety-class controls are part of the confinement strategy, which includes an active ventilation system and five Performance Category (PC)-3 structures: the Plutonium Processing Building, Mechanical and Support Equipment Building, sand filter structure, fan house, and exhaust stack.

Washington Group International (WGI) is the lead design contractor and is performing the structural design work, while the soil-structure interaction (SSI) work is subcontracted to Simpson Gumpertz & Heger (SGH). The structures are in the final design phase, nearing completion of the SSI analyses. The static and dynamic analysis work is ongoing and will be finalized once the SSI results are available. Construction is scheduled to begin in 2007.

General Observations. The project organization and planning, as well as the design, are in good order. The Board's staff is pleased with the technical competence of WGI and its subcontractors. Initial indications are that the quality of the work being performed is at a high level. The Board's staff is encouraged by WGI's use of outside consultants R. P. Kennedy and I. M. Idriss, whose comments are respected and well-received. Likewise, WGI is receptive to issues raised by the Board's staff and is willing to adjust its approach when technically sound arguments are presented. The healthy working relationships established by the project's structural engineering team with outside consultants and the Board's staff will help promote the project's success.

Summary of Involvement of the Board's Staff. The Board's staff and outside experts have made a number of comments and observations throughout the reviews, some of which are being tracked as the design progresses. A summary of the more significant issues raised is provided below.

Structural Configuration—The Mechanical and Support Equipment Building has a concrete portion classified as PC-3 and a steel portion with a lower, PC-2 classification. Early in the design process, the Board's staff urged that special attention be paid to the interface between these two portions. Following the suggestion of the Board's staff, WGI decided to design the main steel framing elements to the higher, PC-3 requirements. Taking this approach has significantly reduced the risks associated with one portion of the structure adversely affecting the behavior of the other in a design basis seismic event.

Load Path—The two portions of the Mechanical and Support Equipment Building share a structural wall. The roof elevation drops by more than 5 feet at this common wall. The Board's staff pointed out that this represents an undesirable design detail with the potential for adverse behavior in a seismic event. Given the location of the lower roof's connection to the common wall, a brittle shear failure could occur. This situation is contrary to the above positive decision to design the steel framing elements to the higher, PC-3 requirements. The Board's staff urged that this design detail be modified to allow a continuous load path at a common roof elevation that would not rely on out-of-plane loading of the common wall. WGI is currently considering this design modification.

Time-History Characteristics—For use in the SSI analyses, SGH developed time histories to match the design response spectrum. The Board's staff reviewed these time histories and noted unconservative characteristics. Specifically, the power of the artificial earthquake was distributed throughout a 13 second strong-motion duration. This duration was chosen on the basis of a magnitude 7.0–7.5 event (Charleston earthquake) and guidance from American Society of Civil Engineers (ASCE) 4-98, *Seismic Analysis of Safety-Related Nuclear Structure*. However, it is noted that the lower-magnitude local events will be of shorter duration, but likely would produce high frequency "spikes." The Board's staff noted that the effects of this type of ground motion should be considered in addition to a distant higher magnitude event such as a re-occurrence of the Charleston Event.

Further, the time histories were generated using software developed in the 1970s. Since then, programs have been developed that would be more appropriate for use on the project. As a result of the issues raised by the Board's staff, the time histories were modified to represent a magnitude 6.0–6.5 event with a 7 second strong motion duration, using more advanced software.

SSI Modeling—The Board's staff made a number of observations concerning the adequacy of the SSI modeling, including the following:

- An inner corridor wall in the Plutonium Processing Building is detailed such that it does not transmit in-plane shear forces to the roof. It does, however, transmit out-of-plane loads to the roof and columns. SGH had modeled the wall by lumping its mass at its base, which does not reflect the load transfer mechanism of the roof-to-wall connection detail. The modeling error was acknowledged and corrected.

- SGH had originally planned to model the soil cover of significant depth by simply lumping the soil mass at the roof nodes. The Board's staff noted that this approach would neglect the overturning effects that the soil imposes on the structure. In response, SGH modified its model to include rigid links to account for the overturning effects. The rigid links connect the center of mass of the soil to the roof slab.

- The PDCF structures have a number of separation joints that must be modeled adequately in the SSI analyses. The Board's staff worked with SGH and WGI to ensure that the modeling technique would accurately depict WGI's structural details.

SSI Model Validation—Two independent three-dimensional finite-element models have been developed for each PC-3 structure. WGI developed models with sufficient detail to enable the design of individual structural elements, while SGH developed simplified models to simulate the dynamic behavior of the structures. WGI performed a mesh size sensitivity study to justify the use of standard 2.5 foot square elements.

The Board's staff emphasized the need to compare the response of the two models in a fixed-base environment to confirm that the models are similar and to increase confidence in the modeling. In response, an extensive comparison of the two models was performed. For each structure, WGI was able to show that the simplified SSI model closely emulates the dynamic behavior of the detailed design model, and therefore is acceptable for use in the SSI analysis.

Process for Determining Design Loads—In the preliminary design phase, the Board's staff raised issues concerning the process by which SSI results are interpreted and processed to arrive at design loads. WGI was planning to use an equivalent static analysis. The Board's staff stressed that averaging of peak accelerations from the SSI analysis may be inappropriate.

The Board's staff proposed an alternative approach with the potential to both simplify the design process and increase confidence in the final design. The staff suggested obtaining an enveloped acceleration response spectrum from the SSI results at the base of the structure and performing a fixed-base response spectrum analysis of the building using the more detailed model. SSI results would be used to generate in-structure response spectra. Not only would this approach capture the dynamic behavior of the building, but a rigorous validation of the design process would be avoided.

After investigating its feasibility and benefits, WGI decided to adopt this approach. Soil springs were included to directly obtain forces and moments in the base mat. Also, WGI is designing the in-plane shear walls to carry all the lateral loads while still designing the out-of-plane walls to carry the design loads from the finite element model.

Design Inconsistency—The Board's staff noted an inconsistency in WGI's structural analysis and design methodology. WGI was planning to use 7 percent of critical damping for design of the PC-3 structures, while not using cracked reinforced concrete section properties in the analysis—this despite the fact that concrete structures generally need to undergo significant cracking before 7 percent damping is mobilized.

The Board's staff noted that if the analysis is based on a nearly elastic response, the higher forces associated with 4 percent damping will need to be used in the design. Alternatively, if the lower forces associated with 7 percent damping are to be used in the design, the structural analysis must consider the material properties of cracked flexural members, which would result in load redistribution to the more rigid resisting elements. WGI, as well as its outside consultants, agreed that its analysis and design were inconsistent and will modify its methodology accordingly.

Soft-Zone Settlements—WGI considers the soft zone subsidence issue as a separate load case in which both the live load and dead load effects are included. The structural analyses rely on softening or cracking of the concrete structures, and as a result, are heavily dependent on the geometry and amplitude of the design settlement profiles. Because of this dependency, the Board's staff is evaluating the surface subsidence calculations, including the following:

- The adequacy of the soft-zone consolidation estimates during the design basis earthquake, including a numerical assessment of uncertainties and dependency on earthquake duration.
- The adequacy of FLAC (Fast Lagrangian Analysis of Continua) software as an analytical tool for calculating ground surface subsidence given a specified displacement at depth.
- User competency and proper use of past FLAC results in calibrations.
- The adequacy of the tunneling approach, which is calibrated to FLAC results, for calculating ground surface subsidence at PDCF.
- Details of the inelastic structural response calculations given a surface subsidence due to multiple soft zones and adherence to code requirements.

Test Fill—The issue of determining the properties of the structural backfill prior to construction has been discussed. There is no clear plan for how WGI will ensure that the design values of the structural backfill properties, such as shear wave velocities and strain-dependent degradation curves, will be validated prior to the start of backfill operations.

Ductile Detailing—As a result of comments made by the Board's staff, WGI has adopted the ductile detailing requirements of ASCE 43-05, *Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities.* Although the Department of Energy's (DOE) standards require ductile detailing, an industry gap formerly existed in the requirements for rigid shear wall buildings typical of those in the complex. ASCE 43-05 fills this gap and represents a major step forward in the design of ductile buildings in the DOE complex.