July 30, 2008

WSB Geotechnical and Structural Analysis

Introduction

A letter sent by the Defense Nuclear Facilities Safety Board (DNFSB) on June 25, 2008 regarding the geotechnical and structural review of the Waste Solidification Building (WSB) Project at the Savannah River Site (SRS) listed three primary concerns. Provided below is a response describing actions being taken to remedy those concerns and the implementation status of these actions, which were discussed with the DNFSB staff in a conference call on July 16, 2008. Although not specifically addressed in the letter, the staff report also discussed the Finite Element Analysis conducted for the WSB. Additional information is provided on the methodology used.

Discussion

The three primary issues are discussed below.

1. Roof Truss Continuity with Roof Slab

The design has been modified to provide a positive connection between the concrete roof slab and the support trusses/beams. Concrete studs have been added to the top flange of the steel members to provide for composite action of the roof structural system. The analyses, design calculations, and drawings have been aligned to reflect this change, and the updated drawings have been provided to the DNFSB staff.

2. Unity of Structural Calculations

The structural design calculations have been revised extensively to address the final as-designed configuration of the facility. Concurrent with this, the analyses have been consolidated and the linkage of the calculations clarified. The structural analyses have been reduced from eleven to six calculations (see Table 1) and transmitted to the staff for review (WSRC letter NNP-WSB-2008-00026, dated July 2, 2008).

3. Dynamic Settlement Profile

Geotechnical analysis at the Savannah River Site (SRS) has relied on an extensive soil exploration and testing program to determine the thickness of soft zones under a facility to be constructed. This program has resulted in the F-Area being one of the most highly characterized areas on the SRS, with approximately 400 penetration tests being drilled and/or pushed in the general vicinity of the WSB and its related projects, the Pit Disassembly and Conversion Facility (PDCF) and the Mixed Oxide Fuel Fabrication Facility, among others. These tests have provided a high degree of confidence that the subsurface conditions in the affected portion of F-Area are well understood. Seven penetrations specifically under the WSB footprint support this conclusion, with the thickest soft zone under the WSB found to be about 4.7 feet. Nevertheless, the WSB project team elected to use a thickness of 7.6 feet for conservatism, which matches the thickest soft zone found under the PDCF Plutonium Processing Building (PPB) and

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resulted in a computed soft zone dynamic settlement of 2.8 inches, even though the geotechnical exploration and testing for the WSB indicates that the soil strata generally improve in the area of the WSB. Uncertainties in the settlement resulting from the soft-zone are addressed by assuming a larger settlement than would be calculated using the actual soft zone thickness under the facility. However, we acknowledge that differences exist between the DNFSB staff and SRS in the determination of settlement resulting from soft settlement in the Santee Formation.

The letter from the DNFSB lists four geotechnical issues concerning dynamic settlement. Three issues concern uncertainty (number of penetrations; soft zone thickness; and the angle of settlement propagation, soft zone shape, and soft zone compressibility). SRS recognizes and agrees that a degree of uncertainty will exist regarding these issues, given that no national code or consensus is available to address this topic; however, the methodology used by the WSB project resulted in an estimate of settlement that correlates well with subsequent analyses that have been conducted since the staff's on-site review. SRS also agrees with the Board that there is uncertainty in calculational methodologies used to determine the amount of soft zone settlement that is propagated to the surface as the result of a seismic event. In order to address these uncertainties, SRS committed to conduct a probabilistic dynamic settlement assessment, similar to the recent analysis performed for the Salt Waste Processing Facility. The assessment, documented in calculation K-CLC-F-00079, incorporated site-specific data to determine distributions for soft zone geometry (i.e., circular or linear), soft zone thickness, depth, width, angle of settlement propagation, and strain. The resulting 84th percentile soft zone settlement for WSB was calculated to be about 3 ½ inches and is assumed to be differential settlement. Additionally, a re-evaluation of the static settlement was performed based on the final design footprint and known structural load which revised the static differential settlement prediction to approximately ½ inch. Adding the probabilistic seismic differential settlement prediction (3 ½ inches) to the revised static differential settlement (½ inch) results in a total differential settlement of about 4.0 inches. This combination of static and dynamic differential settlements is inherently conservative in that it assumes the same profile for both settlement components and assumes that the maximum settlements occur in the same location.

The fourth geotechnical issue addressed by the DNFSB staff deals with the use of cyclic resistance ratio (CRR) curves for liquefaction analysis that have recently been revised. The WSB liquefaction safety factors never drop below 1 (even for a magnitude 7.5 event) resulting in little settlement due to liquefaction. Based on this analysis, the fact that the water table depth at the WSB site is about 70 feet, and the fact that the analysis was performed for the PC-3+ rock spectrum (a 1.25 increase above the PC-3 values at all frequencies at rock depth), revising the liquefaction settlement calculations is not warranted. Additional analyses could be performed, however the results are not expected to change much, if at all, and any computed settlement would be expected to be uniform and not contribute to the differential settlement for the facility.

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WSB Differential Settlement Analysis: Calculation (T-CLC-F-00411) uses a detailed finite element analysis to evaluate various settlement profiles using a 3.8 inch deep trough. This trough was placed at five different locations under the structure and was used as the original design basis to determine reinforcing requirements for the structure. In order to address potential speculation about the proper location of the trough from an infinite number of possibilities, where the five evaluations indicated a need for reinforcement, similar reinforcement was added to all comparable locations throughout the facility.

Following the 3.8 inch differential settlement analysis, where the primary criterion is to keep demand/capacity ratios less than unity, the specified settlement was doubled to 7.6 inches as an evaluation case and comparable demand/capacity ratios for the most critical elements calculated. For the increased settlement, these D/C ratios are evaluated against the ductility limits, $F\mu$, provided in ASCE 43-05, as discussed with the staff in February. For 7.6 inches of differential settlement, in all but a few isolated instances for shear in the foundation slab, the D/C ratios (using the reinforcement required for the 3.8 inch settlement) for the base slab, walls and roof are within the ductility limits of ASCE 43-05. However, out-of-plane shear for the 7.6 inch case is shown to exceed slab capacity in localized areas near some of the interior walls. In actuality, shear cracking deformations would be limited by the shallow soil profile of the settlement trough. Out-of plane shear that exceeds the slab capacity beyond the areas of reinforcement provided for the 3.8 inch differential settlement could be accommodated by increasing the area containing stirrups.

The analysis for the 7.6 inch differential settlement case was then reviewed to determine rotation demands on the base slab, which were evaluated against ASCE 43-05 criteria. For WSB, the span-to-depth ratio (l/h) for the base slab is about 50, giving a Limit State A allowable rotation of 0.010 radians. For the bounding settlement case the maximum rotation is 0.0081 radians (combined elastic and plastic rotation), which is in the allowable plastic hinge range for this Limit State. Roughly 75% of the slab is less than the Limit State B (0.0075) criterion, and about 50% of the slab is less than the Limit State C (0.005) criterion. The rotations do not exceed the ASCE 43-05 criteria, thus the structure is judged to be safe from collapse from bending failure for the 7.6 inch differential settlement.

The 7.6 inch differential settlement causes the highest demand on large open floor areas and areas with walls with re-entrant corners. The High Activity and Cementation Areas are free of these details and are typically more robust than the remainder of the structure. Except for out of plane shear in the mat, most of the D/C ratios in the High Activity and Cementation Areas are estimated to be less than 1 for 7.6 inches of settlement case. Because the 7.6 inch differential settlement case results in limited cases where the demand/capacity ratio are close to the appropriate ductility factor, the maximum settlement the structure could withstand is judged to be greater than 7.6 inches. However, reinforcing for out of plane shear in the mat required for the 7.6 inch settlement case will be added and the settlement analysis (T-CLC-K-00411) will be revised to determine the D/Cs for the High Activity and Cementation Areas to demonstrate the robust design of these areas. Thus, this evaluation provides confidence that a substantial design margin exists between the design demands and the actual capacity of the facility structure and that the High Activity and Cementation Areas will be demonstrably robust at 7.6 inch differential settlement.

Inelastic Finite Element Analysis

During the on-site review, and as discussed in the staff report attached to the subject letter, a question was raised concerning the model used for the settlement analysis. In order to verify that the SHELL181 element is suitable for the settlement analysis, two studies were performed. The first study involved manually modifying a linear elastic model when principal stress in individual elements exceeds the cracking value and comparing the results to the nonlinear analysis. The settlement model was run with uncracked linear elastic properties with compression only springs. Contour plots of element principal stress were produced with a contour specified at 59.2 ksf, the cracking stress for the concrete. The elastic modulus was then manually set at ½ the original (cracked concrete) for the cracked elements and the model was rerun. The process was repeated until a stable configuration was reached. The resulting stresses were compared to the non-linear property model. There was extremely good correlation between the non-linear analysis and the "selectively cracked" linear analysis. To bound the problem, the settlement model was run as a linear elastic model with all elements uncracked, then again with all elements cracked. The second study was a validation of the SHELL181 element against simple problems using closed form solutions. These studies are contained within calculation (T-CLC-F-00411). Based on the close correlation of the various methods, the SHELL181 elements in non-linear Finite Element Analyses provides an accurate and sophisticated methodology for conducting settlement analyses for the WSB.

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Table 1: WSB Project Process Building Geotechnical/Structural Calculations

	Document Number	Title	Summary
1	T-CLC-F-00392	Generation of PC-3+ Acceleration Time Histories for WSB Project for Reg. Guide 1.60 Spectra	Uses ASCE 43-05 criteria in SRS program "FIT" to develop acceleration time-histories that match Reg. Guide 1.60 response spectrum. This is input to calculation T-CLC-F-00393
2	T-CLC-F-00393	Free-Field Shake Analysis - High Strain Soil Properties for WSB Project	Uses program "SHAKE" to develop high strain shear modulus and damping for input to SSI analysis (calculation T-CLC-F-00402).
3	T-CLC-F-00402	Soil-Structure Interaction Analysis of the Waste Solidification Building	Uses "SASSI" program to perform SSI. Concludes that SSI is inconsequential to structural demands. Develops all vertical and horizontal in-structure response spectra. Uses roof stiffness developed in calculation T-CLC-F-00404.
4	T-CLC-F-00404	Structural Evaluation for WSB Roof Support Steel	Designs and analyzes the roof trusses and roof beams. Evaluates adequacy of the roof diaphragm. Develops truss stiffness for SSI model (calculation T-CLC-F-00402).
5	T-CLC-F-00405	Response Spectra Analysis and Gravity Design of the Waste Solidification Building - Concrete	Uses same ANSYS model as in settlement analysis (calculation T-CLC-F-00411) with linear properties. Seismic analysis done by response spectrum modal analysis. Analysis includes all loads and load combinations except settlement, develops reinforcing requirements and capacities and D/C ratios for foundation mat, walls, and roof.
6	T-CLC-F-00411	WSB Building Differential Settlement Analysis	Uses ANSYS non-linear finite element model on soil springs to perform differential settlement analysis at design basis settlement (3.8" total static + dynamic). Reinforcing in mat, walls, opening and roof is developed for the 3.8" case and D/C calculated. A second case of 7.6" differential settlement is analyzed using reinforcing from 3.8" to evaluate the facility response to settlements in excess of the original design case.
7	K-CLC-F-00060	Geotechnical Calculations for Waste Solidification Building	Static settlement reevaluated to account for the revised building footprint and weight.

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	Document Number	Title	Summary
8	K-CLC-F-00079	Waste Solidification Building (WSB) Probabilistic Soft Zone Settlement Analysis	Probabilistic tree evaluation of seismic settlement to account for the soil data ranges and uncertainties.