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DEFENSE NUCLEAR FACILITIES SAFETY BOARD

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December 2, 2009

The Honorable Inés R. Triay
Assistant Secretary for Environmental
Management
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585-0113

Dear Dr. Triay:

Since April 2002, the Defense Nuclear Facilities Safety Board (Board) has reviewed the adequacy of the structural design of the Waste Treatment Plant (WTP) facilities. As noted in its letter of October 17, 2005, the Board determined that the overall approach to the structural analysis and design of the WTP facilities was sound. This conclusion was based on review of the analysis and design of the reinforced concrete portion of the facilities at the time. All of the issues previously raised regarding the reinforced concrete design of these facilities have been satisfactorily resolved. The Board's staff reviewed the adequacy of the structural steel design of these facilities, which has recently been completed, and found that the finite element models used in the analyses do not reflect the as-designed configuration. The adequacy of the structural steel design should be evaluated to determine if design changes are required.

The primary steel supporting the building floor and the concrete floor slab itself are constructed compositely. In composite construction, steel studs are welded to the top flange of the steel such that when concrete is placed to form the building floor, the steel and concrete act as a single member. In its latest review, the Board's staff learned that composite behavior was not considered in the WTP building finite element model analyses and evaluated for compliance with acceptance standards. The use of composite construction results in stiffer floor slabs when compared to non-composite construction. At WTP, the concrete floor slabs are also thicker when compared to typical composite construction. This will cause the loads to be distributed differently and may affect the design adequacy of the structural steel supporting the floor slabs.

In addition to the issue of composite modeling, the Board's staff noted a number of other analysis and design deficiencies during its recent review, as outlined in the enclosed report. These deficiencies should be carefully evaluated and incorporated into the existing building analyses and designs.

The Board notes that in response to issues previously raised concerning the structural analysis and design of the WTP facilities, the Department of Energy's Office of River Protection initiated an independent peer review. This comprehensive review, conducted by a Structural Peer Review Team (PRT) of nationally acknowledged experts in structural engineering, resulted in many improvements to the design of these facilities. The PRT has not been utilized recently and has only now initiated its review of the structural steel design aspects of the WTP facilities. The Board strongly encourages this type of independent review to ensure that the design and analysis methodologies used result in sound building designs.

Therefore, pursuant to 42 U.S.C. § 2286b(d), the Board requests that the Department of Energy provide a report within 90 days of receipt of this letter, presenting its assessment of the issues described in the enclosed report on the existing designs of the WTP facilities. In addition, the Board requests that it be kept apprised of the status of the PRT efforts on a quarterly basis through a list of issues developed and their status and resolution until all issues have been resolved.

Sincerely,

John E. Mansfield, Ph.D.
Vice Chairman

Enclosure

c: Ms. Shirley J. Olinger
Mr. Mark B. Whitaker, Jr.

DEFENSE NUCLEAR FACILITIES SAFETY BOARD

Staff Issue Report

September 21, 2009

MEMORANDUM FOR: T. J. Dwyer, Technical Director

COPIES: Board Members

FROM: J. Blackman

SUBJECT: Structural Steel Analysis and Design, Waste Treatment Plant

This report documents a review by the staff of the Defense Nuclear Facilities Safety Board (Board) of the structural steel analysis and design for the Waste Treatment Plant (WTP) at the Hanford Site. Staff members J. Blackman, B. Caleca, and T. Barker and outside experts J. Stevenson and N. Vaidya were on site during the week of July 13, 2009, to review the structural steel analysis and design for the High Level Waste (HLW), Pretreatment (PT), and Low Activity Waste (LAW) facilities. This review included meetings with representatives from the Department of Energy-Office of River Protection and Bechtel National Incorporated (BNI).

Background. The core of the HLW building is shear wall structure constructed of reinforced concrete extending from the foundation to elevation 58 feet. A structural steel frame extends around the perimeter of the concrete core and supports the steel superstructure at that elevation. The steel superstructure, which extends to the roof at elevation 89 feet, supports the ventilation system and various commodities and does not include concrete floors. The PT building is constructed similarly. Its concrete core and perimeter steel extend from the foundation to elevation 98 feet. The steel superstructure extends to the roof at elevation 119 feet.

The LAW building is constructed of reinforced concrete from the foundation to elevation 28 feet. A structural steel frame extends around the perimeter of the concrete core to that elevation. Above elevation 28 feet, the LAW building consists of a structural steel frame, but unlike PT and HLW, it has reinforced concrete floor slabs extending to the roof at elevation 70 feet. These concrete floor slabs are cast on steel decking acting compositely[1] (steel studs are welded to the top flange) and noncompositely with the supporting steel.

The Board's staff previously reviewed the analysis and design of the concrete core of HLW and PT. In reviewing LAW, the staff considered both the reinforced concrete core and the structural steel portion of the building. All of the issues regarding reinforced concrete core design previously raised have been satisfactorily resolved.

[1] Composite construction is used to enhance stiffness and reducc floor deflection.

Methodology of Structural Steel Frame Analysis. The BNI structural steel frame analysis methodology for HLW and PT consisted of two parts: the building core and perimeter steel were analyzed statically for all loads, and the superstructure was analyzed statically for all loads except seismic.

Seismic loads for the steel superstructure were determined using the response spectra modal analysis (R/S) method. Input motion enveloped the in-structure response spectra at all support points. Use of the R/S method is valid if all support points move as a rigid body (i.e., if they are in phase and move in unison). BNI presented information confirming that rigid body behavior occurs in the north-south and east-west directions of motion for HLW as a result of the design basis earthquake. However, information provided on the vertical direction for HLW does not reflect rigid body behavior for the entire earthquake record. This results in additional deformation loads that were not addressed in the analysis of record. It would be prudent to determine whether the additional deformation loads are significant and if necessary, include them in the analysis. In addition, based on the above issue concerning HLW, it would be advisable to confirm rigid body behavior in all directions for PT to preclude the need for reanalysis of the PT steel superstructure.

HLW Analysis—The finite element model (FEM) representing the concrete floor slab and supporting frame consists of plate membrane and bending elements directly supported by the column (shear and moment are constrained). The supporting girders or beams are not modeled as attached to or supporting the concrete floor slab, but as independent members framing between adjacent columns. As a result, the only loads that develop in the steel beam result from self-weight and secondary effects due to frame action.

In addition, an approximately 1-inch-wide elastomeric joint exists around the perimeter of the steel column, preventing load transfer between the concrete floor slab and supporting members, invalidating the assumption concerning floor slab–column connectivity. Almost all of the girders framing into columns were constructed compositely with the supported concrete floor slab. Steel studs were welded to the top flange of the girders and beams such that when the concrete floor slab was cast, composite action developed between the two members. Inertia and other loads were transferred from the concrete floor slab through the studs to the supporting steel. Thus, the FEM used in the analysis was inconsistent with actual behavior. Further, the stiffness of the supporting member acting compositely with the floor slab affects load distribution in a manner not considered in the analysis of record. These effects need to be considered in the analysis to enable comparison of the originally modeled behavior and a model more representative of actual behavior. If the difference is significant, the analysis and design of record ought to be revised to reflect actual behavior.

PT Analysis—A different modeling approach was used in the analysis of record for PT. Plate membrane and bending elements were used to represent the concrete floor slab and were assumed to be pinned to the column (only shear transfer was considered). The members supporting the concrete floor slab were not included in this model. However, the actual construction of the girders and floor slab is identical to that of HLW. As a result, all of the modeling and analysis issues for HLW are also present in the FEM and analysis of record for PT.

LAW Analysis—The review of the LAW building performed by the Board's staff was satisfactorily completed in July 2004. However, issues raised during the present review regarding details of the modeling of the composite floor slab prompted a reexamination of the LAW model.

Details of the modeling of the steel frame supporting the reinforced concrete floors are not explicitly described in the calculations of record. The Board's staff reviewed computer inputs from the analysis to understand the details of the FEM and predicted behavior. The FEM of the floor slab and supporting girders is identical to that of HLW. The supporting girders frame between adjacent columns but are not modeled as attached to or supporting the concrete floor. The only loads developed in the steel girder result from self-weight and secondary effects due to frame action. The analysis of record for these building elements is inconsistent with the as-built construction.

In LAW, the concrete floor slab is cast directly against the face of the steel columns. Other than bearing and adhesion of the concrete, no engineered load transfer mechanism is provided between the concrete floor slab and the steel columns. The Board's staff determined that the concrete at this interface would crush well before the predicted loads are reached.

In addition, most of the steel girders framing between the steel columns were constructed compositely with the supported concrete floor slab. Steel studs were welded to the top flange of the beam such that when the concrete floor slab was cast, composite action developed between the two members. Loads due to seismic effects on the concrete floor slab will be transferred through the studs to the supporting steel. Because of the modeling approach used, load transfer from the concrete floor slab to the columns was not properly considered. Further, the stiffness of the supporting members acting compositely with the floor slab affects load distribution. This effect needs to be considered in the analysis to enable a comparison of the originally modeled behavior and a more representative model. If the difference is significant, the analysis and design of record ought to be revised to reflect actual behavior.

Structural Steel Design. Consistent methods were used to treat various aspects of the structural steel design for all three facilities. During and subsequent to the staff's review, several issues were noted.

Design of Steel Studs—As discussed above, steel studs were used in the design to effect transfer of loads from the concrete floor slab to the supporting steel beams or girders. However, no calculations exist to validate code allowable load transfer for the various stud spacing patterns used.

Composite Section Stress Distribution—The methodology used to design floor slab-supporting members was based on determining the percentage of applied load resisted by the supporting floor slab and girders or beams for various floor slab thicknesses. The project team developed conservative guidelines as a design expediency. Inherent in this approach is the assumption that the floor slab and girders or beams do not act compositely. In this situation, separate linear bending stress distributions exist for each component. This approach is valid for noncomposite sections. The implementing guidelines used by the project team are reasonable.

However, when the floor slab and supporting girders or beams act compositely, a continuous stress distribution exists throughout the depth of the composite cross-section. While a composite cross-section exhibits greater load-carrying capacity than a comparable noncomposite cross-section, the design adequacy of the composite cross-section must be validated by comparison with code acceptance requirements even if the girders or beams are capable of carrying their share of the total load separately.

Simplified Design of Girders and Beams—The project team used a conservative, simplified method to evaluate the design adequacy of members. The approach did not use bending and shear results from the structural analysis. Instead, flexural members were considered to be simply supported and uniformly loaded. A total uniform load due to the self-weight of members and tributary loads due to the wet weight of concrete (during construction of the concrete floor slab) and the percentage of equipment load resisted by the steel girders or beams was first determined. Seismic loads were estimated by multiplying the dead load and 25 percent of the live load by the peak acceleration multiplied by a factor of 1.5. Midspan moments were then calculated based on a simple beam relationship.

Inherent in the above approach is the assumption that an approximation of seismic loads will always be greater than the seismic loads derived from FEM analysis. This assumption is generally conservative; however, there is no assurance that it will be true in all cases. As a result, it would be prudent, in highly loaded areas of each building, to compare design results based on the approximate method with results obtained from FEM analyses to confirm the adequacy of the design.

Secondary beams, located at the one-third or one-quarter points of the span (based on the number of secondary beams required), were initially used to help support the wet weight of concrete, and were subsequently neglected in the design and analysis. However, it is nonconservative to neglect secondary beams when calculating midspan (maximum) moment. Concentrated loads at the one-third or one-quarter points equal to the total uniform load previously determined result in midspan moments greater than those calculated based on uniform loading. Reevaluation would be advisable to determine the impact on the adequacy of the existing design.

Conclusions. The Board's staff concludes that the analysis and design of the structural steel for HLW, PT, and LAW include nonconservative practices that need to be evaluated to determine whether they affect the existing structural steel design. Specifically:

- Based on the input response of the HLW superstructure motion, anchorages do not appear to act as a rigid body in the vertical direction. The motion of the support points in the vertical direction is out of phase throughout most of the seismic time history. This behavior results in deformation effects not addressed in the R/S analysis and, if significant, needs to be considered in the analysis. Information regarding PT ought to be developed and similarly reviewed.

- Framing members between adjacent columns in HLW, PT, and LAW are not modeled in the analysis as attached to or supporting the concrete floor slab. The resulting analysis is inconsistent with actual behavior. In addition, the stiffness of the supporting member, as well as members acting compositely with the concrete floor slab, affects load distribution in the building. These factors need to be considered in the analysis and compared with the previous results to determine the potential impact on the existing design.

- The project team did not develop calculations to validate the adequacy of the steel stud patterns or evaluate the effect of the actual stress distribution of composite members for the HLW, PT, and LAW building designs. These issues need to be thoroughly evaluated so their impact on the existing designs can be determined.

- The simplified approach used to evaluate the design adequacy of members involves approximating seismic loads and neglecting the action of secondary beams and may not always be conservative. These assumptions need to be thoroughly evaluated so their impact on the existing designs can be determined.