Abstract: The essential difference between Revision 1 and the original issue of this report is in the analysis of the anchor bolts that tie the steel dome of the primary tank to the concrete tank dome. The reevaluation of the AP anchor bolts showed that (for a given temperature increase) the anchor shear load distribution did not change significantly from the initially higher stiffness to the new secant shear stiffness. Therefore, the forces and displacements of the other tank components such as the primary tanks stresses, secondary liner strains, and concrete tank forces and moments also did not change significantly. Consequently, the revised work in Revision 1 focused on the changes in the anchor bolt responses, and a full reevaluation of all tank components was judged to be unnecessary.
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Hanford Double-Shell Tank Thermal and Seismic Project – Increased Liquid Level Analysis for 241-AP Tank Farms

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K. I. Johnson
N. K. Karri
K. L. Stoops
M. W. Rinker
S. F. Pilli
F. G. Abatt

September 2008

Prepared for
CH2M HILL Hanford Group, Inc.
in Support of the
Double-Shell Tank Integrity Program

Sponsored by the U.S. Department of Energy
under Contract DE-AC05-76RL01830
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Pacific Northwest National Laboratory
Richland, Washington 99352

(a) M&D Professional Services, Richland, Washington.
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Executive Summary

This report summarizes the results of the Double-Shell Tank Increased Liquid Level Analysis. This combined analysis provides a thorough, defensible, and documented analysis that will become part of the overall analysis of record for the proposed liquid level increase in the Hanford 241-AP Double-Shell Tank (DST) Farms.

The bases of the analytical work presented herein are two ANSYS® finite element models that were modified from the previous DST structural integrity analyses to represent the AP tank design. The current analysis conservatively assumes that the AP tanks are operating with 460 inches of liquid waste, at a temperature of 210°F, and a specific gravity of 1.83. The Thermal and Operating Loads Analysis (TOLA) model includes the effects of temperature on material properties, creep, concrete cracking, and various waste and annulus pressure-loading conditions. The seismic model considers the interaction of the tanks with the surrounding soil including a range of soil properties, and the effects of the waste contents during a seismic event.

The structural evaluations completed with the AP tank models do not reveal any structural deficiencies with the integrity of the DSTs under these increased waste level operating conditions. The analyses represent 60 years of waste storage in the AP tanks. Bounding material properties were selected to provide the most severe combinations.

The reinforced concrete structure was evaluated according to the American Concrete Institute (ACI) code requirements for nuclear safety-related structures (ACI 1990). The demand was demonstrated to be lower than the capacity at all locations.

The primary tank was evaluated using the American Society of Mechanical Engineers (ASME) Boiler & Pressure Vessel Code, Section III, Division 1, Service Level D capacities for combined seismic plus non-seismic loading as prescribed in Day et al. (1995) and Bandyopadhyay et al. (1995). It was demonstrated that the general primary membrane stress intensity in the primary tank remained well below the material yield stress for combined seismic and non-seismic loading. Similarly, the combined non-seismic and seismic demands for local membrane, plus bending as well as local membrane, plus bending, plus thermal loading, remained well below the capacities defined by the code. The primary tank is acceptable according to the established criteria.

The concrete and steel structures are demonstrated to meet the requirements of the International Building Code 2003 (IBC 2003). While the IBC does not explicitly address underground tanks, provision is made within the code to satisfy its requirements by demonstrating compliance with the requirements of the ACI code for concrete structures. Similarly, the IBC references the ASCE code for steel structures, which in turn requires compliance with the ASME B&PV code. Consequently, by demonstrating compliance with the ACI and ASME codes, the DSTs are shown to satisfy the requirements of the IBC.

The primary tank buckling evaluation demonstrated that the current limit on the maximum vacuum level of 12 inches water gauge is acceptable given the current lack of corrosion in the tanks and the expectation that the maximum waste temperature will not exceed 210°F. For this analysis, the occurrence of the maximum tank vacuum was classified as a service level C, emergency load condition. This limit is

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1 ANSYS is a registered trademark of ANSYS, Inc., Canonsburg, Pennsylvania.
predicated on maintaining the minimum allowable waste level at 12 inches to preclude bottom uplift from occurring.

The potential for stress corrosion cracking (SCC) of the primary tank, particularly in the lower knuckle, was assessed. Based on the recent analysis, current testing, and the historical operational records dating back to 1971, we conclude that SCC is unlikely if the present operating requirements are maintained.

The concrete-backed steel liner was evaluated to ASME Section III, Division 2 requirements (ASME 1992b). The liner strain was determined to be less than the maximum allowable levels for all load cases.

The essential difference between Revision 1 and the original issue of this report is in the analysis of the anchor bolts that tie the steel dome of the primary tank to the concrete tank dome. An independent review of Revision 0 of this report raised concerns about the anchor bolt capacity (see Appendix A.2). Further analysis resulted in changes to the anchor bolt modeling and the evaluation method. A detailed anchor bolt analysis of the AP welded stud and threaded stud configuration was conducted (Appendix A.3) to establish allowable anchor shear loads and the secant shear stiffness for calculating the distribution of anchor bolt loads in the global tank model. An ultimate shear capacity of 14.3 kips and a secant shear stiffness of 65,000 lbf/inch were the result of this work. Reevaluation of the anchor bolt forces with the above secant stiffness showed adequate safety margin for a maximum bulk waste temperature of 135°F with a concrete curing temperature of 80°F (the stress-free baseline temperature). Note that to date, the average bulk waste temperatures in the AP tanks have not reached 135°F, even during evaporator campaigns. An increased margin of safety is assured in that no evaporator discharges will be made to tanks certified to operate with waste at a level of 460 inches. The reevaluation of the AP anchors has been reviewed externally (Appendix A.4, A.5, A.8 and A.9).

The reevaluation of the AP anchor bolts showed that (for a given temperature increase) the anchor shear load distribution did not change significantly from the initially higher stiffness to the new secant shear stiffness. Therefore, the forces and displacements of the other tank components such as the primary tanks stresses, secondary liner strains, and concrete tank forces and moments also did not change significantly. Consequently, the revised work in Revision 1 focused on the changes in the anchor bolt responses, and a full reevaluation of all tank components was judged to be unnecessary.
## Acronyms

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<tr>
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<td>American Concrete Institute</td>
</tr>
<tr>
<td>ASCE</td>
<td>American Society of Civil Engineers</td>
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<tr>
<td>ASME</td>
<td>American Society of Mechanical Engineers</td>
</tr>
<tr>
<td>ASTM</td>
<td>American Society for Testing and Materials Standards</td>
</tr>
<tr>
<td>AWS</td>
<td>American Welding Society</td>
</tr>
<tr>
<td>BEC</td>
<td>Best-estimate concrete</td>
</tr>
<tr>
<td>BES</td>
<td>Best-estimate soil</td>
</tr>
<tr>
<td>B&amp;PV</td>
<td>Boiler and Pressure Vessel</td>
</tr>
<tr>
<td>COF</td>
<td>Coefficient of friction</td>
</tr>
<tr>
<td>CTE</td>
<td>Coefficient of thermal expansion</td>
</tr>
<tr>
<td>DOE</td>
<td>Department of Energy</td>
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<tr>
<td>DSA</td>
<td>Documented Safety Analysis</td>
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<tr>
<td>DST</td>
<td>Double-Shell Tank</td>
</tr>
<tr>
<td>FCC</td>
<td>Fully cracked concrete</td>
</tr>
<tr>
<td>FE</td>
<td>Finite element</td>
</tr>
<tr>
<td>IBC</td>
<td>International Building Code</td>
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<tr>
<td>$K_{SCC}$</td>
<td>Threshold stress intensity factor</td>
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<tr>
<td>LBS</td>
<td>Lower bound soil</td>
</tr>
<tr>
<td>MCE</td>
<td>Maximum considered earthquake</td>
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<tr>
<td>$\nu$</td>
<td>Poisson’s ratio</td>
</tr>
<tr>
<td>NUREG</td>
<td>U.S. Nuclear Regulatory Commission Regulation</td>
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<tr>
<td>PC</td>
<td>Performance Category</td>
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<tr>
<td>PNNL</td>
<td>Pacific Northwest National Laboratory</td>
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<tr>
<td>PSHA</td>
<td>Probabilistic Seismic Hazard Analysis</td>
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<tr>
<td>PWHT</td>
<td>Post weld heat treatment</td>
</tr>
<tr>
<td>SCC</td>
<td>Stress corrosion cracking</td>
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<tr>
<td>SpG</td>
<td>Specific gravity</td>
</tr>
<tr>
<td>SRS</td>
<td>Savannah River Site</td>
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<tr>
<td>TOLA</td>
<td>Thermal and Operating Loads Analysis</td>
</tr>
<tr>
<td>UBS</td>
<td>Upper bound soil</td>
</tr>
<tr>
<td>USGS</td>
<td>U.S. Geological Survey</td>
</tr>
<tr>
<td>Wg</td>
<td>Water gauge</td>
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<tr>
<td>WTP</td>
<td>Waste Treatment Plant</td>
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<td>degree Fahrenheit</td>
</tr>
<tr>
<td>ft</td>
<td>foot/feet</td>
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<tr>
<td>g</td>
<td>gravitational acceleration</td>
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<tr>
<td>in</td>
<td>inch</td>
</tr>
<tr>
<td>kip</td>
<td>1000 pounds</td>
</tr>
<tr>
<td>ksf</td>
<td>1000 pounds per square foot</td>
</tr>
<tr>
<td>ksi</td>
<td>1000 pounds per square inch</td>
</tr>
<tr>
<td>ksi in$^{1/2}$</td>
<td>1000 pounds per square inch square root inch</td>
</tr>
<tr>
<td>lb</td>
<td>pound</td>
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<tr>
<td>mil</td>
<td>1/1000 inch</td>
</tr>
<tr>
<td>psi</td>
<td>pounds per square inch</td>
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<tr>
<td>yr</td>
<td>year</td>
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1.0 Introduction

As provided in the CH2M HILL Hanford Group, Inc. (CH2M HILL) statement of work to the Pacific Northwest National Laboratory (PNNL) entitled Double-Shell Tank (DST) Integrity Project – DST Thermal and Seismic Analyses, Revision 2, the overall scope of this project was to complete an analysis of record of the DST system at Hanford. The analysis was conducted to provide analytical documentation of the DST system’s structural integrity and to support programmatic decisions toward the continued operations of these tanks during waste cleanup operations at the Hanford Site. This work establishes a defensible basis for operating specifications for continued use of the DSTs as well as providing an estimate of the remaining DST useful life.

The overall scope of the project was defined by seven activities that were completed over a 4-year period. The primary activities were:

- Thermal and Operating Loads Analysis (TOLA)
- Evaluation of Alternative Liquid Waste Levels in the DSTs
- Seismic Analysis
- Minimum Allowable Wall Thickness Analysis
- Buckling Analysis

Reports have been published documenting the Thermal and Operating Loads (TOLA) Analysis (Rinker et al. 2004), the Seismic Analysis (Rinker et al. 2006c), the Buckling Analysis (Johnson et al. 2006), and the Combined TOLA + Seismic Analysis (Rinker et al. 2006d). This report documents the evaluation of the proposed increased liquid level in the 241-AP Tank Farms.

1.1 Purpose of the DST Increased Liquid Waste Level Analysis

Ensuring adequate waste storage volume is critical to the success of the U.S. Department of Energy’s (DOE’s) mission to retrieve, treat and dispose of the radioactive waste in the Hanford Tank Farms. Increasing the available waste storage volume in the existing DSTs is an attractive option compared to the construction of new tanks. The purpose of the DST Increased Liquid Level Analysis is to demonstrate the structural integrity of the DSTs under the loading imposed by an increase in the liquid waste level above the current design limits. Review of tank design and operating parameters limited the DSTs under consideration for an increase in waste level to the 241-AP tanks.

The previous analyses (TOLA, Seismic, Buckling and Combined) developed and analyzed a tank model for a set of bounding thermal and operating load cases and bounding geometry of the 241-AY tank design. These nonlinear time-dependent analyses calculated the effects of heating the tank to the maximum operating temperature, long-term operation at elevated temperatures, and operating temperature cycles. These analyses also accounted for the degradation of modulus of elasticity, compressive strength, etc., in the concrete with extended exposure to elevated temperatures. The results predict time-dependent creep, cracking, stresses, strains, and deformations for the entire structure.

The seismic analysis considers the interaction of the tank with the surrounding soil, and the effects of the primary tank contents. The DST and the surrounding soil are modeled as a system of finite elements. The depth and width of the soil incorporated into the analysis model are sufficient to obtain accurate
analytical results. The analysis includes the soil-structure interaction (SSI) model represented by several (nonlinear) contact surfaces in the tank structure. The contained waste was modeled explicitly in order to capture the fluid-structure interaction behavior between the waste and the primary tank. Detailed analyses of the increased interaction between the contained waste and the curved dome area of the primary tank resulting from the increased liquid waste level are described in the Increased Liquid Level Seismic report (Abatt and Rinker 2008).

The previous analyses addressed bounding load cases and geometry and do not consider conditions that would apply to specific tanks. The objective of this work was to perform an analysis for the AP tanks that are the only tanks being considered for the increase waste level. The previously developed models were used with only minor modifications to represent the AP tanks. The load conditions for this analysis are summarized in Table 1-1. The work is documented (including analysis input files) in such a manner to expedite potential future sensitivity calculation and other tank-specific calculations as required by future needs.

Table 1-1. DST 241-AP Required Load Conditions for Analysis

<table>
<thead>
<tr>
<th>Design Load</th>
<th>Value</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design life</td>
<td>&gt;50 years</td>
<td>A 60-year design life is used</td>
</tr>
<tr>
<td>Maximum corrosion</td>
<td>1 mil/yr</td>
<td>A total corrosion allowance of 0.060 inch is applied to the specified nominal thicknesses</td>
</tr>
<tr>
<td>rate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil cover</td>
<td>8.5 ft @ 125 lb/ft³</td>
<td>Relative to dome apex</td>
</tr>
<tr>
<td>Hydrostatic</td>
<td>460 inches @ 1.83 SpG</td>
<td>Current tank contents are below 1.5 SpG</td>
</tr>
<tr>
<td>Pressure</td>
<td>-12 in. w. g. (water gauge)</td>
<td>Primary Tank</td>
</tr>
<tr>
<td>Pressure</td>
<td>-20 in. w. g. (water gauge)</td>
<td>Annulus</td>
</tr>
<tr>
<td>Pressure</td>
<td>40 lb/ft²</td>
<td>Uniform</td>
</tr>
<tr>
<td>Pressure</td>
<td>200,000 lb</td>
<td>Concentrated</td>
</tr>
<tr>
<td>Live load</td>
<td>210°C</td>
<td>Maximum bulk temperature of waste for calculational purposes</td>
</tr>
</tbody>
</table>

1.2 Impact of Analysis

The primary impact of the Increased Liquid Level analysis is to allow for increased waste storage volume in the DSTs. Raising the level in 241-AP Tank Farm by approximately 40 inches will increase the storage volume in each of the eight tanks by roughly 100,000 gallons. The impacts of the additional storage volume on Hanford Site operations are the responsibility of DOE and the Contractor.

1.3 Analysis Methodology

The analysis was conducted with two separate and distinct ANSYS® finite element models. The normal thermal and operating loads are considered in the TOLA model, which is described in detail by Rinker et al. (2004). The seismic loads are considered in the seismic model, which is described in detail by Rinker et al. (2006c). Results from the separate TOLA and seismic analyses are combined as necessary in various Excel spreadsheets for the appropriate code evaluation. The Combined Summary report

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1 ANSYS is a registered trademark of ANSYS, Inc., Canonsburg, Pennsylvania.
(Rinker et al. 2006d) outlines the method of combining results. Details for each model are given in Chapters 2 and 3 of this report. The combined results are presented in Chapter 6.

1.4 Double-Shell Tank Design

Figure 1-1 is a simplified diagram of a typical DST structure, showing an inner primary tank and an outer secondary tank covered by a reinforced-concrete shell. The primary and secondary tanks are made of carbon steel plate varying from 3/8 to 1 inch thick. The top of the concrete dome is 15 inches thick and becomes thicker toward the wall. The walls are 18 inches thick. The entire tank structure is buried at a depth of 6 to 8 feet, measured from the top of the tank dome (Han 1995). Figure 1-2 shows the configuration in 3-dimensional cross section.

The 241-AP Tank Farm was constructed over a period of about 4 years (from 1983 to 1986), with a design life of 50 years. These tanks have been in service for approximately 21 years.

![Figure 1-1. Cross Section of a Typical Double-Shell Tank](image1)

![Figure 1-2. Typical Double-Shell Tank Configuration](image2)
1.4.1 Thermal Characteristics

The bounding analyses reported in the Combined TOLA and Seismic Analysis (Rinker et al. 2006d) used the design thermal load from 422 inches of 350°F waste. That report describes the historical review of actual operating temperatures for all the DSTs. While that review did not indicate any waste temperatures in the AP tanks approaching the design limit of 210°F, a maximum waste temperature of 210°F was assumed for each thermal cycle for the Increased Liquid Level analysis. The ANSYS® thermal model described in the Buckling report (Johnson et al. 2006) was used to develop the thermal profiles for use in the thermal cycle.

1.4.2 Ventilation System

The annulus ventilation systems for the DSTs are designed to perform three functions: 1) provide primary tank leak detection through continuous radiation monitoring of the annulus exhaust air, 2) limit temperature build-up in the secondary tank concrete, and 3) remove heat and moisture from the annulus space. The primary tank ventilation systems perform similar functions: 1) limit flammable gas accumulation, 2) limit temperature build-up in the primary tank and secondary tank concrete, 3) maintain a vacuum on the primary tank, and 4) remove heat and moisture from the primary tank in order to minimize vapor space corrosion (Duncan 2003).

1.4.3 Primary Tank

The 75-foot-diameter primary steel tank provides containment for the stored waste. The primary tank varies in thickness from a minimum of 3/8 inch in the dome to a maximum of 1 inch at the bottom center of the tank. The primary tank is constructed from a series of formed segmented plates welded in a staggered arrangement. All butt welds on the primary tank received 100% radiographic examination during construction. The tanks were also post-weld heat treated to stress relieve the welds. The primary tank resists the hydrostatic and hydrodynamic waste loads and the internal pressure.

1.4.4 Secondary Liner

The secondary steel tank, or liner, lies beneath the insulating concrete and is built directly on top of the concrete foundation. The secondary tanks are about 5 feet larger in diameter than the primary tanks, resulting in a 2.5-foot-wide annular space between the primary and secondary tanks. The secondary liner is joined to the primary tank dome at the upper haunch area, and the two tanks are enclosed in a reinforced concrete shell. The secondary liner provides a second confinement barrier for potential primary tank leaks, thus preventing uncontrolled releases of waste to the environment.

1.4.5 Concrete Shell

On the outside of the secondary tank is a reinforced concrete shell. The exterior concrete shell comprises a foundation, walls, and a dome that completely enclose the secondary tank and primary tank dome. The structural concrete foundations are about 88 feet in diameter and are designed to distribute all weight loads to the ground below. The structural foundation contains drain lines and leak-detection wells to collect any leakage from the secondary liner. The top of the concrete foundation also contains slots to drain any liquid that might leak from the secondary tank.
The concrete shell wall is constructed of steel-reinforced concrete. The shells are about 83 feet in outside diameter and about 18 inches thick and rest on steel slide plates supported by the tank foundation. The concrete shells were poured directly against the secondary liner (i.e., the secondary liner was used as a casting form for the concrete shell). Construction form ties welded to the outside of the secondary tank attach the steel to the concrete walls. The dome is 15 inches thick and is constructed of steel-reinforced concrete. The primary tank is attached to the concrete dome by welded studs and threaded anchor bolts that are cast into the concrete dome.

Steel riser pipes penetrate the concrete dome and the top of the primary and secondary tanks. The risers provide access to the primary tank and the annulus space for waste transfer operations, equipment installation, and monitoring. The risers are located in covered pits or are located at grade at specific locations above the pits.

1.4.6 Insulating Concrete

The primary tank rests on an 8-inch-thick insulating concrete support pad, located between the primary and secondary tank floors. The concrete pad includes air distribution and drain slots in a radial pattern, which are designed to maintain a uniform tank bottom temperature, to provide a means of heat removal and leak detection, and to help eliminate pockets of water condensation. To provide supplemental cooling, air can be routed through the drain slots via the annulus ventilation system. The drain slots allow any leakage from the primary tank to drain into the annular space, where leak-detection instrumentation is installed.

1.5 Organization of the Increased Liquid Level Analysis Report

The organization and content of this report are described briefly as follows:

- Chapter 1 – Introduction: Provides the background and overall purpose of the Double-Shell Tank Thermal and Seismic Analysis. The scope of the Increased Liquid Level analyses is described. Basic DST information is also included in this chapter.
- Chapter 2 – TOLA Model: Describes the ANSYS® finite element model used for the thermal and operating loads analyses. Summarizes the material properties, loads and load case combinations.
- Chapter 3 – Seismic Model: Describes the ANSYS® finite element model used for the seismic analyses. Summarizes the material properties, boundary conditions and acceleration time-histories.
- Chapter 4 – Model Reconciliation: Discusses the differences between the TOLA and seismic models and the methods for combining results.
- Chapter 5 – Structural Acceptance Criteria: Describes the code-based acceptance criteria used to evaluate the combined results.
- Chapter 6 – Analysis Results: Provides a summary of the increased liquid level results. The ACI concrete evaluation for each run is presented and followed by the ASME primary tank evaluation. The stress-corrosion cracking criteria for the primary tank are considered next, followed by buckling analyses of the primary tank. Finally, the evaluation of the anchor bolts and the secondary liner are assessed.
- Chapter 7 – Conclusions and Recommendations: Summarizes the increased liquid level analysis with conclusions regarding DST structural integrity based on the evaluations conducted.
• Chapter 8 – References: Lists the references used in the study.
• Appendix A – Reviewer Comments and Resolution: Independent reviewer comments on Rev. 0.
• Appendix B – Software Acceptance.
• Appendix C – ANSYS® Model Files: Documents the TOLA model input and post-processing files.
2.0 TOLA Model

2.1 Introduction

This chapter describes the ANSYS® finite element (FE) model, material properties, and loads used for the double-shell tank (DST) Increased Liquid Level analysis. Complete documentation of the model is found in the TOLA report (Rinker et al. 2004). The current report contains summaries of the model, material properties, and loads. The TOLA report should be referenced for complete model description and background information.

The TOLA analysis was conducted on a model of the 241-AY tank that was selected as the bounding DST geometry. However, only the 241-AP tanks are being considered for the increase in waste liquid level. It is recognized that significant differences (as summarized in Table 2.4 of the TOLA report) exist between the AP tanks and the TOLA model. These include higher strength structural steel, higher strength concrete, higher strength reinforcing steel, increased thickness foundation, and increased amounts of reinforcing steel. The only modifications to the TOLA model used for the increase liquid level analysis to accommodate the differences in the AP tank design were to the primary tank wall thickness. The use of the TOLA model with the lower strength and thinner materials ensures an additional conservatism to the analysis.

2.2 241-AY Finite Element Model

This section describes the geometry and construction of the ANSYS® finite element model. A comprehensive description of the FE model is found in the TOLA report (Rinker et al. 2004). The TOLA report should be referenced for complete model description and background information. As noted above, these sections will describe the TOLA model of the 241-AY tank.

2.2.1 241-AY Tank Model Geometry

The TOLA report provided the rationale for choosing the 241-AY tank as the basis for the bounding model for the DST analyses. The geometry for this tank was taken from the design drawings listed in Table 2-1. A limited number of construction drawings, relating primarily to the steel tank construction, also were referred to for confirmation of dimensions.

It was helpful to review the other tank drawings, particularly 241-SY, because of its similarity to the 241-AY tank. In addition, the newer tank drawings, such as 241-AP, provided valuable insight to the reinforcing steel details.

<table>
<thead>
<tr>
<th>Drawing #</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>H-2-64306</td>
<td>Tank foundation plan</td>
</tr>
<tr>
<td>H-2-64307</td>
<td>Structural insulating concrete plan and details</td>
</tr>
<tr>
<td>H-2-64310</td>
<td>Concrete tank section and details</td>
</tr>
<tr>
<td>H-2-64311</td>
<td>Concrete dome reinforcement plan and details</td>
</tr>
<tr>
<td>H-2-64449</td>
<td>Tank elevation and details</td>
</tr>
</tbody>
</table>
2.2.2 241-AP Tank Model Modifications

As noted above, modifications to the TOLA model were limited to changes to the primary tank wall thickness. Figure 2-1 illustrates the differences in the wall thickness between the TOLA model and the AP modifications. The difference in waste depth is also depicted in this figure.

![Comparison of 241-AP and TOLA Models](image)

**Figure 2-1.** Comparison of 241-AP and TOLA Models

2.2.3 ANSYS® Model Construction

ANSYS® Version 7.0 was used for the TOLA analyses. The FE model was developed using ANSYS® APDL macros that build the geometry in 2-D and sweep the cross section about the tank central axis. The macros are listed in Appendix C and also are available electronically. A 2.9-degree section of the tank was modeled with symmetry boundary conditions. This gives an element length of 24 inches in the circumferential direction at the concrete tank inside diameter, which is equal to the anchor bolt spacing. Figures 2-2 through 2-5 show various aspects of the model.
Figure 2-2. Finite Element Mesh of Full Model

Figure 2-3. Close-Up Showing Finite Element Mesh of Tank
The model was constructed with a nominal soil overburden of 8.3 feet. The subgrade undisturbed soil depth extends to a depth of 168 feet below the foundation. The lateral soil dimension is 240 feet and includes a “stair step” boundary to distinguish between undisturbed soil and compacted backfill.
SOLID65 elements are used to represent the reinforced concrete regions. The tank liners, insulating concrete confinement ring, liner construction stiffeners, and the anchors use SHELL181 elements with full integration. The anchor bolts use COMBIN40 elements. Nonlinear contacts between various surfaces use the TARGET170 and CONTACT173 elements. SOLID45 elements are used to explicitly represent the soil.

The reinforced concrete is divided into regions that have different steel reinforcement ratios, where it is assumed that the thickness of each rebar layer is 1 inch. The rebar capabilities of the SOLID65 concrete elements were used to represent the reinforcing steel. For regions with nonzero reinforcement ratios, the element attributes include an element coordinate system and two rotation angles that identify the rebar orientation. The element x-axis is parallel to the radial direction, the y-axis is parallel to the circumferential direction, and the z-axis is parallel to the vertical direction. The dome uses the z-axis for the vertical/radial direction. The haunch region uses a spherical coordinate system to define the local x-direction (radially outward from the global origin at the bottom/center of the primary tank) to represent the diagonal ties. Note that the directions used for the rebar's three volume ratios specified as real constants are not in the element coordinate system x-, y-, or z-directions (ESYS), but rather the element x-direction for x, rotation angle theta for y, and rotation angle phi for z. See the ANSYS® Elements Manual and Theory Manual for SOLID65 for more detail.

The ANSYS® concrete material model has no provision for representing the post-cracking tension stiffening behavior of reinforced concrete. The stiffness of an element becomes zero immediately upon cracking. As a consequence, achieving convergence proved nearly impossible during the large-scale cracking that occurs in the model during a thermal cycle. Previous DST analytical reports describe similar difficulties and relate the use of "glue elements" to stabilize the solution. For this analysis, a set of SOLID45 elements was superimposed over the SOLID65 concrete elements to provide numerical stability to the model. These elements were assigned a low modulus (approximately 0.5% of the nominal concrete modulus). The use of these augmented stiffness elements greatly facilitated the model convergence and was demonstrated to have no significant impact on the resulting forces, moments, stress, or strain.

The program flow for the model, including a brief description of each macro, is as follows:

**SET_SLICE.MAC**

- **PNNLAMAC** – basic tank parameters and 2-D geometry, no soil geometry. Geometry divided to accommodate rebar, anchor bolts, and construction stiffeners later. Many area components created.
  - **SET_PARMS** – sets model parameters that may change (e.g., loads, material properties, overburden depth)
- **PNNLAM2.MAC** – element attribute (real, type, mat, esys) assignments (not values) to geometry (not soil)
  - **SET_RX.MAC** – selects areas within a range of x
  - **SET_REAL.MAC** – assigns real constant attribute to each area
  - **SET_RY.MAC** – selects areas within a range of y
  - **SET_REAL.MAC** – assigns real constant attribute to each area
- **SET_REAL.MAC** – assigns real constant attribute to each area

- **PNNLA3.MAC** – identify as components: anchor bolt lines (line_bolt), stiffener lines (line_stiff), anchor lines (line_anch in haunch), primary tank lines (line_prim), secondary liner lines (line_secon), bottom anchor lines (line_botanch)

- **PNNLA4.MAC** – 2-D soil geometry, 2-D mesh of soil and the other 2-D solids, rotate to create 3-D geometry/mesh for slice model (no 3-D shell elements), note that soil geometry/mesh is later redefined in set_soil.mac
  - **MESH_SIZE.MAC** – sets default element size for rebar and soil elements, sets sweep angle, and sets number of divisions per quadrant

- **PNNLA5.MAC** – merges nodes/keypoints at slab/rebar and tank/rebar; couples all soil nodes to corresponding structural nodes and top of slab to bottom of wall and top of slab to bottom of insulating concrete (note that all coupling is later deleted)

- **PNNLA6.MAC** – generates anchor bolts, studs, wall base plate, confining ring below secondary liner, confining ring for insulating concrete, wall, and dome stiffeners.

- **PNNLA7.MAC** – generate primary tank geometry and mesh, define values for all tank real constants, couple vertical displacements at liner bottom

- **PNNLA8.MAC** – generates secondary liner geometry and mesh, couples vertical displacements at liner bottom, couples shell horizontal displacements to sidewall, couples shell vertical displacements to dome, merges secondary liner nodes with slab top nodes

- **PNNLA9.MAC** – merges liner to anchor bolts/studs/anchor nodes, applies constraints
  - **SET_MATERIALS.MAC** – sets all material properties
  - **SET_OPTIONS.MAC** – includes/excludes certain nonlinear material models (e.g., nonlinear concrete, creep, nonlinear steel liner, nonlinear rebar, nonlinear soil)
  - **SET_SOIL.MAC** – creates soil geometry and mesh; couples to concrete

- Delete all coupled sets

- **SET_AREAS_SLICE.MAC** – defines area components for contact definition

- Add steel plate below wall (on slab)

- Add nonlinear contact with appropriate friction coefficients per Section 3.6.2 between soil/concrete, secondary liner/concrete wall, primary tank/dome, primary tank/insulating concrete, slab top/insulating concrete, and wall/slab

- Merge insulating concrete bottom/secondary liner nodes, liner/concrete nodes at centerline

- **SET_ESYS_3D.MAC** – define all rebar elements real, modify secondary liner elements above 357.5 inch to be 3/8 inch thick

- **APPLY_LOADS_SLICE.MAC** – reverse area normal of radiused section of secondary liner, apply parametric loads
  - **MESH_SIZE.MAC** – sets default element size for rebar and soil elements, sets sweep angle, and sets number of divisions per quadrant
• Apply axisymmetric boundary conditions
• Copy anchor bolts, etc. for slice model; divide anchor bolt/bottom anchors by 2 for slice model
• Couple nodes at primary/secondary liner intersection
• Define soil layers including elevation and material properties
  - SET_SLAYER.MAC — applies soil material properties to a layer
  - SET_BACKFILL.MAC — defines backfill region and sets linear and nonlinear material properties
• Define augmented stiffness elements
• Merge duplicate contact elements/nodes
• Apply gravity, waste depth, surface loads, annulus and primary tank pressures
• SET_SLICEB.INP runs the thermal cycling for years 1 through 5
• Extended13yr.INP runs the thermal cycling and creep for years 6 through 18
• TwoYrCycle.INP runs the thermal cycling for years 19 and 20
• TwoYrCycleWith460wh.INP increases the waste level to 460 inches and runs the thermal cycling for year 21 and 22
• Extended36yr.INP runs the thermal cycling and creep for years 23 through 58
• TwoYrCycTo60Yr.INP runs the thermal cycling for year 59 and 60
• SET_SLICED6.INP runs ACI load combination 4
• SET_SLICEH.INP runs the thermal cycle for load combination 9

The ANSYS® concrete material model is used for the SOLID65 elements. This model allows for cracking and crushing, as well as variable shear transfer for open/closed cracks. In addition, the implicit creep material model for concrete was used. ANSYS® allows for the concrete cracking/crushing material model and creep material model to be used simultaneously.

The soil elements use the Drucker-Prager constitutive model, which has an internal friction angle, cohesion, and a dilatancy angle as material properties (see Section 2.3.5). A small positive value of cohesion is used to represent the Hanford cohesionless soils, and the dilatancy angle is assumed to be equal to the friction angle (this parameter induces volume changes as a function of element shear stress).

The soil region surrounding the concrete tank and foundation is coupled to the concrete using nonlinear surface-to-surface contact elements, where the sliding friction coefficient is as specified in Section 2.3.6.

The tank liners are coupled to the structural and nonstructural concrete in a similar manner, i.e., with nonlinear contact elements. A friction coefficient is used for these surfaces as well, as specified in Section 2.3.6. These include contact between the following surfaces:
• secondary liner and tank
• primary tank and dome
• bottom of primary tank and top of insulating concrete
• top of slab and bottom of insulating concrete
• bottom of secondary liner and top of slab
• bottom of tank wall and top of slab.

2.2.4 Real Constants

ANSYS® uses real constants to define element properties for certain element types, e.g., thickness for shell elements. The thicknesses of the different regions of the steel liners are defined in SET_PARMS.MAC and assigned in PNNLA7.MAC. The thickness of the primary tank that is in contact with the waste was given a 0.001 inch/year corrosion allowance for the desired 60-year design life for a total reduction of 0.060 inch at the beginning of the analysis. Real constants for the wall and dome stiffeners are defined in PNNLA6.MAC.

2.2.4.1 Reinforcing Steel

The concrete reinforcing steel is modeled by using the rebar capabilities of the ANSYS® SOLID65 element. Elements of 1-inch thickness were defined in the appropriate locations in the dome, haunch, wall, and foundation. The real constants for the rebar elements include the following for each of three possible rebar directions:

• the rebar material ID
• steel volume ratio
• two angles used to orient the rebar directions relative to the element coordinate system.

Tables 2-2 through 2-5 show the calculations for the steel volume ratios required for the concrete rebar elements. The geometry of the rebar, including the locations of transition between rebar volumes, is defined in PNNLA.MAC. Real constants are initially assigned by location in PNNLA2.MAC. The volume ratios and rebar orientation are defined in SET_ESYS_3D.MAC.

2.2.4.2 Anchor Bolts

The tank design drawings listed in Table 2-1 specify an anchor bolt spacing of 2 feet by 2 feet. The 3-D finite element model was constructed as a 2.9-degree wedge that gives the correct 24-inch spacing at the concrete wall (480 feet). The anchor bolts were modeled with two sets of springs: one normal to the primary tank surface to represent the axial stiffness of the anchor bolt, and one tangent to the surface to represent the shear stiffness.

Rev. 0 of this report utilized beam elements for the anchor bolts. The independent reviewers raised concerns over the anchor bolt capacity used in the evaluation (Appendix A.2). They also suggested accounting for the nonlinear shear response of the anchor bolts that has been well documented in Ollgaard et al. (1971) and Lam and El-Lobody (2005). Detailed finite element models (described in Appendix A.3) were developed and the nonlinear response of the AP anchor bolt design was determined. The appropriate secant modulus was identified and used in the DST model. The secant stiffness is a function of the radial location of the anchor bolt.
Table 2-2. Foundation Concrete Rebar Volume Ratios

<table>
<thead>
<tr>
<th>Description</th>
<th>Slab Bottom</th>
<th>Slab Top</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevation</td>
<td>Radius (in.)</td>
<td>Bar Size</td>
</tr>
<tr>
<td>NA</td>
<td>75</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>115</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>202</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>350</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>369</td>
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<tr>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(a) The drawings used to obtain this information specify rebar by spacing or # bars, therefore, where a measurement for Meridional spacing is given, information for # bars is not recorded, and vice versa.
NA = Not applicable.

Table 2-3. Wall Concrete Rebar Volume Ratios

<table>
<thead>
<tr>
<th>Description</th>
<th>Wall</th>
<th>Meridional Spacing (in.)</th>
<th># Bars</th>
<th>Volume Ratio</th>
<th>Bar Size</th>
<th>Hoop Spacing</th>
<th>Volume Ratio</th>
<th>Real Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevation</td>
<td>Radius (in.)</td>
<td>Bar Size</td>
<td># Bars (in.)</td>
<td>Volume Ratio</td>
<td>Bar Size</td>
<td>Hoop Spacing</td>
<td>Volume Ratio</td>
<td>Real Constant</td>
</tr>
<tr>
<td>NA</td>
<td>147</td>
<td>75</td>
<td>6</td>
<td>12</td>
<td>NA</td>
<td>0.0368</td>
<td>8</td>
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<tr>
<td></td>
<td>204</td>
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<td>12</td>
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<tr>
<td></td>
<td>339.5</td>
<td>350</td>
<td>8</td>
<td>12</td>
<td>NA</td>
<td>0.0654</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>381.5</td>
<td>369</td>
<td>8</td>
<td>12</td>
<td>NA</td>
<td>0.0654</td>
<td>8</td>
<td>12</td>
</tr>
</tbody>
</table>

(a) The drawings used to obtain this information specify rebar by spacing or # bars, therefore, where a measurement for Meridional spacing is given, information for # bars is not recorded, and vice versa.
NA = Not applicable.
### Table 2-4. Dome Concrete Rebar Volume Ratios

<table>
<thead>
<tr>
<th>Description</th>
<th>Elevation (in.)</th>
<th>Dome Radius (in.)</th>
<th>Bar Size</th>
<th>Meridional Spacing</th>
<th># Bars</th>
<th>Volume Ratio</th>
<th>Bar Size</th>
<th>Hoop Spacing</th>
<th>Volume Ratio</th>
<th>Real Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>NA</td>
<td>120</td>
<td>6</td>
<td>NA</td>
<td>51</td>
<td>0.0453</td>
<td>6</td>
<td>12</td>
<td>0.0368</td>
<td>301</td>
<td></td>
</tr>
<tr>
<td></td>
<td>183</td>
<td>6</td>
<td>NA</td>
<td>101</td>
<td>0.0490</td>
<td>6</td>
<td>12</td>
<td>0.0368</td>
<td>302</td>
<td></td>
</tr>
<tr>
<td></td>
<td>270</td>
<td>6</td>
<td>NA</td>
<td>202</td>
<td>0.0651</td>
<td>6</td>
<td>12</td>
<td>0.0368</td>
<td>303</td>
<td></td>
</tr>
<tr>
<td></td>
<td>304.5</td>
<td>6</td>
<td>NA</td>
<td>202</td>
<td>0.0496</td>
<td>8</td>
<td>6</td>
<td>0.1309</td>
<td>304</td>
<td></td>
</tr>
<tr>
<td></td>
<td>314</td>
<td>8</td>
<td>NA</td>
<td>346</td>
<td>0.1399</td>
<td>8</td>
<td>6</td>
<td>0.1309</td>
<td>305</td>
<td></td>
</tr>
<tr>
<td></td>
<td>354</td>
<td>8</td>
<td>NA</td>
<td>346</td>
<td>0.1300</td>
<td>9</td>
<td>6</td>
<td>0.1657</td>
<td>306</td>
<td></td>
</tr>
<tr>
<td></td>
<td>368.9</td>
<td>8</td>
<td>NA</td>
<td>346</td>
<td>0.1197</td>
<td>9</td>
<td>4</td>
<td>0.2485</td>
<td>307</td>
<td></td>
</tr>
<tr>
<td></td>
<td>391</td>
<td>8</td>
<td>NA</td>
<td>346</td>
<td>0.1139</td>
<td>9</td>
<td>4</td>
<td>0.2485</td>
<td>308</td>
<td></td>
</tr>
</tbody>
</table>

(a) The drawings used to obtain this information specify rebar by spacing or # bars; therefore, where a measurement for Meridional spacing is given, information for # bars is not recorded, and vice versa. NA = Not applicable.

### Table 2-5. Haunch Concrete Rebar Volume Ratios

<table>
<thead>
<tr>
<th>Elevation (in.)</th>
<th>Haunch External Radius (in.)</th>
<th>Bar Size</th>
<th>Meridional Spacing</th>
<th># Bars</th>
<th>Volume Ratio</th>
<th>Bar Size</th>
<th>Hoop Spacing</th>
<th>Volume Ratio</th>
<th>Real Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>NA</td>
<td>450</td>
<td>8</td>
<td>NA</td>
<td>519</td>
<td>0.1534</td>
<td>9</td>
<td>4.5</td>
<td>0.2209</td>
<td>401</td>
</tr>
<tr>
<td>NA</td>
<td>496</td>
<td>8</td>
<td>NA</td>
<td>519</td>
<td>0.1375</td>
<td>9</td>
<td>4.5</td>
<td>0.2209</td>
<td>402</td>
</tr>
<tr>
<td>NA</td>
<td>496</td>
<td>8</td>
<td>4</td>
<td>NA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>408</td>
<td>NA</td>
<td>6</td>
<td>6</td>
<td>NA</td>
<td>0.2700</td>
<td>8</td>
<td>6</td>
<td>0.1309</td>
<td>404</td>
</tr>
<tr>
<td>452</td>
<td>NA</td>
<td>8</td>
<td>6</td>
<td>NA</td>
<td>0.1309</td>
<td>9</td>
<td>4</td>
<td>0.2485</td>
<td>403</td>
</tr>
<tr>
<td>NA</td>
<td>480</td>
<td>8</td>
<td>NA</td>
<td>519</td>
<td>0.1489</td>
<td>9</td>
<td>4.5</td>
<td>0.2209</td>
<td>405</td>
</tr>
<tr>
<td>NA</td>
<td>480</td>
<td>8</td>
<td>6</td>
<td>NA</td>
<td>0.1309</td>
<td>8</td>
<td>6</td>
<td>0.1309</td>
<td>406</td>
</tr>
<tr>
<td>408</td>
<td>NA</td>
<td>8</td>
<td>6</td>
<td>NA</td>
<td>0.0261</td>
<td>9</td>
<td>4.5</td>
<td>0.2209</td>
<td>502</td>
</tr>
<tr>
<td>435</td>
<td>485.5</td>
<td>6</td>
<td>NA</td>
<td>163</td>
<td>0.0235</td>
<td>9</td>
<td>8</td>
<td>0.1243</td>
<td>500</td>
</tr>
<tr>
<td>451</td>
<td>NA</td>
<td>6</td>
<td>18</td>
<td>NA</td>
<td>0.0109</td>
<td>9</td>
<td>8</td>
<td>0.1243</td>
<td>501</td>
</tr>
</tbody>
</table>

(a) The drawings used to obtain this information specify rebar by spacing or # bars; therefore, where a measurement for Meridional spacing is given, information for # bars is not recorded, and vice versa. NA = Not applicable.

### 2.3 Material Properties

This section summarizes the material properties used in the TOLA finite element model. A comprehensive description of the structural and thermal properties is found in the TOLA report (Rinker et al. 2004). The TOLA report should be referenced for complete material property description and background information. The lower concrete and steel strengths of the TOLA analysis were maintained in the...
Increased Liquid Level finite element model. The higher strength of the A537 steel used in the AP tanks was used for the allowable stress evaluation of the primary steel tank.

2.3.1 Structural Concrete

This section summarizes the structural properties of reinforced concrete that were used in the finite element analysis. The concrete properties listed here represent Hanford batch concrete with a 3-ksi specified minimum compressive strength, as specified for the 241-AY tank design. The properties are summarized in figures and tables in this section.

The concrete elastic modulus was prescribed to be temperature-dependent, as shown in Figure 2-6. The concrete compressive and tensile strengths are shown in Figure 2-7. These are the mean strengths as described in the TOLA report (Rinker et al. 2004). These values are used in the ANSYS® cracking algorithm employed with the SOLID65 concrete elements. The crushing capabilities of the SOLID65 elements were not used. The ACI code evaluation (see Section 6.1 of Chapter 6) used the lower bound compressive strengths of 4.5 ksi specified minimum strength concrete to determine the load and moment capacities of the reinforced concrete tank structure. Thus the analysis conservatively used the mean strength properties to determine the demand and the lower bound properties to establish the concrete section capacity. The TOLA report (Rinker et al. 2004) describes the basis for the concrete strength degradation as a function of temperature.

The coefficient of thermal expansion (CTE) of concrete was taken to be $0.37 \times 10^{-6}$ in./in./°F. Poisson's ratio was specified to be 0.15.

![Concrete Elastic Modulus](image)
Previous DST analyses have identified concrete creep as being an important material parameter. The TOLA report (Rinker et al. 2004) describes the procedure and data used for defining the concrete creep material model. The time-hardening creep algorithm in ANSYS® is defined as

\[ \varepsilon_c(t) = \frac{C_1}{T} \dot{C}_2 \int_0^t \sigma_C e^{C_4/T} dt \]  

(2.1)

The coefficients used for the ANSYS® time-hardening implicit creep law are given in Table 2-6. The creep law parameters are provided to ANSYS® via the TBDATA command found in SET_PARMS.MAC.

Table 2-6. Coefficients for the ANSYS® Creep Law

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>0.2545 x 10^{-6}</td>
</tr>
<tr>
<td>C2</td>
<td>1</td>
</tr>
<tr>
<td>C3</td>
<td>-0.838</td>
</tr>
<tr>
<td>C4</td>
<td>320</td>
</tr>
</tbody>
</table>

2.3.1.1 Degraded Concrete Properties

It was necessary to develop a method to prevent the concrete modulus and strength from “recovering” during subsequent thermal cycles after the initial degradation due to elevated temperature. This was accomplished by redefining the concrete material properties in their degraded condition at the end of the first year at 210°F. Because the degradation is temperature dependent, this definition required segregating the concrete elements into groups of 10-degree increments based on their maximum
temperature (steady-state). A modified set of concrete properties in the degraded condition was defined. At the conclusion of the first year of creep, the properties of each 10-degree group of concrete elements were changed using the ANSYS® mpsel command to redefine these elements with the degraded properties.

2.3.2 Insulating Concrete

A linear elastic material model was prescribed for the insulating concrete. Table 2-7 lists the structural properties that were used. The compressive strength was not used in the finite element analysis, but was employed in the evaluation of the insulating concrete stress level.

<table>
<thead>
<tr>
<th>Material Property</th>
<th>Units</th>
<th>Value – Tank AY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strength</td>
<td>psi</td>
<td>200</td>
</tr>
<tr>
<td>Elastic modulus</td>
<td>psi</td>
<td>165,000</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td></td>
<td>0.15</td>
</tr>
<tr>
<td>Density</td>
<td>lbf/ft³</td>
<td>50</td>
</tr>
<tr>
<td>Coefficient of thermal expansion</td>
<td>in./in.-°F</td>
<td>3.7</td>
</tr>
</tbody>
</table>

2.3.3 Structural Steel

The elastic modulus of the primary tank and the secondary liner structural steels was defined to be temperature-dependent, as shown in Figure 2-8. An elastoplastic material model was defined with a yield of 36,000 psi and a tangent modulus of 1% of the nominal elastic modulus. The density of steel was taken as 490 lb/ft³. Poisson’s ratio was taken as 0.30. The steel CTE was defined to be temperature dependent as shown in Figure 2-9.

![Figure 2-8. Structural Steel Elastic Modulus](image-url)
2.3.4 Reinforcing Steel

Two grades of reinforcing steel were used in the construction of the 241-AY DST. Rebar with 40,000 psi yield strength was used in the slab, and steel with 60,000 psi yield strength was used in the wall and dome. The nonlinear stress-strain curves shown in Figure 2-10 for both grades of rebar were implemented in the ANSYS® model. The density was specified to be 490 lb/ft$^3$. Poisson's ratio was taken as 0.3 and the mean CTE was specified as $6 \times 10^{-6}$ in./in.-°F.

2.3.5 Soils

Distinction was made between the undisturbed soil and the compacted backfill, as shown Figure 2-11. The DST foundation is supported by the undisturbed native soil. The backfill applies radial pressure and axial frictional force to the tank walls and a dead load to the dome. The FE soil properties were distributed accordingly, as depicted in Figure 2-12.

The soil dimensions are:

- Soil depth below foundation: 168 feet
- Overburden depth: 8.3 feet
- Radial extent (from center of tank): 240 feet
- Excavation slope: Stair-stepped approximation with 1.5:1 slope
Figure 2-10. Steel Reinforcing Bar Stress-Strain Curves: a) Grade 40 Rebar (slab), b) Grade 60 Rebar (wall and dome)
The soil constitutive model used for the DST analysis was the ANSYS® Drucker-Prager elastoplastic model. The elastic response is determined by the elastic modulus ($E$) and the Poisson’s ratio ($\nu$). The elastic modulus and Poisson’s ratio must be assigned according to the soil depth because the Drucker-Prager model does not adjust the stiffness for confining pressure. The undisturbed soil elastic modulus and Poisson’s ratio are shown in Figure 2-13. The compacted backfill soil modulus is shown in Figure 2-14. The backfill Poisson’s ratio was constant at 0.27.

The Drucker-Prager plasticity parameters were defined to be constant with soil depth and temperature. The values used are: cohesion = 1.0 psi, friction angle = 35°, and dilatancy angle = 8°. The undisturbed soil density was 110 lb/ft$^3$ and the compacted backfill density was 125 lb/ft$^3$. A detailed discussion is presented in the TOLA report (Rinker et al. 2004).
2.3.6 Coefficients of Friction at Material Interfaces

The DST finite element model includes several contact interfaces where friction forces must be accounted for. Table 2-8 summarizes the coefficients of friction (COF) that are used in the DST model. The basis for these values is given in Rinker et al. (2004).
Table 2-8. Coefficients of Friction

<table>
<thead>
<tr>
<th>Material Interface Description</th>
<th>Coefficient of Friction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil-to-concrete:</td>
<td>0.3</td>
</tr>
<tr>
<td>Concrete-to-steel (concrete cast against steel)</td>
<td>0.4</td>
</tr>
<tr>
<td>Concrete-to-steel (insulating concrete-to-primary tank)</td>
<td>0.3</td>
</tr>
<tr>
<td>Steel-to-steel (graphite-lubricated)</td>
<td>0.2</td>
</tr>
</tbody>
</table>

2.4 Loads

This section describes the loads used in the thermal and operating load analysis. A comprehensive description of the load and boundary conditions is found in the TOLA report (Rinker et al. 2004). The TOLA report should be referenced for complete load description and background information.

The load parameters are defined in SET_PARMS.MAC and are applied in APPLY_LOADS_SLICE.MAC. The loading sequence is defined in SET_SLICE.MAC and subsequent input files.

2.4.1 Thermal Loads

The temperature distributions described in the TOLA report (Rinker et al. 2004) were applied as thermal loads. The temperature profiles represented a yearly thermal cycle that includes the design basis heat up transient, a steady-state dwell time at the maximum design waste temperature, followed by the design basis temperature cool down transient. Table 2-9 presents the time and waste temperatures that define the cycle. Multiple temperature distributions were solved during the waste heating and cooling segments of the transient to ensure that the maximum effect of the transient temperature gradients was captured in the structural evaluations of the concrete and steel sections. It was also conservatively assumed that the steady-state temperature distribution corresponding to a maximum waste temperature of 210°F was achieved at the end of the high-temperature segment of the transient. This approach ensures that the maximum concrete temperatures and the maximum thermal degradation in the concrete strength and stiffness are considered. At the low waste temperature of 50°F it was also assumed that the transient ended with the tank and surrounding soil returning to the uniform 50°F initial temperature. The mechanical analyses assume 50°F as the initial stress-free temperature for the soil, steel, and concrete.

The DST model temperatures are used in the analysis for including the effects of concrete thermal degradation, temperature-dependent steel properties, and differential thermal expansion between the steel and the concrete. The different temperature fields corresponding to the mechanical solution (steps 2 through 12 in Table 2-9) are shown in Figures 2-15 through 2-24. (Note that solution steps 7 and 8 are the same temperature state and only plotted once.) Data files for the temperature distributions are prohibitively large for inclusion in this report as appendices but are available on the electronic media version of this report.
Table 2-9. Temperature States that Define the Design Basis Annual Thermal Cycle for the ANSYS® Structural Model

<table>
<thead>
<tr>
<th>Step No.</th>
<th>Comment</th>
<th>Days</th>
<th>Waste Temp., °F</th>
<th>Plot Label</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Initial temperature = 50°F uniform</td>
<td>0</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Fast heat to 125°F (@ 10°F/hour)</td>
<td>0.3</td>
<td>125</td>
<td>h1</td>
</tr>
<tr>
<td>3</td>
<td>First step to 210°F (@ 20°F/day)</td>
<td>2.4</td>
<td>167.5</td>
<td>h2</td>
</tr>
<tr>
<td>4</td>
<td>Second step to 210°F</td>
<td>4.6</td>
<td>210</td>
<td>h3</td>
</tr>
<tr>
<td>5</td>
<td>Intermediate step toward steady-state</td>
<td>23</td>
<td>210</td>
<td>h4</td>
</tr>
<tr>
<td>6</td>
<td>Steady-state @ 210°F</td>
<td>38</td>
<td>210</td>
<td>Ss</td>
</tr>
<tr>
<td>7</td>
<td>$T_{H_{in}}$ = steady-state @ 210°F</td>
<td>350</td>
<td>210</td>
<td>$T_{H_{in}}$</td>
</tr>
<tr>
<td>8</td>
<td>Material property change</td>
<td>351</td>
<td>210</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>First step to 125°F cool down (@ 20°F/day)</td>
<td>353</td>
<td>167.5</td>
<td>c1</td>
</tr>
<tr>
<td>10</td>
<td>Second step to 125°F</td>
<td>355</td>
<td>125</td>
<td>c2</td>
</tr>
<tr>
<td>11</td>
<td>Fast cool down to 50°F (@ 10°F/day)</td>
<td>355.6</td>
<td>50</td>
<td>c3</td>
</tr>
<tr>
<td>12</td>
<td>Tank cool down transient to 50°F</td>
<td>356.6</td>
<td>50</td>
<td>c4</td>
</tr>
<tr>
<td>13</td>
<td>Uniform 50°F</td>
<td>365</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

The service life of the 241-AP Tank Farm is 50 years. For the purpose of this analysis, a life of 60 years was selected. This value was chosen based on the number of years already in service and the anticipated continuing waste storage. While the historical data suggest a three-year full-temperature cycle, an annual cycle was conservatively specified for the thermal loading. However, the completion of an analysis with 60 thermal cycles proved problematic with the model convergence issues. Review of the preliminary results demonstrated little change in the concrete cracking, concrete force and moments and tank stress beyond the first several cycles. In addition, the creep rate decreases over time (see the TOLA report Chapter 3). Accordingly, analyses consisted of one thermal cycle per year of 422 inches of waste for five years followed by 13 years of creep at elevated temperature followed by two annual thermal cycles. The waste level was then increased to 460 inches. Two annual thermal cycles were conducted at this waste level followed by 36 years of creep at elevated temperature, concluding with two final thermal cycles as described in Section 2.4.4.

The concerns raised by the independent reviewers (Appendix A) regarding the capacity of the anchor bolts resulted in modifications to the anchor bolt modeling as described in Chapter 2.2.4.2 and Appendix A.3. However, evaluation of the anchor bolts continued to be problematic at the higher waste temperatures. Accordingly, as described in Appendix A.3, a separate, distinct 60-year analysis was conducted at a reduced waste temperature of 135°F. This temperature corresponded to the anchor bolt limit load, and it is still higher than the temperatures expected for future AP tank operations. The DST thermal cycle ranged from a uniform 80°F to the steady state temperature distribution corresponding to the 135°F waste temperature. Only one intermediate heat up and cool down load step was required. The temperature distribution for these load steps and the steady state waste condition are shown in Figures 2-25 through 2-27.
Figure 2-15. Temperature (°F) Distribution at Step 2 (Table 2-9) in the Design Basis Transient (waste temperature = 125°F)
Figure 2-16. Temperature (°F) Distribution at Step 3 (Table 2-9) in the Design Basis Transient (waste temperature = 167.5°F)
Figure 2-17. Temperature (°F) Distribution at Step 4 (Table 2-9) in the Design Basis Transient (waste temperature = 210°F)
<table>
<thead>
<tr>
<th>NODAL SOLUTION</th>
<th>SUB</th>
<th>TIME</th>
<th>BFETEMP (AVG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>STEP = 130</td>
<td>16</td>
<td>21196</td>
<td>130</td>
</tr>
<tr>
<td>TOP</td>
<td></td>
<td></td>
<td>112.222</td>
</tr>
<tr>
<td>DMX = 1.6</td>
<td></td>
<td></td>
<td>94.444</td>
</tr>
<tr>
<td>SMN = 50</td>
<td></td>
<td></td>
<td>76.667</td>
</tr>
<tr>
<td>SMX = 210</td>
<td></td>
<td></td>
<td>58.889</td>
</tr>
<tr>
<td>A   = 112.222</td>
<td></td>
<td></td>
<td>58.889</td>
</tr>
<tr>
<td>B   = 76.667</td>
<td></td>
<td></td>
<td>56.667</td>
</tr>
<tr>
<td>C   = 94.444</td>
<td></td>
<td></td>
<td>58.889</td>
</tr>
<tr>
<td>D   = 112.222</td>
<td></td>
<td></td>
<td>58.889</td>
</tr>
<tr>
<td>E   = 130</td>
<td></td>
<td></td>
<td>58.889</td>
</tr>
<tr>
<td>F   = 147.778</td>
<td></td>
<td></td>
<td>76.667</td>
</tr>
<tr>
<td>G   = 181.333</td>
<td></td>
<td></td>
<td>76.667</td>
</tr>
<tr>
<td>H   = 201.111</td>
<td></td>
<td></td>
<td>76.667</td>
</tr>
</tbody>
</table>

**Figure 2-18.** Temperature (°F) Distribution at Step 5 (Table 2-9) in the Design Basis Transient (waste temperature = 210°F)
Figure 2-19. Temperature (°F) Distribution at Step 6 (Table 2-9) in the Design Basis Transient (waste temperature = 210°F)
Figure 2-20. Steady-State Temperature (°F) Distribution at Steps 7 and 8 (Table 2-9) in the Design Basis Transient (waste temperature = 210°F)
Figure 2.21. Temperature (°F) Distribution at Step 9 (Table 2-9) in the Design Basis Transient (waste temperature = 167.5°F)
Figure 2.22. Temperature (°F) Distribution at Step 10 (Table 2-9) in the Design Basis Transient (waste temperature = 125°F)
Figure 2.23. Temperature (°F) Distribution at Step 11 (Table 2-9) in the Design Basis Transient (waste temperature = 50°F)
Figure 2-24. Temperature (°F) Distribution at Step 12 (Table 2-9) in the Design Basis Transient (waste temperature = 50°F)
Figure 2-25. Temperature (°F) Distribution During Heat up in the Anchor Bolt Design Basis Transient (waste temperature = 135°F)
Figure 2-26. Temperature (°F) Distribution at Steady State in the Anchor Bolt Design Basis Transient (waste temperature = 135°F)
Figure 2-27. Temperature (°F) Distribution During Cool Down in the Anchor Bolt Design Basis
Transient (waste temperature = 80°F)

2.4.2 Mechanical Loads

Table 2-10 lists the non-seismic loading conditions that are specified in the statement of work for this project. The list contains both structural and thermal operating loads that are both static and transient in nature. The concentrated live load was increased at the end of the nominal 60-year analysis.
Table 2-10. DST 241-AP Load Conditions for Analysis

<table>
<thead>
<tr>
<th>Design Load</th>
<th>Value</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design life</td>
<td>&gt; 50 years</td>
<td>A 60-year design life is used.</td>
</tr>
<tr>
<td>Maximum corrosion rate</td>
<td>1 mil/yr</td>
<td>A total corrosion allowance of 0.060 inch is applied to the specified nominal thickness.</td>
</tr>
<tr>
<td>Soil cover</td>
<td>8.3 ft @ 125 lb/ft²</td>
<td>Relative to dome apex.</td>
</tr>
<tr>
<td>Hydrostatic Pressure</td>
<td>-12 in. w.g. ≤ P_{primary}≤ +60 in. w.g.</td>
<td>Primary tank</td>
</tr>
<tr>
<td></td>
<td>-20 in. w.g. ≤ P_{annulus}≤ +60 in. w.g.</td>
<td>Annulus</td>
</tr>
<tr>
<td></td>
<td>-12 in. w.g. ≤ P_{primary} - P_{annulus}</td>
<td>Differential</td>
</tr>
<tr>
<td>Live load</td>
<td>40 lb/ft²</td>
<td>Uniform</td>
</tr>
<tr>
<td></td>
<td>200,000 lb. nominal</td>
<td>Concentrated</td>
</tr>
<tr>
<td>Thermal</td>
<td>210°F</td>
<td>Maximum bulk temperature of waste</td>
</tr>
<tr>
<td></td>
<td>20°F/day</td>
<td>Waste maximum heatup/cooldown rate</td>
</tr>
<tr>
<td></td>
<td>1/yr</td>
<td>Cyclic rate</td>
</tr>
</tbody>
</table>

2.4.3 ACI Load Factors

The load factors required by ACI 349-90 (ACI 1990) were achieved by directly applying them to the relevant load in a separate load step. The load factors to be applied in this analysis are a subset of the possible combinations specified in ACI 349, Section 9.2 (ACI 1990). The subset is defined by WHC-SD-WM-DGS-003 (Day et al. 1995). The normal operating and thermal loads specified for analysis are:

- **U** = Demand Load (comprised of combinations of the following):
  - **D** = Dead Load (tank + overburden + concentrated dead load + piping and equipment)
  - **L** = Live Loads
  - **L1** = uniform live load
  - **L2** = concentrated live load
  - **F** = Hydrostatic waste pressure
  - **V** = Vapor pressure loading (annulus and vapor space)
  - **H** = Lateral soil pressure
  - **T** = Thermal load (internal forces and moments caused by temperature distribution within the concrete). Normal (T₀) and abnormal (T_{abnormal}) cases are specified. As described in Chapter 4, the abnormal temperature cases are bounded by the design thermal transient that is applied in the thermal and operating loads analysis.
  - **R₀** = Piping and equipment reactions

The credible but improbable extreme environmental load is:

- **E_{es}** = Safe Shutdown Earthquake (SSE) effects – Design Basis Earthquake effects

WHC-SD-WM-DGS-003 does not distinguish L1 from L2, or V from F. Those items are combined into L and F. We chose to maintain a distinction and combine them algebraically as a matter of form.

1 R₀ is not considered in this analysis.
The applicable ACI load combinations reduce to:

Load Combination 1: \( U = 1.4(D + F + V) + 1.7(H + L1 + L2) \)
Load Combination 4: \( U = D + F + V + H + L1 + L2 + T + E_{as} \)
Load Combination 9: \( U = 1.05D + 1.05(F + V) + 1.3(L1 + L2 + H) + 1.05T_{o} \)

Load Combination 9 is, in terms of load factors, intermediate between Load Combination 1 and Load Combination 4. Instead of applying Load Combination 9, we conservatively applied Load Combination 1 then added the thermal loads with the temperatures increased by 5% as discrete load steps; that is, Load Combination 9': \( U = 1.4(D + F + V) + 1.7(H + L1 + L2) + 1.05T \).

### 2.4.4 Load Step Procedure

Figure 2-28 shows the flow plan used to model the 61 years of thermal cycles. The analysis is divided into several distinct analyses to facilitate a restart in the event of convergence difficulties. The time spans from years 5 to 18 and from 22 to 58 are single thermal cycles held at the steady state temperature for nominally 13 and 53 years, respectively. These are followed by 2 thermal cycles to capture any effect the long term creep may have had on the cracking of the concrete and subsequent load distribution. The waste level was increased from 422 inches to 460 inches following year 20. The ASME and ACI load combinations 1 and 4 evaluations are carried out at the end of or during year 60. An additional thermal cycle (year 61) is completed with the temperatures increased by 5% to provide a conservative evaluation of ACI load combination 9.

![Figure 2-28. Analysis Flow Plan](image-url)

---

2.34
3.0 Seismic Model

3.1 Introduction

This chapter describes the ANSYS® finite element (FE) model, material properties, and loads used for the double-shell tank (DST) seismic analysis. Complete documentation of the seismic model supporting the proposed liquid level increase in the AP Tank Farms may be found in the Seismic Analysis report (Abatt and Rinker 2008). The current report contains summaries of the model, material properties and loads. The Seismic Analysis report should be referenced for complete model description and background information.

3.2 Finite Element Model

The model used for the evaluation of the AP tank configuration and increased liquid level is based on the model developed for the AY tank and a liquid level of 422 inches (Rinker et al. 2006c). Key differences in the increased liquid level and the AY model are as follows:

- AP tank geometry used (geometry and wall thicknesses)
- Waste level increased to 460 inches
- Waste specific gravity increased to 1.83
- Number of contact areas used for waste/primary tank interface increased

For completeness, a detailed description of the model development is provided below.

3.2.1 Model Description

A model of a Hanford double-shell tank was created and analyzed using version 8.1 of the general purpose finite element program ANSYS®. A half-symmetry model of the DST, including the concrete tank, primary tank, secondary liner, anchor bolts, waste, and surrounding soil was developed to evaluate the seismic loading on the DST.

The tank model geometry was based on the AP tank configuration shown in Hanford Drawing H-2-90534. The primary tank has a 450-inch radius and the height of the vertical wall is 422.3 inches. The nominal dome apex is 561.5 inches above the bottom of the tank. The models were run using waste depths of 460 inches. An excerpt from Drawing H-2-90534 is shown as Figure 3-1. Figure 3-2 shows the complete model. Details for each part of the model are discussed in the following sections.

The detailed ANSYS® model was developed based on coordinates used in the TOLA model. A series of input files were used to break the model creation into manageable parts. The files used, and a short description is provided in Table 3-1. Files that are common to all load cases are provided in Appendix E of the Increased Liquid Level Seismic report (Abatt and Rinker 2008). Files that are unique to a specific load case are provided in the appendix of that report for each load case.
Figure 3-1. AY Primary Tank Dimensions

Figure 3-2. Composite Tank Model Detail
### Table 3-1. ANSYS® Model Input File Description

<table>
<thead>
<tr>
<th>File Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run-tank.txt</td>
<td>Calls each input for development of model</td>
</tr>
<tr>
<td>Tank-coordinates-AY.txt</td>
<td>Defines key geometry and model parameters. Concrete geometry set to match PNNL section cut locations</td>
</tr>
<tr>
<td>Tank-props-###.txt</td>
<td>Defines concrete material and real properties for model. Uses properties based on best-estimate or fully cracked conditions. Each tank layer can be assigned unique properties</td>
</tr>
<tr>
<td>Tank-mesh1.txt</td>
<td>Creates concrete tank mesh. Foundation and wall are separate entities</td>
</tr>
<tr>
<td>Primary-props-AY.txt</td>
<td>Defines primary tank material and real properties.</td>
</tr>
<tr>
<td>Primary.txt</td>
<td>Creates primary tank mesh. Primary tank is not connected to concrete tank.</td>
</tr>
<tr>
<td>Insulate.txt</td>
<td>Creates insulating concrete mesh. Uses existing geometry from concrete and primary tanks, but is not connected.</td>
</tr>
<tr>
<td>Interface1.txt</td>
<td>Creates interface connections or contacts between pieces of model.</td>
</tr>
<tr>
<td>Interface-gap1.txt</td>
<td>Creates interface connections or contacts between pieces of model.</td>
</tr>
<tr>
<td>Bolts-friction.txt</td>
<td>Creates elements for anchor bolts and contact surface between the primary tank and concrete tank in the dome</td>
</tr>
<tr>
<td>Liner.txt</td>
<td>Creates elements for Secondary Liner</td>
</tr>
<tr>
<td>Near-soil-1.txt</td>
<td>Creates soil model for excavated region around tank. Merges coincident nodes with concrete tank.</td>
</tr>
<tr>
<td>Soil-props-###-geo.txt</td>
<td>Defines all soil geometry and material properties. Excavated region and native soil have different material properties. Unique files are used for each soil condition (UB, BE, LB).</td>
</tr>
<tr>
<td>Far-soil.txt</td>
<td>Creates far-field/native soil to a radius of 320 ft and depth of 266 ft. Merges coincident nodes with near soil and concrete tank. Places large mass at bottom of model for excitation force.</td>
</tr>
<tr>
<td>Fix-soil.txt</td>
<td>Creates the contact interface between the excavated soil and native soil portions of the model.</td>
</tr>
<tr>
<td>Slave.txt</td>
<td>Creates slaved boundary conditions around exterior of model.</td>
</tr>
<tr>
<td>Boundary.txt</td>
<td>Creates boundary conditions for symmetry. Does not set boundary conditions for solution phase.</td>
</tr>
<tr>
<td>Live load.txt</td>
<td>Applies surface concentrated load over center of dome</td>
</tr>
<tr>
<td>Outer-spar.txt</td>
<td>Creates spar elements at edge of soil model to control shear behavior.</td>
</tr>
</tbody>
</table>

(a) Unique files are used for each concrete and soil condition – best-estimate, lower bound, upper bound soils and fully cracked concrete.

All components of the model are based on 9-degree slices over the half model, for a total of twenty slices. The model description will address the tank components first, then the surrounding soil.

#### 3.2.2 Concrete Model

The first component developed in the model is the concrete tank shell and footing. Thirty-three sections are used between the dome and center of the floor for each 9-degree slice. In the detailed TOLA slice model, seventy sections were identified and used for extracting forces and moments. Using the profile coordinates for these seventy sections, a subset of 33 sections was developed for the profile of the ANSYS® seismic model (see Figure 3-3). Based on the need to allow for connecting other portions of the full model, some coordinates were adjusted relative to the TOLA slice model.
The geometry of the concrete tank is based on a combination of data from drawings and TOLA slice model. The basic geometry is based on drawings H-2-90439 and H-2-90442. Nodal locations were selected to correspond reasonably well to the TOLA model. This placement was done to simplify load combinations. Table 3-2 provides a listing comparison of nodal coordinates for the ANSYS® seismic model and TOLA slice model.

Input file “Tank-Coordinates-AY.txt” is used to read coordinate data for the concrete tank.

<table>
<thead>
<tr>
<th>Section</th>
<th>Coordinates</th>
<th>ANSYS®</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R (inch)</td>
<td>H (inch)</td>
</tr>
<tr>
<td>Dome</td>
<td>1</td>
<td>30.2</td>
</tr>
<tr>
<td>Dome</td>
<td>2</td>
<td>61.4</td>
</tr>
<tr>
<td>Dome</td>
<td>3</td>
<td>90.4</td>
</tr>
<tr>
<td>Dome</td>
<td>4</td>
<td>120.72</td>
</tr>
<tr>
<td>Dome</td>
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<td>152.9</td>
</tr>
<tr>
<td>Dome</td>
<td>6</td>
<td>184.14</td>
</tr>
<tr>
<td>Dome</td>
<td>7</td>
<td>211.4</td>
</tr>
<tr>
<td>Dome</td>
<td>8</td>
<td>239.1</td>
</tr>
<tr>
<td>Dome</td>
<td>9</td>
<td>271.85</td>
</tr>
<tr>
<td>Dome</td>
<td>10</td>
<td>306.63</td>
</tr>
<tr>
<td>Dome</td>
<td>11</td>
<td>316.22</td>
</tr>
<tr>
<td>Dome</td>
<td>12</td>
<td>335.6</td>
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<tr>
<td>Dome</td>
<td>13</td>
<td>356.7</td>
</tr>
<tr>
<td>Dome</td>
<td>14</td>
<td>371.86</td>
</tr>
<tr>
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<tr>
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<td>Haunch</td>
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<tr>
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<td>489</td>
</tr>
</tbody>
</table>
Table 3-2. (contd)

<table>
<thead>
<tr>
<th>Section</th>
<th>Coordinates</th>
<th>ANSYS*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R (inch)</td>
<td>H (inch)</td>
</tr>
<tr>
<td>Wall</td>
<td>39</td>
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<td>489</td>
</tr>
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<td>489</td>
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<tr>
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<td>508.5</td>
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</tr>
<tr>
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</tr>
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<td>493</td>
</tr>
<tr>
<td>Slab</td>
<td>53</td>
<td>489</td>
</tr>
<tr>
<td>Slab</td>
<td>54</td>
<td>485.1</td>
</tr>
<tr>
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<td>481</td>
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<tr>
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<td>471</td>
</tr>
<tr>
<td>Slab</td>
<td>58</td>
<td>465</td>
</tr>
<tr>
<td>Slab</td>
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<td>440</td>
</tr>
<tr>
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</tr>
<tr>
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</tr>
<tr>
<td>Slab</td>
<td>63</td>
<td>338</td>
</tr>
<tr>
<td>Slab</td>
<td>64</td>
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<tr>
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<tr>
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<td>67</td>
<td>129.9</td>
</tr>
<tr>
<td>Slab</td>
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</tr>
<tr>
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<td>69</td>
<td>54</td>
</tr>
<tr>
<td>Slab</td>
<td>70</td>
<td>20</td>
</tr>
</tbody>
</table>

Note: The concrete tank wall is 8 inches short due to modeling error.

Element stiffnesses are also based on the TOLA slice model for best-estimate concrete conditions for a maximum temperature of 250°F. Common properties for all concrete sections are provided below.

\[ v = 0.18 \]

Damping – 7%

Input file “Tank-Props-BEC-250.txt” defines the concrete tank material properties and real constants (thickness) for the best-estimate concrete. Input file “Tank-Props-BEC-Crack.txt” defines the concrete tank material properties and real constants (thickness) for the fully cracked concrete. Table 3-3 provides a complete listing of section properties based on the TOLA model. Table 3-4 provides concrete section properties assuming all sections are cracked.
RPP-RPT-32237, Rev. 1
Table 3-3. Best-Estimate Concrete Properites, 250°F
Cracked
Y/N
N
N
N
N
N
N
N
N
N
N
N
N
N
N
N
N
N
N
Y
Y
N
N
Y
Y
Y
Y
Y
Y
Y
Y
Y
Y
Y
Y
Y
Y
Y
N
N
Y
Y
Y
Y
Y
Y
Y
Y
N
N
Y
Y
Y
Y

Eshl
(psi)
4 502E+06
4.352E+06
4.306E+06
4.282E+06
4.262E+06
4.243E+06
4.315E+06
4.295E+06
4.216E+06
4.201 E+06
4 439E+06
4.425E+06
4.405E+06
4.392E+06
4.316E+06
4.406E+06
4 366E+06
4.323E+06
1.655E+06
1.345E+06
4.000E+06
3.960E+06
1264E+06
1.409E+06
1.120E+06
1.093E+06
1.076E+06
1.068E+06
1.068E+06
1.068E+06
9.490E+05
9.490E+05
9.490E+05
9.490E+05
9.490E+05
9.490E+05
9.490E+05
9.589E+05
3.467E+06
3.435E+06
8.568E+05
8.568E+05
8.655E+05
8.655E+05
8.568E+05
8.638E+05
8.871 E+05
3.810E+06
3.764E+06
1.038E+06
1.054E+06
1.075E+06
7.157E+05

Shell Thickness t-shl
(ksf)
(in.)
648,297
15.35
626,754
15.18
620,114
15.12
616,594
15.09
613,774
15.15
610,922
15.13
621,305
15.21
618,475
15.19
607,093
15.17
604,939
15.15
639,237
15.39
637,265
15.34
634,338
15.32
632,441
15.31
621,503
15.30
634,531
19.32
628,756
20.73
622,528
22.99
238,350
26.72
193,677
26.78
575,959
37.86
570,283
30.93
182,025
21 60
202,953
18.00
161,221
15 28
157,426
15.36
155,010
15.42
14 00
153,784
14 00
153,784
14 00
153,784
136,651
13.53
136,651
13.53
136,651
13.53
136,651
13.53
136,651
13.53
136,651
13.53
136,651
13.53
138,084
14 89
499,310
18.08
494,646
18 06
123,378
12 89
123,378
12 89
124,633
14.21
124,633
14.21
123,378
12 89
124,388
12 86
127,746
14.12
548,683
23 64
542,010
23.65
149,405
20.05
151,733
20.06
154,870
20.12
103,055
14.04

Shell Density, Rho-shl
(lb/in3)
(ft)
0.08484
1.28
1.26
0.08578
0 08609
1.26
1.26
0.08627
1.26
0.08595
1.26
0.08609
1.27
0.08559
1.27
0.08572
1.26
0.08583
1.26
0.08594
1.28
0.08463
1.28
0.08487
1.28
0.08497
1.28
0.08504
1.28
008510
1 61
0 08499
1.73
0.08505
1.92
0.08527
2.23
0.08302
2.23
0.09548
3.15
0.08337
2.58
008339
1 80
0 09052
1.50
0.09197
1.27
0.10227
1.28
0.10170
1.28
0.10133
1.17
0.11163
1.17
0 11163
1.17
0.11163
1.13
0.11552
1.13
0.11552
1.13
0.11552
1.13
0.11552
1.13
0.11552
1.13
0.11552
1 13
0.11552
1.24
0.10496
1.51
0.08644
1.50
0.08652
1.07
0.12123
1.07
0.12123
1 18
0.10997
0 10997
1 18
1.07
0.12123
1.07
0.12149
1.18
0.11067
1.97
0.09606
1.97
0.09604
1.67
0.10680
1.67
0.10674
1 68
0.10643
1.17
0.13627

3.6

M&D Section
(lbf/ft3)
No.
147
148
1
2
149
149
3
149
149
4
148
5
148
148
6
148
146
7
147
147
8
147
147
147
147
9
147
143
165
10
144
11
144
156
159
12
177
176
13
175
193
193
14
193
200
200
200
15
200
200
16
200
200
181
17
149
150
209
18
209
190
19
190
209
210
20
191
166
21
166
185
184
184
22
235

PNNL Section
No.
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
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38
39
40
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43
44
45
46
47
48
49
50
51
52
53


Table 3-3. (contd)

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<th>M&amp;D Section No.</th>
<th>PNLL Section No.</th>
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Table 3-4. Fully Cracked Concrete Properites

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<th>Shell Density, Rho-shl (lb/ft³)</th>
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<th>PNLL Section No.</th>
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Table 3-4. (contd)

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<th>Shell Density, Rho-shl (lb/in³)</th>
<th>M&amp;D Section No.</th>
<th>PNGL Section No.</th>
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</table>

Input file “Tank-Mesh1.txt” develops the concrete tank model. Element type SHELL143 is used for the concrete tank to be able to extract through-wall shear forces.

Figures 3-3 and 3-4 show the profile and full concrete tank model, respectively.
3.2.3 Primary Tank

The geometry of the primary tank is based on drawing H-2-90534. To ensure that the anchor bolt elements are perpendicular to the primary tank, the primary tank dome coordinates were calculated based on the location of the corresponding concrete tank coordinate, taking into account the concrete shell thickness, and normal to the primary tank (see Figure 3-5). The concrete shell thickness used is based on the nominal concrete thickness.
The location of the primary tank nodes were iteratively determined as follows:

Select a value for \( x \) (radial distance from center of the tank).

Calculate the respective location for \( y' \) based on the defined shape of the primary tank. The primary tank is an ellipse with a major axis of 80 feet and minor axis of 30 feet. The equation for location of \( y' \) is as follows:

\[
y' = a \sqrt{1 - \frac{x^2}{b^2}} - a, \quad \text{where}
\]

\[
a = \text{Minor Radius} = 180 \text{ in}
\]
\[
b = \text{Major Radius} = 480 \text{ in}
\]
\[
x = \text{Test Location for} \ x
\]

For \( x = 61.0398 \), \( y' = 180 \sqrt{1 - \frac{61.0398^2}{480^2}} - 180 = -1.46 \)

The slope of the ellipse can be calculated by taking the derivative of the equation for \( y' \).

\[
\frac{d}{dx} \left( a \sqrt{1 - \frac{x^2}{b^2}} \right) = -\frac{x}{b} \frac{a}{\sqrt{b^2 - x^2}}
\]

For \( x = 61.0398 \), the slope of the ellipse is \(-0.048\). The corresponding angle is the arctangent of the slope, or in this case, \(-0.048\). The length of line connecting the centerline of the concrete to the primary tank is half the thickness of the tank at that point. Therefore, to check the accuracy of the assumed \( x \) location of the primary tank, back-calculate the location of the concrete coordinates. If the back-calculated concrete location is the same as the known location, the \( x \) location of the primary tank must be correct, otherwise, reselect \( x \) until it is correct. The primary tank dome coordinate calculations are summarized in Table 3-5.
Following the example, for concrete location of \((60.4)\), the \(x\) location of the primary tank is 61.0398. \(y'\) was determined to be -1.46. Adjusting this to value for the vertical location of the center of the ellipse, add 561.45 (elevation of the primary tank at the apex). For this case, \(y=559.99\). The check is as follows:

\[
X_{\text{conc}} = X_{\text{primary}} + \frac{t}{2} \sin(\theta), \text{ where } \theta \text{ is the angle of the slope from horizontal}\]  
(3.4)

\[
X_{\text{conc}} = 61.0398 + \frac{15}{2} \sin(0.048) = 61.39966 \approx 61.4
\]  
(3.5)

\[
Y_{\text{conc}} = Y_{\text{primary}} + \frac{t}{2} \cos(\theta) = 559.99 + \frac{15}{2} \cos(0.048) = 567.48136 = 567.5
\]  
(3.6)

Table 3-5. Primary Tank Dome Coordination Calculation

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<th>X</th>
<th>Y</th>
<th>T</th>
<th>Error</th>
<th>x</th>
<th>y</th>
<th>(y')</th>
<th>Slope (rad)</th>
<th>Angle (rad)</th>
<th>Angle (Deg)</th>
<th>Y Offset</th>
<th>X Offset</th>
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<td>0</td>
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<td>-0.210</td>
<td>-12.055</td>
<td>7.335</td>
<td>-1.566</td>
</tr>
<tr>
<td>306.63</td>
<td>527.68</td>
<td>15</td>
<td>0%</td>
<td></td>
<td>304.4248</td>
<td>520.62</td>
<td>-40.83</td>
<td>-0.308</td>
<td>-0.298</td>
<td>-17.099</td>
<td>7.169</td>
<td>-2.205</td>
</tr>
<tr>
<td>335.6</td>
<td>518.2</td>
<td>15</td>
<td>0%</td>
<td></td>
<td>333.0513</td>
<td>511.07</td>
<td>-50.38</td>
<td>-0.361</td>
<td>-0.347</td>
<td>-19.866</td>
<td>7.054</td>
<td>-2.549</td>
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<tr>
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<td>494.5</td>
<td>15</td>
<td>0%</td>
<td></td>
<td>390.2214</td>
<td>486.27</td>
<td>-75.18</td>
<td>-0.524</td>
<td>-0.482</td>
<td>-17.633</td>
<td>6.645</td>
<td>-3.479</td>
</tr>
<tr>
<td>428.7</td>
<td>476.2</td>
<td>22</td>
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<td></td>
<td>422.2643</td>
<td>467.04</td>
<td>-94.41</td>
<td>-0.694</td>
<td>-0.607</td>
<td>-34.752</td>
<td>9.276</td>
<td>-6.436</td>
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<td>A</td>
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<td></td>
<td></td>
<td>432</td>
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<td>-101.54</td>
<td>-0.774</td>
<td>-0.659</td>
<td>-37.750</td>
<td>0.000</td>
<td>0.000</td>
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<tr>
<td>B</td>
<td></td>
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<td></td>
<td></td>
<td>440</td>
<td>455.39</td>
<td>-108.06</td>
<td>-0.860</td>
<td>-0.710</td>
<td>-40.700</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Element thicknesses are based on the drawing H-2-90534 but reduced by 0.06 inches for the corrosion allowance (see Section 2.2.4). General steel properties are used and are as follows:

- Elastic Modulus \((E)\) = 4,176,000 kip/ft\(^2\)
- Poisson’s Ratio \((v)\) = 0.30
- Mass Density \((\rho)\) = 0.001522 kip-sec\(^2\)/ft\(^4\) = \((0.490 \text{ kip/ft}^3)/(32.2 \text{ ft/sec}^2)\)
- Damping = 2%

Tank coordinates are developed in the model from input file “Tank-Coordinates-AY.txt.” Tank element properties are from input file “Primary-Props-AY.” The tank mesh is generated using “Primary.txt” and uses SHELL143 elements.

Figure 3-6 shows the full primary tank model and Figure 3-7 shows the detail in the knuckle region at the bottom of the tank.
**Figure 3-6.** Primary Tank Model Detail

**Figure 3-7.** Primary Tank Model Detail – Knuckle Region
3.2.4 Insulating Concrete

The insulating concrete uses the geometry defined for the concrete and primary tanks and fills in the open volume with solid element (SOLID45). Concrete properties are taken as follows Rinker et al. (2004).

Elastic Modulus \(E\) = 23,760 kip/ft\(^2\)

Poisson’s Ratio \(\nu\) = 0.15

Mass Density \(\rho\) = 0.00155 kip-sec\(^2\)/ft\(^3\) = (0.050 kip/ft\(^3\))/\((32.2 \text{ ft/sec}^2)\)

Damping = 7%

Material properties for the insulating concrete are in the file “Tank-Props-BEC-250.txt.” The element mesh is generated using “Insulate.txt.” Figure 3-8 shows the insulating concrete elements.

![Insulating Concrete Model Detail](image)

3.2.5 Anchor Bolts

The anchor bolts connecting the primary tank to the concrete shell are modeled using beam elements (BEAM4) and spring elements (COMBIN14). Based on drawing H-2-64310 the anchor bolts are spaced on an average of 2 ft in each direction. Therefore, the contributing area of the bolts in the model is based on the number of 4 ft\(^2\) areas associated with the element. The required area is calculated based on the number of bolts to be represented and the thickness of the concrete at the bolt location.
Table 3-6. Anchor Bolt Area Calculation

<table>
<thead>
<tr>
<th>Ring No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
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<tbody>
<tr>
<td>x</td>
<td>0.00</td>
<td>0.00</td>
<td>44.72</td>
<td>89.87</td>
<td>120.00</td>
<td>151.97</td>
<td>210.05</td>
<td>237.53</td>
<td>304.42</td>
<td>333.05</td>
<td>390.22</td>
</tr>
<tr>
<td>y</td>
<td>561.45</td>
<td>560.77</td>
<td>558.37</td>
<td>555.83</td>
<td>552.29</td>
<td>543.49</td>
<td>537.96</td>
<td>520.72</td>
<td>511.17</td>
<td>486.27</td>
<td>467.14</td>
</tr>
<tr>
<td>Delta Y</td>
<td>0.00</td>
<td>0.68</td>
<td>3.08</td>
<td>5.62</td>
<td>9.16</td>
<td>18.05</td>
<td>23.49</td>
<td>40.73</td>
<td>50.28</td>
<td>75.08</td>
<td>94.31</td>
</tr>
<tr>
<td>x'</td>
<td>0.00</td>
<td>1.00</td>
<td>2.40</td>
<td>3.56</td>
<td>8.89</td>
<td>5.43</td>
<td>17.25</td>
<td>9.55</td>
<td>24.80</td>
<td>19.23</td>
<td></td>
</tr>
<tr>
<td>x''</td>
<td>0.00</td>
<td>44.72</td>
<td>89.92</td>
<td>120.13</td>
<td>152.24</td>
<td>210.83</td>
<td>238.69</td>
<td>307.14</td>
<td>316.83</td>
<td>397.38</td>
<td>432.67</td>
</tr>
<tr>
<td>Horizontal midpoint</td>
<td>22.36</td>
<td>57.33</td>
<td>105.05</td>
<td>136.26</td>
<td>181.72</td>
<td>225.11</td>
<td>273.65</td>
<td>323.28</td>
<td>369.53</td>
<td>419.37</td>
<td>443.88</td>
</tr>
<tr>
<td>Ring area</td>
<td>785.52</td>
<td>5355.52</td>
<td>10214.81</td>
<td>11827.27</td>
<td>22708.34</td>
<td>27726.13</td>
<td>38033.10</td>
<td>46534.03</td>
<td>56329.54</td>
<td>61766.66</td>
<td>41420.22</td>
</tr>
<tr>
<td>Number of bolts in ring</td>
<td>1.36</td>
<td>1.36</td>
<td>1.36</td>
<td>1.36</td>
<td>1.36</td>
<td>1.36</td>
<td>1.36</td>
<td>1.36</td>
<td>1.36</td>
<td>1.36</td>
<td>1.36</td>
</tr>
<tr>
<td>Bolts per element (20 sections)</td>
<td>1.36</td>
<td>0.55</td>
<td>0.89</td>
<td>1.03</td>
<td>1.97</td>
<td>2.41</td>
<td>3.30</td>
<td>4.04</td>
<td>4.37</td>
<td>5.36</td>
<td>3.60</td>
</tr>
</tbody>
</table>

The BEAM4 elements are modeled as essentially rigid, and are oriented normal to the tank dome. Attached to the base of each beam element are three orthogonal springs oriented in the directions of the global coordinate system. Because the beams are rigid, the springs define the response of the anchor bolts in the model.

The stiffness of a single anchor bolt was set to 780 kip/ft (65,000 lbf/in.) in all three directions. This formulation will underestimate the axial stiffness of an anchor bolt and thus conservatively overestimate the total deformation of the bolt. Not only does this modeling assumption err on the conservative side, but the axial response of the anchor bolts in the seismic model is essentially inconsequential when combined with the results of the TOLA model.

The anchor bolt model is developed using input file “Bolt-Friction.txt.” See Figure 3-9 for the distribution of anchor bolts. Figure 3-10 shows the locations of spring elements connecting the end of each anchor bolt to the primary tank.

3.2.6 Secondary Liner

The secondary liner is modeled using SHELL143 elements and its geometry is taken from H-2-90534. The steel thickness is 0.375 inch in the floor transitioning to 0.5625 inch in the knuckle and 0.5 inch in the lower wall. The model stops after the 1st full wall element coincident with the liner. The secondary liner is shown in Figure 3-11.

Input file “Liner.txt” develops the model for the liner using the geometry defined for the concrete tank in “Tank-Coordinates.txt.” The following material properties are used for the steel liner.

Elastic Modulus (E) = 4,176,000 kip/ft²
Poisson’s Ratio (v) = 0.30
Mass Density (ρ) = 0.001522 kip·sec²/ft⁴ = (0.490 kip/ft³)/(32.2 ft/sec²)
Damping = 2%
Figure 3-9  Anchor Bolt Model Detail

Figure 3-10  Spring Elements – Anchor Bolts to Primary Tank
3.2.7 Waste

The waste is modeled using solid elements (SOLID45) with material properties defined to emulate a liquid. The waste elements are meshed such that there are no common nodes with the primary tank; however, those on the exterior (at the primary tank) are coincident with the primary tank nodes. Contact elements are used for the interface between the waste and the primary tank. The material properties are as follows:

- Elastic Modulus (E) = 25.92 kip/ft\(^2\)
- Poisson’s Ratio (ν) = 0.4999
- Mass Density (ρ) = 0.003294 kip·sec\(^3\)/ft\(^4\)
- Damping = 0
- Shear Modulus (G) = 0.216 kip/ft\(^2\)

The elastic modulus, E, was calculated based on the Bulk Modulus of water (~300,000 psi). Using a value of ν close to 0.5 (0.49999), the value of E can be calculated.

\[
B = \frac{E}{3(1-2ν)} \quad \text{or} \quad E = B[3(1-2ν)] = 300,000[3(1-2(0.49999))] = 1816\text{lb/in}^2 = 2.592\text{kip/ft}^2
\]

The shear modulus, G, can then be calculated based on E and ν, \(G = \frac{E}{2(1+ν)}\). For the values shown above, this gives a value for G of 0.864 kip/ft\(^2\). However, because a fluid cannot carry shear, a smaller value is used. The value was selected such that the solution remains mathematically stable.

Figure 3-12 shows the waste elements.
Two benchmarking studies were performed to assess the fluid-structure interaction behavior of the primary tank and contained waste under seismic excitation. In the study documented in Rinker et al. (2006b), the fluid-structure interaction was simulated in ANSYS®. In the studies documented in Rinker and Abatt (2006a, 2006b), the fluid-structure interaction was simulated using MSC.Dytran®

The studies showed that the modeling approach used in ANSYS® adequately predicts the total hydrodynamic reaction force and pressure distribution both vertically and circumferentially, but that the model was deficient in predicting the convective response of the waste.

The fundamental difference between the current increased liquid level analysis and the earlier analysis at the baseline liquid level of 422 inches (Rinker et al. 2006c) is increased interaction between the contained waste and the curved dome area of the primary tank (see Figure 3-13). Thus, the stresses induced by the interaction of the liquid and the dome are of particular concern. The results from the Dytran® sub-model analysis are compared to the results of a similar ANSYS® sub-model of a primary tank, as well as to the results from the global ANSYS® models in the Increased Liquid Level Seismic report (Abatt and Rinker 2008).

3.2.8 Primary Tank/Concrete Dome Interface

A combination of TARGE170 and CONTA173 elements are used to model the interface between the top of the primary tank and the inside face of the concrete dome. Key-Option controls are used to place the interface location at the inside face of the concrete (or bottom of the concrete shell element). A coefficient of friction of 0.01 was used for the contact surface. The low friction value results in the anchor bolts being the primary load path for shear between the primary tank and the dome. A small value is used instead of zero to improve model solution stability.

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Dytran is a registered trademark of MSC Software Corporation, Santa Ana, California.
The contact surface is developed using input file “bolt-friction.txt.” Figure 3-14 shows the contact and target elements comprising the dome contact surface.

3.2.9 Primary Tank/Insulating Concrete Interface

A combination of TARGE170 and CONTA173 elements are used to model the interface between the bottom of the primary tank and the top of the insulating concrete. The contact and target surfaces are modeled as coincident (i.e., no offsets are included for shell thicknesses). A coefficient of friction of 0.4 was used for the contact surface. The contact surface is developed using input file “interface1.txt.” Figure 3-15 shows the contact elements (top layer of elements).
3.2.10 Insulating Concrete/Secondary Liner Interface

A combination of TARGE170 and CONTA173 elements are used to model the interface between the bottom of the primary tank and the top of the insulating concrete. The contact and target surfaces are modeled as coincident (i.e., no offsets are included for shell thicknesses). A coefficient of friction of 0.4 was used for the contact surface. The contact surface is developed using input file “interface1.txt.” Figure 3-15 shows the contact elements (bottom layer of elements).

3.2.11 Soil/Concrete Tank Interface

A combination of TARGE170 and CONTA173 elements are used to model the interface between the soil and the concrete tank, and for the interface plane between the native and excavated soils. A coefficient of friction of 0.2 was used for the contact surface between the soil and the concrete tank during the gravity loading solution phase (static case) to realistically simulate the distribution of geostatic loads. The friction coefficient was then increased to 0.6 for the transient portion of the solution to simulated the dynamic frictional response at this interface. Rinker et al. (2006c) describes the soil friction model in complete detail. See Figure 3-16 for the contact surface model.

For the interface between the bottom of the footing and the native soil, COMBIN14 (spring) elements were used. Arbitrary high stiffness values were applied to these springs because the flexibility at the interface is already included in the material properties for the concrete and soil. See Figure 3-17 for the location of the interface springs.

![Figure 3-15. Contact Elements – Insulating Concrete Top and Bottom](image)
A combination of TARGE170 and CONTA173 elements are used to model the interface between the native and excavated soils. An initial coefficient of friction of 0.3 is used for the gravity (static) analysis. The coefficient of friction is changed to 0.7 for the transient analysis. This surface is included to improve the initial conditions for the transient analysis by allowing an initial displacement between the native and excavated soil but located far enough away that it does not have a significant effect on the tank behavior. Figure 3-18 shows the contact elements constituting the soil interface.
3.2.13 Waste/Primary Tank Interface

A combination of TARGE170 and CONTA173 elements are used to model the interface between waste and primary tank. No friction is included for this surface. A high stiffness was defined for this contact to obtain the correct hydrostatic pressure on the tank. The high stiffness of the contact was needed because the waste model was very soft. Excessive displacements occur without modifying the contact stiffness. The contact surface is divided into multiple zones to enhance the performance of the contacts. This approach captures more realistic waste pressures in areas of higher curvature (dome and knuckle regions). The contact surface is developed using input file “Waste-Soild-AY.txt.” The interface between the waste and primary tank is shown in Figure 3-19.
3.2.14 Concrete Wall/Footing Interface

The contact at the bottom of the wall was modeled using CONTA178 elements. A friction coefficient of 0.2 was used for this contact to reflect the steel on steel interface. Use of contact elements for this interface will be used to determine if displacement can occur during a seismic event. The contact elements allow only normal and shear forces (no moments) to be transferred to the footing. The contact between the bottom of the wall and the footing is shown in Figure 3-20.

![Figure 3-20. Contact Elements – Concrete Wall to Footing](image)

3.2.15 Surface Loads

MASS21 elements were added to the soil surface over the center of the dome to create a “live load” over the tank dome. The mass provides an equivalent weight of 200,000 lbf. Mass elements were used in lieu of forces to capture the dynamic participation of equipment that creates this load. Figure 3-21 illustrates the placement of the mass elements.

![Figure 3-21. Mass Elements – Soil Surface](image)
3.3 Soil Model

This section describes the geometry and construction of the ANSYS® finite element model of the soil surrounding the DST. A comprehensive description of the FE model is found in the Seismic Analysis report (Rinker et al. 2006c). The Seismic Analysis report should be referenced for complete model description and background information.

3.3.1 Soil Properties

The soil surrounding the tank is modeled in two groups, the excavated soil, and the far-field soil. The excavated soil fills the volume outside the concrete tank and bounded by the slope matching the soil removed during construction. The far-field soil is comprised of all other soil out to a radius of 320 feet and a depth of 266 feet. Both regions are modeled using SOLID45 elements.

Two SHAKE analyses were performed for each soil condition to obtain soil properties for the layering used in the model (Rinker et al. 2006a). One run used the native soil properties and is used for the far-field soil material properties. The second run used material properties associated with structural backfill and the results are used for the material properties in the excavated soil region.

Soil properties used for the model are listed in Tables 3-7 through 3-12.

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<tr>
<th>Layer Depth</th>
<th>Damping</th>
<th>G</th>
<th>Poisson's Ratio</th>
<th>E</th>
<th>Density</th>
<th>Material Property No.</th>
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Table 3-8. Best-Estimate Excavated Soil Iterated Soil Properties

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<th>E</th>
<th>Density</th>
<th>Material Property No.</th>
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<td>125</td>
<td>803</td>
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<td>0.039</td>
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<td>8209</td>
<td>125</td>
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Table 3-9. Upper Bound Native Soil Iterated Soil Properties

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Table 3-10. Upper Bound Excavated Soil Iterated Soil Properties

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Table 3-11. Lower Bound Native Soil Iterated Soil Properties

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Table 3-12. Lower Bound Excavated Soil Iterated Soil Properties

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3.3.2 Excavated Soil

The excavated soil portion of the soil is developed using the input file “Near-Soil-l.txt.” Figures 3-22 through 3-24 show the detail of the excavated region of soil. Two zones in the soil above the dome are softened to break the potential arching that can occur in the soil model. This arching effect can occur because linear elastic properties are used for soil, which means that the soil as modeled can carry tension. The development of the softened regions of the soil over the tank dome is discussed in detail in the Seismic Analysis report (Rinker et al. 2006c).
Figure 3-22. Excavated Soil Model Detail

Figure 3-23. Excavated Soil – Softened Soil Zones
3.3.3 Native Soil

The native soil region of the model is developed using input file “Far-Soil.txt.” SOLID45 elements are used and the material properties are discussed above. Figure 3-25 shows the native soil portion of the model.
LINK8 elements are used to connect the native soil slaved nodes on each layer to the symmetry plane. These are required because the slaved node of a couple cannot have a boundary condition applied to it. Therefore, to maintain the desired soil behavior, the link elements effectively complete the coupling of the outside soil node at each layer. Figure 3-26 shows the locations of the link elements. Input file “Outer-Spar.txt” develops these elements.

3.4 Boundary Conditions

This section describes the boundary conditions applied to the ANSYS® seismic finite element model. A comprehensive description of the FE model is found in the Seismic Analysis report (Rinker et al. 2006c). The Seismic Analysis report should be referenced for complete model description and background information.

3.4.1 Soil Boundary Conditions

All nodes on the outside edge (radius = 320 feet) have been “slaved” to a single node at each layer. Couples are used in each of the three translations to force the soil to behave essentially as a shear beam. This approach is used to create the appropriate conditions for vertical and horizontal waves to pass through the model (see Figures 3-28 and 3-29). The effectiveness of this approach is documented in Rinker et al. (2006a). All nodes on the bottom of the model (–266 ft) are coupled together to create a rigid foundation (see Figure 3-27). The symmetry plane for the soil has all nodes fixed for Y translation, see Figure 3-30.
Figure 3-27. Boundary Conditions—Soil Base

Figure 3-28. Boundary Conditions—Typical Soil Layer
3.4.2 Tank Boundary Conditions

The tank model has all nodes on the symmetry plane fixed to the Y translation, X rotation, and Z rotation (see Figures 3-31 and 3-32). Couples have been used between some components to ensure compatible...
displacements occur. Where no common nodes exist between the concrete tank and secondary liner, couples are used to control the deformation of the secondary liner where it is in contact with the concrete tank. This ensures that the secondary liner does not “pass through” the concrete on the footing and on the walls (see Figure 3-33).

Figure 3-31. Boundary Conditions – Concrete Tank

Figure 3-32. Boundary Conditions – Primary Tank
3.5 Seismic Input

The seismic analysis of the DSTs requires appropriate acceleration time-history records representing the required seismic excitation. Time history records must be available for both the horizontal and vertical directions. Typically, the required seismic input is specified in terms of design spectra. If time-histories are required, such time histories are often synthesized numerically subject to certain requirements related to the proper representation of the design spectra (ASCE 1998; NUREG-0800). The time-history records used in this analysis of the DSTs were existing time-histories that were used on the Hanford Waste Treatment Project (WTP). The justification for the use of existing time-histories is presented below.

The Hanford Tank Farms Documented Safety Analysis or DSA (Tomaszewski 2004) designates the DSTs as Performance Category 2 (PC-2) structures. DOE-STD-1020-2002, Section 2, states that the ground motions for PC-2 shall be developed following IBC (2000), in which the surface response spectra are specified to be 2/3 of the Maximum Considered Earthquake (MCE) ground motions. The MCE ground motions are defined as the ground motions with a mean annual frequency of exceedance of $4 \times 10^{-4}$ (2% probability of exceedance in 50 years). The MCE motions may be defined based on either the USGS National Hazard Mapping results, adjusted for the appropriate site classification, or from a site-specific Probabilistic Seismic Hazard Analysis (PSHA). If the MCE response spectrum is to be defined from a site-specific PSHA, it cannot be less than 80% of the spectrum defined from the USGS National Hazard Mapping results. The PC-2 ground motions used in the DST analysis are based on a site-specific PSHA. The detailed development of the PC-2 spectra for the DST Farms is documented in Rinker and Youngs (2006).

Acceleration time-histories for two horizontal components and one vertical component of seismic motion were synthesized for the seismic design and evaluation of the Hanford Site WTP (BNFL 2000). The horizontal design spectrum for the WTP is anchored at 0.257g (peak ground acceleration (PGA)), and the vertical design spectrum is anchored at 0.175g PGA. The time-histories generated to match the WTP design spectra were previously used by M&D in the preliminary soil-structure interaction analysis of the WTP high-level waste and pretreatment facilities, and were readily available (M&D 2001a; 2001b).
The Hanford Double-Shell Tank Farms horizontal design spectrum for 5% spectral damping is shown in Figure 3-34. Also shown in Figure 3-35 are the horizontal control motion spectra for the WTP project. All reference or control motions are defined at the soil surface. Similar plots for the vertical direction are shown in Figure 3-35.

The relationships between the design spectra and the control motion response spectra show that it is acceptable to use the acceleration time-histories from the WTP for the analysis of the DSTs.

![Horizontal Surface Response Spectrum Comparison at 5% Spectral Damping](image1)

**Figure 3-34. Comparison of Horizontal Surface Spectra at 5% Spectral Damping**

![Vertical Surface Response Spectrum Comparison at 5% Spectral Damping](image2)

**Figure 3-35. Comparison of Vertical Surface Spectra at 5% Spectral Damping**
Acceleration and displacement time histories for horizontal and vertical input are shown in Figures 3-36 and 3-37, respectively.

**Figure 3-36.** Horizontal and Vertical Surface Acceleration Time History

**Figure 3-37.** Horizontal and Vertical Surface Displacement Time History
3.6 Load Cases

Four separate load cases have been considered in this analysis. These cases are:

- Lower Bound Soil, Best-Estimate Concrete (LBS-BEC) Properties
- Best-Estimate Soil, Best-Estimate Concrete (BES-BEC) Properties
- Upper Bound Soil, Best-Estimate Concrete (UBS-BEC) Properties
- Best-Estimate Soil, Fully Cracked Concrete (BES-FCC) Properties

These four cases are intended to cover the most significant areas of uncertainty for response of the DSTs to seismic loading. The three variations in soil properties address the variability and uncertainty in soil properties. The fully cracked concrete case covers the additional uncertainty of expected concrete condition.

Each load case consists of two analyses. First a gravity case is analyzed. Results from the gravity only case will be used to determine the seismic only results from the non-linear transient analysis. The second analysis for each case is a non-linear time history analysis. Two input motions (horizontal and vertical) have been defined as acceleration time histories consisting of 2048 time steps. Acceleration time histories were developed for each of the three soil conditions at the -266-foot level.

3.6.1 Acceptance Criteria for Response Spectra

The following acceptance or screening criteria were applied to the tank foundation-level response spectra generated by the ANSYS® column model:

1. The envelope of the best-estimate, lower bound, and upper bound response spectra at the tank foundation level (-57.6 feet) should be at least 60% of the surface control motion. This criterion applies to both horizontal and vertical motion.

2. The envelope of the best-estimate, lower bound, and upper bound ANSYS® and Dytran® response spectra at the tank foundation level (-57.6 feet) should be at least 90% of the SHAKE response spectrum.

3. The envelope of the best-estimate, lower bound, and upper bound ANSYS® and Dytran® response spectra at the tank foundation level (-57 feet) should be greater than or equal to the SHAKE response spectrum over any \( \pm 15\% \) bandwidth.

The above criteria should be met for both horizontal and vertical spectra. Additional criteria were evaluated for these input motions and response spectra. The additional criteria are discussed in Rinker et al. (2006a). The first condition is intended to minimize the dip that can occur in deconvolved response spectra at moderate depth at the frequency of the overlying soil column. Such a dip appears in the foundation level SHAKE spectrum shown in Figure 3-38 as well as in other plots.

The tests of the first criterion are shown graphically for both horizontal and vertical input as shown in Figures 3-38 and 3-39, respectively. The results indicate that the first condition is not met at all frequencies. Modifications to ensure that the condition is met will be discussed in Section 3.6.2.
Figure 3-38. Ratio of the ANSYS® Tank Foundation Level Spectra to the SHAKE Surface Spectrum for Horizontal Excitation

Figure 3-39. Envelope of the Ratio of the ANSYS® Tank Foundation-Level Spectra to the SHAKE Surface Spectrum for Vertical Excitation
3.6.2 Modification to ANSYS® Base Time Histories

Comparison of the ANSYS® soil column spectra at the tank foundation level to the SHAKE surface spectra for horizontal and vertical excitation (Figures 3-39 and 3-40) showed that the tank foundation spectra do not meet the first criterion. The envelope of the best-estimate, lower bound, and upper bound response spectra at the tank foundation level (~57.6 feet) should be at least 60% of the surface control motion. This applies to both horizontal and vertical motion. To ensure that the envelope of the tank foundation level spectra is at least 60% of the SHAKE surface spectrum, the horizontal lower and upper bound base time histories used as input to the ANSYS® soil column model were scaled up by factors of 1.175 and 1.12, respectively. The vertical lower and upper bound base time histories were scaled up by factors of 1.12 and 1.19, respectively. Comparisons of the tank foundation-level spectra to the SHAKE surface spectra for the modified base time histories are shown in Figures 3-40 and 3-41. Increasing the base time histories by the above factors results in the ratio of the tank foundation-level spectra to SHAKE surface spectra meeting the 60% criterion.

![Figure 3-40. Ratio of the ANSYS® Tank Foundation Level Spectra to the SHAKE Surface Spectrum for Modified Horizontal Excitation](image)

3.6.3 ANSYS® Base Acceleration Time Histories

Individual time histories are applied for each different soil condition. Lower Bound, Best-Estimate, and Upper Bound soil horizontal and vertical acceleration time histories are shown in Figures 3-42, 3-44, and 3-46, respectively. Lower Bound, Best-Estimate, and Upper Bound soil horizontal and vertical displacement time histories are shown in Figures 3-43, 3-45, and 3-47, respectively.
Figure 3-41. Envelope of the Ratio of the Tank Foundation Level Spectra to the Surface Spectra for Modified Vertical Excitation

Figure 3-42. Horizontal and Vertical Base Acceleration Time History, —266 feet, Lower Bound Soil
Figure 3-43. Horizontal and Vertical Base Displacement Time History, -266 feet, Lower Bound Soil

Figure 3-44. Horizontal and Vertical Base Acceleration Time History, -266 feet, Best-Estimate Soil
Figure 3-45. Horizontal and Vertical Base Displacement Time History, −266 feet, Best-Estimate Soil

Figure 3-46. Horizontal and Vertical Base Acceleration Time History, −266 feet, Upper Bound Soil
Figure 3.47. Horizontal and Vertical Base Displacement Time History, −266 feet, Upper Bound Soil

3.7 Model Excitation

An acceleration time history extracted from SHAKE at the −266-foot level is used for the excitation of the full model. A very large mass element is located at the bottom of the soil model (−266 feet) and a force is applied to that node. The force is the product of the point mass and the acceleration for that time step of the time history. The point mass used is greater than 100 times the mass of the full model to faithfully simulate the seismic excitation.
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4.0 Model Reconciliation

The finite element models used in the TOLA and seismic analyses are significantly different. Reviewing the figure and model description in Chapters 2 and 3 readily demonstrates the dissimilarities (e.g., the TOLA model represents a 2.9° section of the tank and the seismic model represents a 180° section of the tank). The non-axisymmetric nature of the earthquake load requires the seismic model to encompass at least 180°. The acceleration time history used to represent the earthquake comprised 2048 load steps to achieve the 20.48 seconds of the transient analysis. Minimizing the model size was important in achieving a reasonable solution run time on the computer. Consequently, the element size is quite large in comparison to the TOLA model.

In contrast, the TOLA analysis has no inherent non-axisymmetric features. The 3-D model was made necessary only by the desire to use SOLID65 concrete element in ANSYS®. A refined mesh was implemented to obtain better resolution of stress throughout the model, particularly in the knuckle region.

The disparity between models required a mapping procedure in order to combine the TOLA and seismic results. This section summarizes the mapping for the different evaluations.

- Table 4-1 shows the element correlation for the ACI evaluation.
- Table 4-2 shows the element correlation for the ASME primary tank evaluation
- Table 4-3 shows the element correlation for the ASME concrete-backed liner evaluation. As shown in Figure 3-12, the secondary liner in the seismic model extended only across the floor and up to the second element in the tank wall. Consequently, seismic strain in the wall and haunch was taken from the concrete shell elements representing the wall. Strain in the dome was taken from the steel liner.
- Table 4-4 shows the correlation for the anchor bolts.
Table 4-1. Element Correlation for ACI Evaluation

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4.2
Table 4-2. Element Correlation for Primary Tank Evaluation

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Table 4-3. Element Correlation for Concrete-Backed Liner Evaluation

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Table 4-4. Element Correlation for Anchor Bolt Evaluation

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5.0 Structural Acceptance Criteria

5.1 Introduction

This chapter describes the code-based acceptance criteria that are used to evaluate the AP tanks for the Increased Liquid Level Analysis. A complete description of the evaluation criteria is found in the Thermal and Operating Loads Analysis report (Rinker et al. 2004).

Day et al. (1995) provides a definitive summary of code-based structural acceptance criteria that govern the current and future uses of the Hanford DSTs. The document covers the primary objectives of any reevaluation of the existing waste storage tanks for continued operation or remediation, namely: 1) to show that the tank structures remain within code-based limits for the original design-based loads, 2) to evaluate if the actual service conditions or changes in requirements will exceed the design conditions, or 3) to evaluate current operating loads and future remediation activity loads.

The structural acceptance criteria document by Day et al. (1995) describes the tank designs, loads that must be sustained, potential failure modes, and the recommended approaches to protect against such failure. The application of code-based evaluation methods is discussed in detail. Alternate methods to the code-based approach are recommended to account for localized overstressing, load redistribution, and reduction in section capacities due to material degradation. Code reconciliation issues and material degradation under aging conditions also are addressed.

The purpose of this chapter is to identify a) the design and construction standards that were used for the double-shell tank designs, b) the allowable stresses for the steels and the minimum specified strengths of the concrete that were specified in the design, and c) the analysis methods that will be used to evaluate the structural adequacy of the AP tank design. Because Day et al. (1995) specifically identifies the recommended code-based methods for tank evaluation, they are not reproduced in this document.

5.2 Design and Construction Specifications for 241-AP Tanks

The 241-AP Tank Farm was constructed as part of Project B-340, 241-AP Tank Farm Project. For that project, the design and construction specifications list the standards that were used in the design and construction of the 241-AP tank farm. Specifications that are pertinent to the steel and concrete structure include:

- B-340-C4, Primary and Secondary Steel Tanks
- B-340-C3, Tank Foundations
- B-340-C5, Side Walls and Dome.

B-340-C4 documents that the 241-AP tanks were designed, fabricated, and inspected to the intent of the 1980 ASME Boiler and Pressure Vessel Code, Section VIII, Division 2. (Note: Although the ASME code standards were followed, the tanks were not registered as ASME vessels due to the non-standard nature of their design, use, and contents.) The steel plate used to construct the primary and secondary liners is specified as ASTM A537 Class 1 (ASTM 1965). Abatt (1996) lists the ASME S_m allowables that were specified for the pressure vessel steels for each of the DST designs (see Table 5-1).
B-340-C3 and B-340-C5 document that the 241-AP tanks were constructed to the 1977 ACI 318 building code requirements for reinforced concrete (ACI 1977). In addition, structural concrete for the foundation was required to have a minimum allowable compressive strength of 4500 psi at 28 days. The concrete in the walls and dome was specified at 5000 psi.

5.3 Applicable Codes

5.3.1 Design Codes of Record for the DSTs

Abatt (1996) identifies SDC 4.1, *Standard Arch-Civil Design Criteria - Design Loads for Facilities*, as the standard for the design of tanks at the Hanford Site. This standard has been in existence since the original document was published in April 1957, and it has been revised since then to comply with current DOE orders. More recently, SDC 4.1 was superseded by HNF-PRO-097, *Engineering Design and Evaluation (Natural Phenomena Hazard)* (HNF-PRO-097 2002). However, HNF-PRO-097 (2002) is a more general standard in use by the Project Hanford Management Contractor and a similar standard, TFC-ENG-STD-06, *Design Loads for Tank Farm Facilities* (Mackey 2004) is used by the Tank Farm Contractor.

5.3.2 Steel Design Codes of Record

Abatt (1996) summarized the codes of record that were used during the design of the various DST farms. The codes pertaining to the steel liner and tank components are listed in Table 5-1.
Table 5-1. Summary of the $S_m$ Allowables that were Specified for Each of the DST Designs (Abatt 1996)

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<td></td>
<td></td>
<td></td>
<td>$S_m(ksi)$</td>
<td>23.3</td>
</tr>
</tbody>
</table>
5.3.3  **Concrete Design Codes of Record**

Abatt (1996) also summarized the codes of record that pertain to the reinforced concrete structure of the tanks. These codes are listed in Table 5-2. Table 5-2 shows that the 241-AY tanks were designed to the standards of the 1963 revision of ACI 318 (ACI 1963).

**Table 5-2. Summary of Hanford Double-Shell Tank Structural Concrete Design Basis (Abatt 1996)**

<table>
<thead>
<tr>
<th>Tank Farm 241-</th>
<th>Const. Years</th>
<th>Design Code</th>
<th>Specified 28-day Compressive Strength (lb/in²)</th>
<th>Reinforcing Steel</th>
<th>Cross-Ties (ASTM)</th>
<th>Welds</th>
</tr>
</thead>
<tbody>
<tr>
<td>AY 241-AY</td>
<td>1968–70</td>
<td>ACI 318 (1963)</td>
<td>3 (Type III)</td>
<td>A15-65 FDN Gr. 40</td>
<td>A302-66 Gr. 60</td>
<td>NA</td>
</tr>
<tr>
<td>AZ 241-AZ</td>
<td>1971 &amp; 77</td>
<td>ACI 318 (1963)</td>
<td>3 (Type II)</td>
<td>A615-68 Gr. 60</td>
<td>A615-72 Gr. 60</td>
<td>NA</td>
</tr>
<tr>
<td>SY 241-SY</td>
<td>1974–76</td>
<td>ACI 318 (1971)</td>
<td>4.5 (Type III)</td>
<td>A615-72 Gr. 60</td>
<td>A615-72 Gr. 60</td>
<td>AWS D12.1</td>
</tr>
<tr>
<td>AW 241-AW</td>
<td>1978-80</td>
<td>ACI 318 (1971)</td>
<td>5 (Type III)</td>
<td>A615-76a Gr. 40</td>
<td>A615-76a Gr. 40</td>
<td>AWS D12.1</td>
</tr>
<tr>
<td>AN 241-AN</td>
<td>1980-81</td>
<td>ACI 318 (1971)</td>
<td>5 (Type III)</td>
<td>A615-75 Gr. 60</td>
<td>A615-75 Gr. 60</td>
<td>AWS D12.1</td>
</tr>
<tr>
<td>AP 241-AP</td>
<td>1983-86</td>
<td>ACI 349 (1979)</td>
<td>5 (Type II)</td>
<td>A615-81a Gr. 60</td>
<td>A615-81a Gr. 60</td>
<td>AWS D1.4</td>
</tr>
</tbody>
</table>

(a) The insulating concrete material is a cast-in-place lightweight refractory concrete material.
(b) From H-2-37704.
(c) From H-2-71907.

**Type II** = Low-alkali Portland cement — used where moderate exposure to sulfate attack is anticipated. Type II cement is in common use in western United States. Type II cement gains strength a little more slowly than general-purpose Type I cement but ultimately attains strength of Type I cement.

**Type III** = High-early-strength cement — develops in 7 days the same strength that is achieved at 28 days for concrete made from Types I or II cement, but may not achieve the long-term strength of Types I or II.

**Type V** = Sulfate-resisting cement — strength characteristics are equivalent to Type II.

**ACI** = American Concrete Institute.

**ASTM** = American Society of Testing and Materials.

**AWS** = American Welding Society.

**FDN** = Foundation (basemat).

**HPS** = Hanford Plant Standard.

**NA** = Not applicable.
5.3.4 Contemporary Codes for Structural Evaluation of the DSTs

Day et al. (1995) lists the following DOE orders as applicable to the analysis and structural qualification of the existing DSTs for continued operation:

- DOE Order 6430.1A, General Design Criteria (DOE 1989)
- DOE Order 5480.28, Natural Phenomena Hazard Mitigation (DOE 1993)

Note that DOE Order 420.1, Facility Safety, Section 4.4, Natural Phenomena Hazard Mitigation (DOE 2000), superseded DOE Order 5480.28. In addition, DOE Order 6430.1A has been cancelled.

Day et al. (1995) further states that the analysis and structural qualification of the existing DSTs for continued operation must be performed using the following codes and standards as guidance:

- BNL 52527, Guidelines for Development of Structural Integrity, Programs for DOE High-Level Waste Storage Tanks (Bandyopadhyay 1997)
- ASCE Standard 4-86, Seismic Analysis of Safety Related Nuclear Structures and Commentary on Standard for Seismic Analysis of Safety Related Nuclear Structures (ASCE 1986)
- TFC-ENG-STD-06, Design Loads for Tank Farm Facilities, CH2M Hill Hanford Group, Inc. (Mackey 2004)
- BNL 52361, Seismic Design and Evaluation Guidelines for the Department of Energy High Level Waste Tanks and Appurtenances (Bandyopadhyay et al. 1995)

Specific guidance is given by Day et al. (1995) on the code analysis methods to be used in evaluating the major components of the tank, namely:

Primary Tank: The primary tank shall be evaluated against the requirements of the ASME Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NC, Article NC-3200 (ASME 1992a). (Note: The design by analysis methods of Section III, Article XIII-1000, "Design Based on Stress Analysis," are equivalent to the analysis requirements of Section VIII, Division 2 (ASME 1992d). The primary difference between Section III (nuclear vessels and piping) and Section VIII (non-nuclear vessels and piping) involves the increased level of material qualification and fabrication inspection required by Section III.

Secondary Concrete Structure: The secondary concrete structure shall be evaluated against the requirements of ACI 349-90, Code Requirements for Nuclear Safety Related Concrete Structures (ACI 1990). While the AY tanks were designed to ACI 318 (ACI 1963), ACI 349 provides essentially the same technical design provisions. Mackey (2004a) notes that using ACI 349 as the evaluation criteria would not change the calculation results.
Secondary Tank Liner: The secondary tank liner shall be evaluated using the requirements of the ASME Boiler and Pressure Vessel Code, Section III, Division 2, Subsection CC (ASME 1992c). Those portions of the liner that are not backed by concrete shall be evaluated to the requirements of the ASME Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NC (ASME 1992a). (Note: The evaluation methods of Section III, Division 2, Subsection CC are recommended because the steel-lined, reinforced concrete tanks are similar in construction to concrete nuclear containment vessels, which Subsection CC covers. Section VIII does not provide specific guidance on the evaluation of steel liners backed by concrete. Therefore, the analysis methodology recommended in Section III will be adopted [as recommended by Day et al. (1995)], even though the tanks were not strictly designed, constructed, and inspected to Section III standards.)

Insulating Concrete Pad: The insulating concrete pad shall be evaluated against the bearing stress requirements of ACI 349-90, *Code Requirements for Nuclear Safety Related Concrete Structures* (ACI 1990).

Primary Tank Dome and Secondary Liner Anchorage System: The anchorage systems for that portion of the tank steel which is backed by concrete shall meet the requirements of the ASME Boiler and Pressure Vessel Code, Section III, Division 2, Subsection CC (ASME 1992c). Abatt (1996) presents a compilation of the ASME allowable stresses and the load factor combinations that were used in performing “design by analysis” evaluations of the DST primary tanks. Later sections of Day et al. (1995) give detailed guidance on how to apply these codes to analyze the tanks. Section 2 of Day et al. (1995) provides guidance on defining the tank loads (normal, abnormal, and extreme loads) for consideration in the analysis.

Potential failure modes are identified and discussed in detail in Section 3 of Day et al. (1995) for specific tank components as summarized here in Table 5-3.

Section 4 of Day et al. (1995) presents detailed discussion of the ASME code methods for evaluating the above failure modes in the primary tanks, secondary liner, and the anchor bolts. For anchor bolts, Section 4 gives specific guidance on the appropriate liner anchor allowables to use in the code evaluation (see Tables 4.1.4-1, 4.1.4-2, and 4.1.4-3 in Day et al. 1995). Section 4 also presents a similarly detailed discussion of the ACI code methods for evaluating the reinforced concrete tank walls and dome. This includes examples of the load combinations and load scaling factors required by the code.

Section 5 of Day et al. (1995) gives guidance on what to consider in reconciling differences in the current versions of the ASME and ACI codes when reanalyzing the double-shell tanks. The “design by analysis” methods recommended by the ASME code have not changed in their application since the design of the 241-AY tanks. Therefore, the primary and secondary tank steels will be evaluated to the current methods using the $S_m$ allowables and stress intensity classifications listed in Tables 5-1 and 5-4.
Table 5-3. Summary Table of the Local and Global Significance of Failure of the Various DST Components (Day et al. 1995)

<table>
<thead>
<tr>
<th>Failure Mode</th>
<th>Steel Tank or Liner</th>
<th>Steel Reinforcement</th>
<th>Concrete</th>
<th>Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buckling</td>
<td>L→L</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collapse</td>
<td></td>
<td></td>
<td>G</td>
<td></td>
</tr>
<tr>
<td>Fatigue</td>
<td>L→L</td>
<td>L→G</td>
<td>L→G</td>
<td></td>
</tr>
<tr>
<td>Fracture</td>
<td>L→L</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bond-slip</td>
<td></td>
<td>L→G</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plastic failure</td>
<td>L→L</td>
<td>L→G</td>
<td>L→G</td>
<td></td>
</tr>
<tr>
<td>Bearing failure</td>
<td></td>
<td>L→L</td>
<td>L→G</td>
<td></td>
</tr>
</tbody>
</table>

L→L Local failure that could lead to leakage.
L→G Local failure that could lead to a global instability failure.
G Global instability failure.

Table 5-4. Stress Intensity Classification (Abatt 1996)

<table>
<thead>
<tr>
<th>Vessel Component</th>
<th>Location</th>
<th>Origin of Stress</th>
<th>Type of Stress</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cylindrical or spherical shell</td>
<td>Shell plate remote from discontinuity</td>
<td>Internal pressure</td>
<td>General membrane gradient through plate thickness</td>
<td>P_m</td>
</tr>
<tr>
<td></td>
<td>Axial thermal gradient</td>
<td></td>
<td>Membrane bending</td>
<td>Q</td>
</tr>
<tr>
<td></td>
<td>Junction with head or flange</td>
<td>Internal pressure</td>
<td>Membrane bending</td>
<td>Q</td>
</tr>
<tr>
<td>Any shell or head</td>
<td>Any section across entire vessel</td>
<td>External load or moment, or internal pressure</td>
<td>General membrane averaged across full section</td>
<td>P_m</td>
</tr>
<tr>
<td></td>
<td>Near nozzle or other openings</td>
<td>External load or moment, or internal pressure</td>
<td>Bending across full section</td>
<td>P_m</td>
</tr>
<tr>
<td>Dished head or conical head</td>
<td>Crown</td>
<td>Internal pressure</td>
<td>Membrane bending</td>
<td>P_m</td>
</tr>
<tr>
<td></td>
<td>Knuckle or injection to shell</td>
<td>Internal pressure</td>
<td>Membrane bending</td>
<td>P_L, Q</td>
</tr>
</tbody>
</table>

P_m = Primary membrane.
P_L = Local membrane.
Q = Secondary.

(a) Consideration shall also be given to the possibility of wrinkling and excessive deformation in vessels with large diameter-to-thickness ratio.
Intentionally left blank.
6.0 Analysis Results

6.1 ACI Structural Concrete Evaluation

The Structural Acceptance Criteria document, WHC-SD-WM-DGS-003 (Day et al. 1995), specifies that the reinforced concrete structure of the tanks shall be evaluated to the standards of ACI 349-90, Section 9.2 (ACI 1990). The requirements of the IBC are satisfied by virtue of meeting the standards of ACI 349. Chapter 19 of the IBC states that structural concrete shall be designed in accordance with the requirements of ACI 318 (ACI 1977). The commentary on ACI 349 describes the additional conservatisms for nuclear structures that exceed those in ACI 318. Accordingly, a structure that is shown to conform to ACI 349 satisfies the IBC.

The load factors to be applied in the DST analyses are a subset of the possible combinations specified in ACI 349, that subset being defined by and, further, reduced by the definition of the current work scope. Chapter 7 of the TOLA report (Rinker et al. 2004) indicates that load combinations 1, 4, and 9 are relevant for this study. The seismic loads are considered in load combination 4.

As noted previously, the seismic model contains larger elements than the TOLA model. Accordingly, the ACI evaluation of combined TOLA + seismic loads was conducted at 30 locations in the secondary concrete tank rather than the 63 locations recorded in the TOLA report. Figures 6-1 through 6-3 show the locations of these 30 sections.

The peak loads and moments from the seismic analysis were combined with the loads and moments from each load step of the thermal cycle in such a way as to maximize the demand/capacity ratio. In other words, the direction of the seismic loads and moments was ignored and the results were summed so as to give the worst possible combination of force and moments for that section. The peak seismic loads and moments were extracted from the seismic time history results without regard to location in the tank or time during the seismic event. This simplified the combination of seismic and TOLA demands while maintaining a conservative evaluation.

The capacity of each section was determined according to the reinforcing steel and concrete geometry and properties specified on the 241-AP tank drawings. In other words, the section capacities were increased from the TOLA analysis (Rinker et al. 2004), which was based on the 241-AY Tank Farm design. The 241-AP tanks have more and larger rebar (in some locations), higher strength rebar (foundation), higher concrete nominal strength, and the lower operating temperatures also results in higher concrete strength.

The 3-D seismic analysis generates non-axisymmetric response that requires evaluation of the in-plane shear forces in addition to the cross-section shear forces. The method of ACI 349, Section 11.10 was applied to the in-plane shear force (ACI 1990).

The concrete in the TOLA analyses is allowed to crack; therefore there are no distinct Fully Cracked Concrete (FCC) TOLA results. Accordingly, results are presented for the three ACI load combinations for the Best-Estimate Soil, Best-Estimate Concrete (BES-BEC); Lower Bound Soil (LBS)-BEC; and Upper Bound Soil (UBS)-BEC soil – concrete cases. Only load combination 4 results are presented for the BES-FCC case.
6.1.1 **Best-Estimate Soil, Best-Estimate Concrete**

Figure 6-4 shows the demand/capacity ratios for load combination 1 of the Best-Estimate Soil, Best-Estimate Concrete (BES-BEC) material combination. Load combination 4 is shown in Figures 6-5-6-8. Load combination 9 is shown in Figures 6-9-6-11. The demand/capacity ratios are all less than 1.0 in the meridional, circumferential, and shear directions.
Figure 6-2. Reinforced Concrete Sections – Wall

Figure 6-3. Reinforced Concrete Sections – Slab
ACI-349 Demand/Capacity Ratios - LC 1, AP, 460", BES-BEC, TOLA

<table>
<thead>
<tr>
<th>ACI-349 Demand/Capacity Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dome</td>
</tr>
</tbody>
</table>

Tank Section Number (1 = Dome Center -> 63 = Slab Center)

Figure 6-4. BES-BEC, Load Combination 1

ACI-349 Demand/Capacity Ratios - LC 4
BES-BEC, TOLA + Seismic, Meridional

<table>
<thead>
<tr>
<th>ACI-349 Demand/Capacity Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dome</td>
</tr>
</tbody>
</table>

Tank Section Number (1 = Dome Center -> 30 = Slab Center)

Figure 6-5. BES-BEC, Load Combination 4, Meridional
ACI-349 Demand/Capacity Ratios - LC 4
BES-BEC, TOLA + Seismic, Circumferential

Figure 6-6. BES-BEC, Load Combination 4, Circumferential

ACI-349 Demand/Capacity Ratios - LC 4
BES-BEC, TOLA + Seismic, Shear

Figure 6-7. BES-BEC, Load Combination 4, Shear

6.5
<table>
<thead>
<tr>
<th>Tank Section Number (1 = Dome Center -&gt; 30 = Slab Center)</th>
</tr>
</thead>
</table>

Figure 6-8. BES-BEC, Load Combination 4, In-Plane Shear

<table>
<thead>
<tr>
<th>Tank Section Number (1 = Dome Center -&gt; 63 = Slab Center)</th>
</tr>
</thead>
</table>

Figure 6-9. BES-BEC, Load Combination 9, Meridional
Figure 6-10. BES-BEC, Load Combination 9, Circumferential

Figure 6-11. BES-BEC, Load Combination 9, Shear
6.1.2 Upper Bound Soil, Best-Estimate Concrete

Figures 6-12 through 6-19 show the demand/capacity ratios for load combinations 1, 4, and 9 of the Upper Bound Soil, Best-Estimate Concrete (UBS-BEC) material combination. The demand/capacity ratios are all less than 1.0 in all directions.

6.1.3 Lower Bound Soil, Best-Estimate Concrete

Figures 6-20 through 6-27 show the demand/capacity ratios for load combinations 1, 4, and 9 of the Lower Bound Soil, Best-Estimate Concrete (LBS-BEC) material combination. The demand/capacity ratios are all less than 1.0 in all directions.

6.1.4 Best-Estimate Soil, Fully Cracked Concrete

Figures 6-28 through 6-31 show the demand/capacity ratios for load combination 4 of the Best-Estimate Soil, Fully Cracked Concrete (BES-FCC) material combination. The demand/capacity ratios are all less than 1.0 in all directions.

![ACI-349 Demand/Capacity Ratios - LC 1, AP, 460°, UBS-BEC, TOLA](image)

Figure 6-12. UBS-BEC, Load Combination 1
ACI-349 Demand/Capacity Ratios - LC 4
UBS-BEC, TOLA + Seismic, Meridional

Tank Section Number (1 = Dome Center -> 30 = Slab Center)

Figure 6-13. UBS-BEC, Load Combination 4, Meridional

ACI-349 Demand/Capacity Ratios - LC 4
UBS-BEC, TOLA + Seismic, Circumferential

Tank Section Number (1 = Dome Center -> 30 = Slab Center)

Figure 6-14. UBS-BEC, Load Combination 4, Circumferential
Figure 6-15. UBS-BEC, Load Combination 4, Shear

Figure 6-16. UBS-BEC, Load Combination 4, In-Plane Shear
Figure 6-17. UBS-BEC, Load Combination 9', Meridional

Figure 6-18. UBS-BEC, Load Combination 9', Circumferential
Figure 6-19. UBS-BEC, Load Combination 9', Shear

Figure 6-20. LBS-BEC, Load Combination 1
Figure 6-21. LBS-BEC, Load Combination 4, Meridional

Figure 6-22. LBS-BEC, Load Combination 4, Circumferential
Figure 6-23. LBS-BEC, Load Combination 4, Shear

Figure 6-24. LBS-BEC, Load Combination 4, In-Plane Shear
ACI-349 Demand/Capacity Ratios - LC 9
LBS-BEC, TOLA, Meridional

Figure 6-25. LBS-BEC, Load Combination 9', Meridional

ACI-349 Demand/Capacity Ratios - LC 9
LBS-BEC, TOLA, Circumferential

Figure 6-26. LBS-BEC, Load Combination 9', Circumferential
Figure 6-27. LBS-BEC, Load Combination 9', Shear

Figure 6-28. BES-FCC, Load Combination 4, Meridional
ACI-349 Demand/Capacity Ratios - LC 4
BES-FCC, TOLA + Seismic, Circumferential

Figure 6-29. BES-FCC, Load Combination 4, Circumferential

ACI-349 Demand/Capacity Ratios - LC 4
BES-FCC, TOLA + Seismic, Shear

Figure 6-30. BES-FCC, Load Combination 4, Shear
6.2 ASME Primary Tank Evaluation

The primary tank was evaluated against the requirements of ASME B&PV Code, Section III, Division 1, Subsection NC, Article NC-3200 (ASME 1992a). Section 1622 of the IBC mandates that nonbuilding structures comply with the requirements of Section 9.14 of ASCE 7. That document, in turn, references the ASME B&PV Code as the applicable standard. Therefore, while the DST primary tank structure is not specifically addressed in IBC, they can be shown to meet the requirements of IBC by demonstrating their compliance with the ASME code.

The Evaluation Criteria document (Day et al. 1995) states that earthquake loads may be considered as Service Level D loading. The Seismic Design and Evaluation document (Bandyopadhyay et al. 1995) also states that load combinations including the design basis earthquake should use Service Level D capacities.

6.2.1 Primary Tank Results

Appendix A.7 of this report describes a study of the mesh refinement of the lower knuckle of the primary tank in the seismic FE model. That study concluded that the seismic stress intensities in the primary tank lower knuckle should be multiplied by a factor of at least 2.0 before being combined with the TOLA results. Given the uncertainties in the interpretation of the study results, a conservative factor of 3.0 was applied to the lower knuckle elements in the spreadsheets used to combine the primary tank stress intensities. The general primary membrane stress intensity, the general primary membrane plus bending stress intensity and the primary plus secondary stress intensity range are shown in Figures 6-33 through 6-52. The demands are well within the allowable capacity for each of the four material combinations.
6.2.2 Evaluation Criteria Discussion

The evaluation of the primary tank capacity was in accord with ASME Section III, Division 1, Service Level D as specified by the Structural Acceptance Criteria document (Day et al. 1995) and the guidance of the Seismic Evaluation document (Bandyopadhyay et al. 1995). The ASME code specifies the following load combinations and capacities for an elastic analysis:

General primary membrane stress intensity \[ P_m \leq kS_m \] (6.1)

Local primary membrane stress intensity \[ P_L \leq 1.5kS_m \] (6.2)

Primary membrane + bending stress intensity \[ (P_m \text{ or } P_L) + P_b \leq 1.5kS_m \] (6.3)

Primary + secondary stress intensity \[ (P_m \text{ or } P_L) + P_b + Q \leq 3S_m \] (6.4)

In these equations, \( P_m \) is the primary membrane stress, \( P_L \) is the local primary stress, \( P_b \) is the primary bending stress, and \( Q \) is a secondary stress (thermal in the case of the DSTs). The factor \( k \) is equal to 2.0 for Service Level D capacities.

The general primary membrane stress in the DST primary tank is dominated by hoop tension. Section 5.5 of the Seismic Evaluation document (Bandyopadhyay et al. 1995) imposes the additional condition that the hoop membrane stress capacity should be taken as the ASME Section III, Division 1, Service Level D limit of \( 2S_m \) or the yield strength, whichever is less. The intent of the additional condition is that \( kS_m \) should be limited to the yield strength if credit is taken for inelastic energy absorption in the computation of demands. Accordingly, the general primary membrane stress intensity criterion becomes:

\[ P_m \leq \min(kS_m, S_y) \] (6.5)

While the factored inelastic demand was not used, the additional conservatism afforded by the yield strength was maintained for each of the DST evaluations as shown in Figures 6-24, 6-29, 6-34, and 6-39.

The allowable stresses, \( S_m \) and \( S_y \) were conservatively taken at 250°F for the A537 steel used in the AP tanks as 23.1 ksi and 42.3 ksi, respectively.

6.2.3 Best-Estimate Soil, Best-Estimate Concrete

Figures 6-33–6-37 show the demand/capacity ratios for the primary tank for the BES-BEC material combination. All demand/capacity ratios are all less than 1.0.

6.2.4 Upper Bound Soil, Best-Estimate Concrete

Figures 6-38–6-42 show the demand/capacity ratios for the primary tank for the UBS-BEC material combination. All demand/capacity ratios are all less than 1.0.

6.2.5 Lower Bound Soil, Best-Estimate Concrete

Figures 6-43–6-47 show the demand/capacity ratios for the primary tank for the LBS-BEC material combination. All demand/capacity ratios are all less than 1.0.
6.2.6 Best-Estimate Soil, Fully Cracked Concrete

Figures 6-48–6-52 show the demand/capacity ratios for the primary tank for the BES-FCC material combination. All demand/capacity ratios are all less than 1.0.

Figure 6-32. Relative Magnitude of TOLA and Seismic Primary Membrane Stress Intensity
Figure 6-33. BES-BEC Primary Membrane Stress Intensity

Figure 6-34. BES-BEC Primary Membrane + Bending (inside) Stress Intensity

Figure 6-35. BES-BEC Primary Membrane + Bending (outside) Stress Intensity
Figure 6-36. BES-BEC Primary + Secondary (inside) Stress Intensity Range

Figure 6-37. BES-BEC Primary + Secondary (outside) Stress Intensity Range
Primary Tank Membrane Stress Intensity
AP tank, 460" waste, 1.83 SpG, UBS, BEC

Figure 6-38. UBS-BEC Primary Membrane Stress Intensity

Primary Tank Membrane + Bending Stress Intensity (Inside)
AP tank, 460" waste, 1.83 SpG, UBS, BEC

Figure 6-39. UBS-BEC Primary Membrane + Bending (inside) Stress Intensity

6.23
Figure 6-40. UBS-BEC Primary Membrane + Bending (outside) Stress Intensity

Figure 6-41. UBS-BEC Primary + Secondary (inside) Stress Intensity Range
Primary Tank Primary + Secondary Stress Intensity Range (outside)
AP tank, 460" waste, 1.83 SpG, UBS, BEC

Figure 6-42. UBS-BEC Primary + Secondary (outside) Stress Intensity Range

Primary Tank Membrane Stress Intensity
AP tank, 460" waste, 1.83 SpG, LBS, BEC

Figure 6-43. LBS-BEC Primary Membrane Stress Intensity
Primary Tank Membrane + Bending Stress Intensity (Inside)
AP tank, 460" waste, 1.83 SpG, LBS, BEC

Figure 6-44. LBS-BEC Primary Membrane + Bending (inside) Stress Intensity

Primary Tank Membrane + Bending Stress Intensity (Outside)
AP tank, 460" waste, 1.83 SpG, LBS, BEC

Figure 6-45. LBS-BEC Primary Membrane + Bending (outside) Stress Intensity
Figure 6-46. LBS-BEC Primary + Secondary (inside) Stress Intensity Range

Figure 6-47. LBS-BEC Primary + Secondary (outside) Stress Intensity Range
Figure 6-48. BES-FCC Primary Membrane Stress Intensity

Figure 6-49. BES-FCC Primary Membrane + Bending (inside) Stress Intensity
Figure 6-50. BES-FCC Primary Membrane + Bending (outside) Stress Intensity Range

Figure 6-51. BES-FCC Primary + Secondary (inside) Stress Intensity Range
6.3 Primary Tank Stress Corrosion Cracking Evaluation

The Structural Acceptance Criteria document (Day et al. 1995) raised the issue of primary tank fracture by stress corrosion cracking (SCC) as a potential failure mode. However, the report does not set forth a criterion by which to assess the limits on stress, temperature, or waste chemistry to preclude such failure. The TOLA report (Rinker et al. 2004) used the previously postulated limit on the primary tank principal stress on the inner surface to 90% of the yield strength of the tank steel. Perhaps the earliest appearance of this criterion is the AP Tank Farm Functional Design Criteria (Garfield and Guenther 1981). Other indications are that the criterion was “less than yield” prior to construction of the AZ farm, but was changed to “90% of yield” beginning with the AZ tanks.

Intervening analyses, particularly the Expert Panel discussions regarding waste chemistry (Terry et al. 2004) raised concerns regarding the validity of this criterion. The subsequent evaluation of the stress criteria for stress corrosion cracking (Rinker et al. 2005) was unable to establish a technical basis for the 90% yield criterion. That report also observed that while other industries and other design codes are concerned about SCC, they do not address the issue solely on the basis of a stress limit. Other approaches to addressing SCC include reduction of tensile residual stress by post weld heat treatment (PWHT), control of environmental conditions (chemistry and temperature), in-service inspection to confirm the lack of stress corrosion cracks, and fracture mechanics calculations to assess the possibility of crack growth.

6.3.1 Analytical Evaluation

The SCC report (Rinker et al. 2005) developed a damage tolerance approach based on fracture mechanics methods as an alternative means of evaluation. That report focused specifically on Tank AN-107 because
of the historical difficulty of maintaining the desired pH levels in the waste. The fracture mechanics calculations referenced crack growth rate data being developed concurrently (Brongers et al. 2005).

Earlier crack growth testing (Blackburn 1995a, 1995b) in highly aggressive solutions has demonstrated relatively high crack growth rates. It was recognized, however, that these test conditions were very conservative in comparison to the lower temperatures and less aggressive chemical conditions of past and current tank operations. This conservatism was confirmed by the recent test results (Brongers et al. 2005) which showed no propensity to crack at equilibrium corrosion potentials, and one to two orders of magnitude lower crack growth rates with an induced voltage to bring the system into the SCC sensitivity range. Only insignificant crack growth was predicted over the projected life of tank operations. Accordingly, conservative values of $K_{\text{ISCC}}$ were assigned to facilitate the fracture mechanics calculations.

Application of the fracture mechanics method to Tank AN-107 showed a very low potential for stress corrosion crack growth. There are, however, differences between the loads and tank geometry (wall thickness) of the AN-107 and bounding TOLA analysis described herein. The differences in load are summarized in Table 6-1.

<table>
<thead>
<tr>
<th>Feature</th>
<th>TOLA</th>
<th>AN-107</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil overburden (ft)</td>
<td>8.3</td>
<td>7.4</td>
</tr>
<tr>
<td>Overburden density (lb/ft$^3$)</td>
<td>125</td>
<td>120</td>
</tr>
<tr>
<td>Waste height (in.)</td>
<td>422</td>
<td>388</td>
</tr>
<tr>
<td>Waste specific gravity</td>
<td>1.70</td>
<td>1.43</td>
</tr>
<tr>
<td>Waste temperature (°F)</td>
<td>350</td>
<td>110</td>
</tr>
</tbody>
</table>

The effect of these differences on the lower knuckle inner surface principal stress is shown in Figure 6-53.

Figure 6-53. Comparison of TOLA and AN-107 Lower Knuckle Principal Stress
A parametric study on the effect of the applied bending stress to the sensitivity to crack growth was conducted as part of the SCC study (Rinker et al. 2005). Figure 5-5 from that report is reproduced here as Figure 6-54. Interpolation of the results to the TOLA bending stress of ±27 ksi suggest that crack growth is unlikely for an existing 0.10 inch crack unless $K_{\text{SSCC}}$ is less than 21 ksi-in$^{1/2}$. These results are predicated on the assumption of the lower knuckle steel temperature being more moderate ($\leq 150^\circ$F) than was historically recorded in the AY/AZ tanks.

![Image of Figure 6-54: Effect of Applied Bending Stress on Calculated Stress Intensity Factor for the Lower Knuckle of Tank AN-107](image)

**Figure 6-54.** Effect of Applied Bending Stress on Calculated Stress Intensity Factor for the Lower Knuckle of Tank AN-107

### 6.3.2 DST Operating Experience

Appendix C of the SCC report (Rinker et al. 2005) summarized the operating experience with DSTs at both the Hanford Site and the Savannah River Site (SRS). Stress corrosion cracking occurred with some early waste tank designs, without PWHT, at Savannah River. These tanks were constructed of carbon steel but, unlike the Hanford DSTs, were not given post-weld heat treatments to reduce welding residual stresses. The SRS tanks with confirmed SCC were exposed to relatively high-temperature wastes with adverse waste chemistries that were outside the current limits imposed on both Savannah River and Hanford tanks. Other early Savannah River tanks (also of low carbon steels and without PWHT) were operated at less severe waste chemistries and temperatures without reported SCC.

Savannah River initiated research programs in response to the early cracking incidents. Results of this research showed the benefits of PWHTs and improved specifications for waste chemistry. Implementation of these mitigative measures has evidently been effective because there has been no further SCC either in the older tanks (without PWHT) or in newer tanks that used PWHT.
Hanford waste storage tanks have experienced leaks from the older single-shell tanks (no PWHT) but also achieved a record of no leakage from the newer DSTs with PWHT. It is not possible to examine failed liners of single-shell tanks which precludes the detailed analyses needed to determine whether the failures were caused by corrosion, wall thinning, pitting, or cracking. It is likely that SCC was a factor because none of the older tanks were given PWHT to reduce welding residual stresses. Furthermore, the past service conditions included storage of wastes at high temperatures with chemical compositions known to contribute to SCC.

In contrast, no SCC has been observed in any of the 28 Hanford DSTs over periods of operation that date back to 1971. Detection methods include observation of leakage from through-wall cracks, visual inspections of the outer surface of the tanks, and monitoring for moisture and the increased radiation levels caused by leakage from the primary tank into the outer annulus. Ultrasonic (UT) examinations have been used to look for cracks with less than through-wall depths (present sensitivity can detect very small defects but can only dimension them to 0.050 inch depth), and none have been detected in the lower knuckle region. These crack inspections are done on a 30 inch wide top-to-bottom vertical pass (~40 feet), as well as a 20-foot long segment of the lower knuckle region. However, these UT examinations have covered only a fraction of the tank wall, and depend on the covered fractions being representative of entire tank conditions. Uncertainties aside, it can nevertheless be concluded that the Hanford DSTs appear to have experienced no significant SCC degradation.

There has been no stress corrosion cracking observed in the Hanford DSTs under the present chemistry controls and operating parameters. Recent corrosion testing and analysis overseen by the Expert Panel (Terry et al. 2004), when coupled with the historical operational record dating back to 1971, shows that SCC is unlikely if the present operating requirements are maintained. Temperature limits are lower and waste chemistry is much less aggressive than those that have caused cracking incidents in laboratory experiments and SRS waste storage tanks.

### 6.3.3 Seismic Considerations

Implicit in the definition of stress corrosion cracking is the presence of a static tensile stress. A seismic event is by definition a transient event, lasting a much shorter duration than that required to produce SCC. However, it has been posited that seismically induced stresses, when added to the baseline stresses from the thermal and operating loads, may exceed the yield strength of the primary tank steel. Consequently, the stress state following the earthquake may be higher thus possibly promoting the development of SCC.

A simplified stress analysis of the lower knuckle was conducted to evaluate this scenario. A model of the lower knuckle was loaded with a downward displacement of the wall sufficient to achieve an inside surface stress just below the yield strength (32 ksi) of the steel. This load condition was selected to conservatively represent the nominal operating loads. The displacement was then increased to give an additional 10 ksi compressive stress resulting in yielding of the knuckle such as might occur in an earthquake. The wall stress was then evaluated after returning the load to the nominal operating level. It was observed that the maximum inside surface stress was decreased by nearly 5 ksi following this over stress event.
This analysis demonstrates that yielding of the lower knuckle due to increased meridional compression such as might result from an earthquake does not increase the inside surface stress after the transient event has passed. The model predicts that such an overstress condition may actually decrease the subsequent surface stress due to the load reversal effect in going from the over stress state back to the normal operating condition.

6.4 Primary Tank Buckling Evaluation

Buckling of the primary tank was considered in Section 8.5 of the TOLA report (Rinker et al. 2004). The evaluation method was based on the method defined in Code Case N-284-1 of the ASME B&PV Code, Section III, Division 1 (ASME 1992a). The buckling evaluation for service Level D was conducted using seismic demands from the original design calculations (Blume and Associates 1974). A separate task of the DST Integrity Project was to conduct detailed buckling analyses, in part to “develop an approximate influence function to estimate the effect of changes between the finite element analysis parameters and the tank specific conditions.” Accordingly, a new finite element model was developed, distinct from the TOLA model, and buckling evaluations were performed incorporating the results from the current seismic analysis. Complete documentation of the TOLA buckling evaluation is found in the Buckling Analysis report (Johnson et al. 2006).

6.4.1 Evaluation Method

Large displacement finite element analyses were used to predict the limiting vacuum load for the DST primary tanks under combined axial and vacuum loads. Figure 6-55 shows the model of the primary tank used in this analysis. A downward deflection was applied to the dome of the tank (the area in contact with the concrete tank structure) to simulate the displacement controlled axial compression of the tank wall that occurs due to concrete thermal degradation and creep, plus the confined thermal expansion of the steel tank inside the concrete shell. The model includes a geometric imperfection to initiate the buckling instability under the radially symmetric vacuum load. The imperfection was sized to the maximum out of roundness (1-inch deviation in a 7-foot arc length) allowed in the AY tank farm construction specifications (HWS-7789 Hanford Engineering Services 1968). Additional loads on the model include gravity and hydrostatic pressure of the waste at height, h, and specific gravity, SpG (see Figure 6-56).

The onset of the buckling instability was predicted by applying an increasing vacuum load on the inside surface of the tank while monitoring the maximum radial displacement of the tank wall as a function of the increasing vacuum load. The onset of instability is signaled by an increasing rate of radial deflection for a constant increment in the applied vacuum load. Figure 6-57 shows an example load deflection curve from one of the cases that were analyzed. Because vacuum is a primary load, the stresses are not self limiting and the model eventually fails to converge (numerically) as the physical load carrying capacity of the tank is reached. However, using the final converged vacuum load as the buckling limit is not a reliable measure of the onset of instability because the final convergence is sensitive to non-physical factors including the load step size, the convergence tolerance, and the numerical precision of the computer. Therefore, the ASME code was reviewed to find an appropriate method for defining the limiting vacuum load.
Figure 6-55  Buckling Model

Figure 6-56  Buckling Model Loads
The ASME Boiler and Pressure Vessel Code, Section III, NB-3213.25, provides guidance on establishing a reasonable collapse load for a structure undergoing controlled plastic deformation (ASME 1992a). Although an elastic buckling phenomenon is being evaluated (the buckling models predict that the tank membrane stresses are well below the elastic limit), the increasing rate of distortion in the tank wall (for a constant increasing vacuum load) represents a gradual decrease in structural stiffness that is similar to a structure undergoing progressive plastic deformation. In the former case, the stiffness reduction is due to the large deformations of the tank geometry that progressively decrease the load carrying capacity of the tank. In the latter case, it is due to plastic softening. The ASME code method establishes the collapse load by limiting the reduction in structural stiffness under increasing load.

**NB-3213.25 Plastic Analysis — Collapse Load.** A plastic analysis may be used to determine the collapse load for a given combination of loads on a given structure. The following criterion for determination of the collapse load shall be used. A load-deflection or load-strain curve is plotted with load as the ordinate and deflection or strain as the abscissa. The angle that the linear part of the load-deflection or load-strain curve makes with the ordinate is called \( \theta \). A second straight line, hereafter called the collapse limit line, is drawn through the origin so that it makes an angle of \( \tan^{-1}(2 \tan \theta) \) with the ordinate. The collapse load is the load at the intersection of the load-deflection or load-strain curve and the collapse limit line. If this method is used, particular care should be given to ensure that the strains or deflections that are used are indicative of the load carrying capacity of the structure.

Figure 6-57 graphically illustrates the ASME code method based on the factor of two stiffness reduction. The radial displacement is offset from zero (at zero vacuum) because the initial loads (axial compression, hydrostatic pressure, and gravity) cause an initial radial deflection in the tank wall. The initial load-deflection slope was calculated and a second line was drawn at an angle with twice the tangent measured from the vertical axis. The vacuum limit was then calculated by interpolating to find the vacuum load.
where the second line crossed the load/deflection curve (Figure 6-57). In this case, the ASME collapse load is about 62% of the last converged vacuum load. Figure 6-58 shows the displaced shape of the tank model at the ASME collapse load. The displacements are magnified by a factor of 50 for visual effect. For the tank geometry, the ASME method results in a minor amount of tank distortion.

A matrix of tank models was run to develop equations for the tank vacuum limit as a function of waste height, specific gravity, wall thickness, and axial compressive load. Influence functions were developed to estimate the applied axial force in the primary tank wall that is required for evaluating buckling of the primary tank. The axial force contributions from the applied loads were evaluated, giving the total axial force as the sum of the following loads:

- Differential thermal expansion,
- Gravity,
- Surface loads,
- Concrete thermal degradation and creep,
- Seismic excitation, and the
- Effect of hydrostatic waste pressure on the confined axial force.

Once the unfactored axial force and vacuum limits are calculated, then the safety factors for the ASME Section III service levels are applied to calculate the allowable tank vacuum limits.
6.4.2 Evaluation Criteria

The buckling calculations are conducted for the four different service levels defined in ASME Section III, each with required factors of safety for local and global buckling:

<table>
<thead>
<tr>
<th>Level</th>
<th>Local Buckling</th>
<th>Global Buckling</th>
</tr>
</thead>
<tbody>
<tr>
<td>A = Normal operating conditions</td>
<td>2.0</td>
<td>2.4</td>
</tr>
<tr>
<td>B = Upset conditions</td>
<td>2.0</td>
<td>2.4</td>
</tr>
<tr>
<td>C = Emergency conditions</td>
<td>1.67</td>
<td>2.0</td>
</tr>
<tr>
<td>D = Faulted conditions</td>
<td>1.34</td>
<td>1.61</td>
</tr>
</tbody>
</table>

Attachment B of Julyk (2002) makes the argument that axial compression in the tank cylinder will be relieved by local bowing of the wall before the onset of general instability. This position is justified since the meridional (axial) compressive stresses are displacement controlled as a result of differential thermal expansion and concrete creep induced loads on the primary tank. The load deflection response of the large displacement finite element models using in the current buckling analysis confirm that the axial stress in the tank is self-limited by the deformation of the primary tank geometry. This rational leads to the following buckling criteria when combining the effects of axial and hoop loads on the allowable vacuum:

The allowable vacuum (net negative pressure) in the double shell tanks is controlled by the minimum of two cases,

A. **Local Buckling** (with *local* buckling safety factors imposed) evaluated considering the interaction of the net internal vacuum load ($\Delta p$) combined with the meridional compressive stress ($\sigma_\phi$).

B. **General Instability** (with *global* buckling safety factors imposed) evaluated considering the net internal vacuum load ($\Delta p$) acting alone. No interaction with the meridional compressive stress shall be considered ($\sigma_\phi = 0$).

These criteria were used by Julyk (2002) are they also used in the current buckling evaluation.

Julyk (2002) states that activation of the tank relief valves at the limiting vacuum load should be classified as a Level C (emergency) load condition. This is justified because the normal vacuum imposed by the tank ventilation systems is about 3 inches w.g. compared to the vacuum limit of 6.6 inches w.g. for the AY, SY, AN, AW, and AZ tanks and 12 inches w.g. for the AP primary tank. The relief valves (set at the limit values) are not expected to activate over the operating life of the tanks and at worst this would occur no more than 25 times. Therefore, activation of the relief valves would be an off-normal occurrence, which is consistent with the ASME Service Load Classification for Level C events.

It is assumed in this analysis that the design basis loads used in the thermal and operating loads analysis conservatively represent Service Levels A, B, and C. This is consistent with the loading conditions assumed by Julyk (2002). Service Level D, however, requires that the incremental seismic stresses be added to the design basis stresses for evaluating the faulted condition.
6.4.3 Buckling Results

An Excel™ spreadsheet was constructed using the relationships documented in detail in the Buckling report (Johnson et al. 2006) and it applies the Section III service level safety factors to calculate the vacuum allowable for the primary tanks. Table 6-2 shows a summary of the allowable vacuum calculations that are based on the current 210°F operating limits for waste temperature, 460 inch waste height, and waste specific gravity of 1.83. A corrosion allowance of 0.060 inch was assumed in these calculations. Table 6-2 shows the specified vacuum limit of 12 inches w.g. is greater than the current vacuum allowable to prevent buckling of 10.46 inch w.g.

Table 6-3 summarizes the additional analyses that showed that the allowable vacuum was above the 12-inch limit for corrosion allowances less than 0.025 inch. Little or no corrosion has been observed in the primary tanks (Jensen 2003, 2005) such that this wall thickness is appropriate for the buckling calculation. With this assumption, the AP tank passes the buckling criteria. Additional consideration may be given to the operational capabilities of the ventilation equipment.

Table 6-2. Primary Tank Buckling Evaluation

<table>
<thead>
<tr>
<th></th>
<th>AP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approx. Operating History</td>
<td></td>
</tr>
<tr>
<td>Temp, F</td>
<td>120</td>
</tr>
<tr>
<td>Hwaste, inch</td>
<td>422</td>
</tr>
<tr>
<td>Operating Limits</td>
<td></td>
</tr>
<tr>
<td>Temp, F</td>
<td>210</td>
</tr>
<tr>
<td>Hwaste, inch</td>
<td>460</td>
</tr>
<tr>
<td>SpG</td>
<td>1.83</td>
</tr>
<tr>
<td>Corrosion Allowance, inch</td>
<td>0.060</td>
</tr>
<tr>
<td>Yield at Temp, ksi</td>
<td>43.8</td>
</tr>
<tr>
<td>Calculated Axial Forces</td>
<td></td>
</tr>
<tr>
<td>Operating Axial Force, kip/inch</td>
<td>-0.355</td>
</tr>
<tr>
<td>Oper+Seismic Force, kip/inch</td>
<td>-0.869</td>
</tr>
<tr>
<td>Axial Force Limit, kip/inch</td>
<td>-2.842</td>
</tr>
<tr>
<td>Calculated Allowable Vacuum Limits, inches w.g.</td>
<td></td>
</tr>
<tr>
<td>Local Buckling</td>
<td></td>
</tr>
<tr>
<td>Service Level A&amp;B</td>
<td>9.61</td>
</tr>
<tr>
<td>Service Level C</td>
<td>11.51</td>
</tr>
<tr>
<td>Service Level D</td>
<td>13.37</td>
</tr>
<tr>
<td>Global Buckling</td>
<td></td>
</tr>
<tr>
<td>Service Level A&amp;B</td>
<td>8.71</td>
</tr>
<tr>
<td>Service Level C</td>
<td>10.46</td>
</tr>
<tr>
<td>Governing Allowable Vacuum, inch w.g.</td>
<td>8.71</td>
</tr>
<tr>
<td>Governing Allowable when vacuum = Level C load</td>
<td>10.46</td>
</tr>
<tr>
<td>Current Vacuum Limit, inches w.g.</td>
<td>12</td>
</tr>
</tbody>
</table>
### Table 6-3. Summary of Primary Tank Buckling Evaluation

<table>
<thead>
<tr>
<th>Approx. Operating History</th>
<th>AP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp, F</td>
<td>120</td>
</tr>
<tr>
<td>Hwaste, inch</td>
<td>422</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Maximum Expected Future Operating Conditions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp, F</td>
<td>210</td>
</tr>
<tr>
<td>Hwaste, inch</td>
<td>460</td>
</tr>
<tr>
<td>SpG</td>
<td>1.83</td>
</tr>
<tr>
<td>Yield at Temp, ksi</td>
<td>43.80</td>
</tr>
<tr>
<td>Corrosion Allowance, inch</td>
<td>0.000</td>
</tr>
<tr>
<td>Level C Vacuum Limit, inch w.g.</td>
<td>13.35</td>
</tr>
<tr>
<td>Corrosion Allowance, inch</td>
<td>0.010</td>
</tr>
<tr>
<td>Level C Vacuum Limit, inch w.g.</td>
<td>12.85</td>
</tr>
<tr>
<td>Corrosion Allowance, inch</td>
<td>0.025</td>
</tr>
<tr>
<td>Level C Vacuum Limit, inch w.g.</td>
<td>12.11</td>
</tr>
<tr>
<td>Corrosion Allowance, inch</td>
<td>0.060</td>
</tr>
<tr>
<td>Level C Vacuum Limit, inch w.g.</td>
<td>10.46</td>
</tr>
</tbody>
</table>

#### 6.5 ASME Concrete-Backed Steel Evaluation

The evaluation criteria for the concrete-backed steel liner (both primary and secondary liner) are specified by Day et al. (1995) in WHC-SD-WM-DGS-003. These requirements were taken from the ASME B&PV Code, Section III, Division 1, Subsection NC-3700 (ASME 1992a). The seismic load component is added to the factored load combination under the abnormal/extreme environmental category.

##### 6.5.1 Best-Estimate Soil, Best-Estimate Concrete

Figures 6-59–6-64 show the demand/capacity ratios for the primary tank for the BES-BEC material combination. All demand/capacity ratios are less than 1.0.

##### 6.5.2 Upper Bound Soil, Best-Estimate Concrete

Figures 6-65–6-70 show the demand/capacity ratios for the primary tank for the UBS-BEC material combination. All demand/capacity ratios are less than 1.0.

##### 6.5.3 Lower Bound Soil, Best-Estimate Concrete

Figures 6-71–6-76 show the demand/capacity ratios for the primary tank for the LBS-BEC material combination. All demand/capacity ratios are less than 1.0.
6.5.4 Best-Estimate Soil, Fully Cracked Concrete

Figures 6-77–6-82 show the demand/capacity ratios for the primary tank for the LBS-FCC material combination. All demand/capacity ratios are less than 1.0.

![Membrane Strain - Tensile](image1)

**Figure 6-59.** BES-BEC, Principal Membrane Strain – Tension ($\varepsilon_1$)

![Membrane Strain - Compressive](image2)

**Figure 6-60.** BES-BEC, Principal Membrane Strain – Compression ($\varepsilon_3$)
Figure 6-61. BES-BEC, Principal Membrane + Bending Strain Outer Surface – Tension ($\varepsilon_1$)

Figure 6-62. BES-BEC, Principal Membrane + Bending Strain Outer Surface – Compression ($\varepsilon_3$)
Membrane + Bending (inside) Strain - Tensile

Figure 6-63. BES-BEC, Principal Membrane + Bending Strain Inner Surface – Tension ($\varepsilon_1$)

Membrane + Bending (inside) Strain - Compressive

Figure 6-64. BES-BEC, Principal Membrane + Bending Strain Inner Surface – Compression ($\varepsilon_3$)
Figure 6-65. UBS-BEC, Principal Membrane Strain – Tension (εt)

Figure 6-66. UBS-BEC, Principal Membrane Strain – Compression (εc)
Figure 6-67. UBS-BEC, Principal Membrane + Bending Strain Outer Surface – Tension ($\varepsilon_t$)

Figure 6-68. UBS-BEC, Principal Membrane + Bending Strain Outer Surface – Compression ($\varepsilon_c$)
Figure 6-69. UBS-BEC, Principal Membrane + Bending Strain Inner Surface – Tension ($\varepsilon_i$)

Figure 6-70. UBS-BEC, Principal Membrane + Bending Strain Inner Surface – Compression ($\varepsilon_i$)
Figure 6-71. LBS-BEC, Principal Membrane Strain – Tension ($\varepsilon_1$)

Figure 6-72. LBS-BEC, Principal Membrane Strain – Compression ($\varepsilon_3$)
Figure 6-73. LBS-BEC, Principal Membrane + Bending Strain Outer Surface – Tension ($\varepsilon_t$)

Figure 6-74. LBS-BEC, Principal Membrane + Bending Strain Outer Surface – Compression ($\varepsilon_c$)
Figure 6-75. LBS-BEC, Principal Membrane + Bending Strain Inner Surface – Tension ($\varepsilon_t$)

Figure 6-76. LBS-BEC, Principal Membrane + Bending Strain Inner Surface – Compression ($\varepsilon_s$)
Figure 6-77. BES-FCC, Principal Membrane Strain – Tension ($\varepsilon_1$)

Figure 6-78. BES-FCC, Principal Membrane Strain – Compression ($\varepsilon_3$)
Membrane + Bending (outside) Strain - Tensile

Figure 6-79. BES-FCC, Principal Membrane + Bending Strain Outer Surface – Tension ($\varepsilon_3$)

Membrane + Bending (outside) Strain - Compressive

Figure 6-80. BES-FCC, Principal Membrane + Bending Strain Outer Surface – Compression ($\varepsilon_3$)
Figure 6-81. BES-FCC, Principal Membrane + Bending Strain Inner Surface – Tension (ε₁)

Figure 6-82. BES-FCC, Principal Membrane + Bending Strain Inner Surface – Compression (ε₃)
6.6 Anchor Bolt Evaluation

The initial evaluation of the primary tank dome anchor bolts documented in Rev. 0 of this report was conducted in accordance with the ASME B&PV Code per (Day et al 1995). In July 2007, independent reviewers raised concerns regarding the anchor bolt capacity used in that evaluation (Appendix A.2). In response to the reviewer comments, the anchor bolts were re-evaluated using an approach based on a combination of test data and analytical modeling.

Because the DST configuration of an internally threaded weld stud with a threaded anchor bolt is not supported directly by test data, detailed finite element models were developed to establish an equivalent diameter for the shear response of the anchors. Once the equivalent diameter was established, test data were used to determine the ultimate shear deformation for the anchors. The models and incorporation of the test data are described in Appendix A.3.

Test data on similar anchors show ductile responses represented by highly nonlinear load-deformation curves in both shear and tension. The known nonlinear response of the DST anchors was characterized by consistent linearizations of the shear and tensile load-deformation curves using a secant modulus approach as described in Chapter 2.2.4.2 and Appendix A.3.

The reviewer comments on the anchor re-evaluation are provided in Appendixes A.4 and A.5. The follow-up review documented in Appendix A.5 questioned the use of a single shear stiffness for all the anchor bolts in the tank dome. Subsequent analyses described in Appendix A.6 demonstrated the validity of this approach.

An additional review of the anchor bolt modeling and evaluation is documented in Appendix A.9. In addition to finding the anchor bolt modeling and evaluation methods used in the DST structural evaluation to be appropriate, an important development in this review was the procedure for combining thermal and non-thermal demands. Because the evaluation of the DST anchor bolts did not reduce the thermal demands on the anchor bolts in accordance with the given procedure, that aspect of the anchor bolt evaluation was considered by the reviewer to be very conservative.

A conservatism identified during the July 2007 review was the use of the 0.5 strength reduction factor specified by the ASME code compared to the 0.75 factor specified by both the ACI (2001) and AISC (2005). The ASME B&PV criteria are intended for the design of concrete containments in nuclear facilities. Since 1995, the DSTs have been downgraded from PC-3 to PC-2 structures, and the application of the concrete containment code to the anchor bolt evaluation is viewed as unnecessarily restrictive. Consequently, the current evaluation of the AP anchors follows the procedure given in ACI-349-01 (ACI 2001). The change of criteria from ASME to ACI 349-01 has the effect of increasing the capacity of the AP anchors by 50%.

By comparing AP anchor bolt model results with the available test data on anchor ultimate shear forces and displacement, it was determined that an ultimate shear displacement $\delta_{UN} = 0.22$ inch is appropriate for the welded stud and threaded anchor configuration used in the AP tanks. The corresponding ultimate shear force is $V_{UN} = 14.34$ kips. The secant shear modulus, $k_s$, is calculated as:

$$k_s = \frac{V_{UN}}{\delta_{UN}} = \frac{14.34 \text{kips}}{0.22 \text{inch}} = 65.187 \text{lbf/in}$$
The value of 65,000 lbf/in. was selected for the TOLA and seismic models in both shear and tension.

The demands from the combination of the 210°F waste thermal load with the seismic loads exceed the anchor bolt capacity. A review of historical tank operation data indicated maximum dome temperatures of approximately 100°F. Discussions with Tank Operations confirmed that a bulk waste temperature of 135°F was sufficient to accommodate expected future operations. Additionally, the stress-free concrete curing temperature was identified as 80°F rather than the previously assumed, more conservative 50°F.

Four (one for each soil – concrete combination) full 60-year analyses were conducted with the thermal cycle ranging from 80°F to 135°F. These analyses were used only for the evaluation of the anchor bolts. The anchor bolt demands from the thermal and operating loads were combined with the seismic demands. The anchor bolt evaluations are shown in Figures 6-83 through 6-86.

The primary tank dome anchor bolt forces and displacements are within the allowable limit for all combinations of soil and concrete with a maximum waste temperature of 135°F.

![Anchor Bolt Displacement, BES-BEC Demand/Capacity Ratio](image)

**Figure 6-83.** BES – BEC, Anchor Bolt Displacement Evaluation
Figure 6-84. UBS – BEC, Anchor Bolt Displacement Evaluation

Figure 6-85. LBS – BEC, Anchor Bolt Displacement Evaluation
6.7 The Effect of Waste Model Uncertainties on Anchor Bolt Evaluation

In the Dytran® analysis of the AP Tanks, the waste was modeled as a homogeneous, nearly incompressible, inviscid liquid with a bulk specific gravity of 1.83. In the ANSYS® analysis, the waste is modeled as a homogeneous, nearly incompressible deformable solid with very low shear resistance, also with a bulk specific gravity of 1.83. During a project review meeting held in June 2007, one review comment stated that there are fundamental uncertainties in idealizing the tank waste as a homogeneous liquid (Appendix A). The technical issue of concern is that hydrodynamic effects for a tank storing a solid-like material may be larger than for a liquid-containing tank.

The potential for an increased response from a tank containing a solid-like material relative to a tank containing a liquid arises from two mechanisms. First, the solid-like material will have reduced sloshing response relative to a liquid, so a higher portion of the mass responds impulsively, thereby increasing some response parameters. Second, depending on the excitation as well the structural characteristics and geometrical configuration of the tank and contained waste, it is possible for the response of the tank to amplify the response of the tank walls (Veletsos and Younan [1998]).

The second phenomenon can occur when the natural frequencies of contained material are “in tune” with the natural frequencies of the tank. This also depends on the ratio of the waste height to the tank radius (slenderness ratio), and the characteristics of the forcing function. For this to occur, the contained material must be “solid” in the sense that it has structural frequencies and mode shapes independent of the tank itself. This characterization appears to be inconsistent with Hanford DST waste properties and will
not be discussed further. Depending on the DST waste composition, the first phenomenon may occur to some degree.

Based on the current waste composition data for the AP tanks reported in the Tank Waste Information Network System (TWINS) database (TWINS 2008), the waste composition in the AP tanks includes a sludge-like material with depths less than the bottom one-third of the total waste height. The waste is similar in consistency to over-saturated soil with a low angle of repose and a specific gravity of 1.5 to 1.83. More than two-thirds of the waste is a liquid with a specific gravity of 1.3 to 1.5 that covers the sludge layer. Increasing the liquid level to 460 inches will not exceed the current assumption of 1/3 sludge and 2/3 liquid.

When the waste is completely liquid, the mass of the waste in the DSTs that responds in the impulsive and convective modes is roughly the same, with somewhat greater than half the waste mass responding in the impulsive mode (BNL 1995).

If it is assumed conservatively that the lower one-third of the waste is a sludge layer of specific gravity of 1.83 that responds 100% impulsively, and that the upper two-thirds of the waste is liquid with specific gravity of 1.83, which responds equally in the impulsive and convective modes, then two-thirds of the total waste mass responds impulsively. This gives an approximate increase of 1/6 (16.7%) in the portion of the waste responding impulsively. The increase in impulsive mass will affect both the demands on the anchor bolts, and the waste pressures in the primary tank.

Some simple conservative estimates of the effects of a sludge layer at the bottom of the tank can be made based on the equations in Chapter 4 of BNL (1995) and Rinker and Abatt (2006a).

As a first approximation, it is assumed that the increase in the maximum horizontal hydrodynamic reaction force is proportional to the increase in the impulsive mass of the waste. That is, the increase in the maximum horizontal reaction force is estimated to be 16.7%. The increased shear reaction is split between the bottom of the primary tank (contact interface with the insulating concrete) and the top of the primary tank (anchor bolts and normal and shear forces between steel and concrete dome).

With several load paths available to accommodate the increased shear force, not all of the additional shear will be reacted by the anchor bolts. Moreover, a significant portion of the anchor bolt demand (roughly 1/3) is from thermal and operating loads, which are largely unaffected by the presence of a sludge layer. With the above considerations in mind, the increase in the anchor bolt demands from this conservative estimate appears to be less than 10%. This upper bound estimate of the increase in anchor bolt loads is exclusive of several other notable conservative factors in the analysis including the following:

- The most recent site response analyses performed at the Hanford Site Waste Treatment Plant (WTP) show that the currently published design spectra for the WTP Site are significantly lower than the interim spectra published in 2005 (Youngs 2007). This indicates that the governing spectra being used for the DST analysis are likely to be conservative.

- The TOLA and seismic demands reported for the AP tanks do not credit any friction between the concrete dome and the steel tank. Initial indications are that the benefit of friction may reduce the demands by approximately 5%.
So far, a simplified routine that smears spatial and temporal results has been used to calculate peak seismic demands. Use of a more refined methodology is estimated to reduce the seismic demand by approximately 5-10%.

The assumption of a bulk modulus of 1.83 is conservative.

In lieu of further more detailed analysis, it appears that for a sludge height not exceeding one-third of the primary tank height, the potential increase in anchor bolt loads due to increased impulsive response is offset by the increase in capacity associated with the conservatisms inherent to the analysis.

Due to the margins available in the primary tank stresses that are shown in Section 6.2, an even more conservative argument suffices to show that the increased dynamic pressures in the primary tank are acceptable. For this estimate, assume that all of the tank waste responds impulsively. In this case, the peak hydrodynamic wall pressure is independent of the vertical position along the tank wall and is given by

\[ p_{\text{wall}}(\theta) = p_a \cdot R \cdot (S_A)_{1/2} \cdot \cos(\theta). \]

The spectral acceleration for the impulsive mode of the primary tank and waste can be estimated from the impulsive mode frequency and in-structure response spectrum at the base of the primary tank.

The ANSYS® simulation for the increased liquid level shows an impulsive frequency of 5.78 Hz. The Dytran® simulations show 5.7 and 5.88 Hz depending on whether the input is single- or two-component motion. The effective impulsive damping from either model is in the range of 4% of critical damping. Based on the horizontal response spectrum shown in Figure 3-21 of Abatt and Rinker (2008), an upper bound estimate of the spectral acceleration for the impulsive mode of the primary tank is 0.35g. The corresponding peak dynamic wall pressure along the plane of excitation (\(\theta=0\)) is 10.4 lbf/in².

Figure 6-87 below is a reproduction of Figure 6-6 in Abatt and Rinker (2008) that includes the predicted waste pressures for the 100% impulsive response. In the critical middle third of the primary tank, the increase in total gage pressure (stress producing pressure) is 10-15%. Although the percentage increase in the dynamic pressure is higher, the waste pressures are dominated by the gravity-induced hydrostatic pressure over the majority of the tank. The increase in dynamic pressures associated with the increase in the impulsive response is mitigated by the superimposed static pressure. Thus, even with highly conservative assumptions, increases in the AP tank waste pressures and tank stresses are easily accommodated with the present analysis.
Maximum and Minimum Total Waste Pressures vs. Normalized Height from Tank Bottom for Horizontal Excitation Only at \( \theta = 0 \) Degrees

Figure 6-87. Comparison of Maximum Waste from the ANSYS® Primary Tank Sub-Model for Waste Elements at \( \theta = 0^\circ \) Subjected to Horizontal Seismic Excitation Only to Maximum Waste Pressures for the 100% Impulsive Case.
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7.0 Conclusions and Recommendations

The code evaluations reported in Chapter 6 for the AP tank model with 460 inches of 1.83 SpG waste do not reveal any structural deficiencies with the integrity of the DST. The analyses represent 60 years of use, which corresponds to an additional 40 years of use beyond the current date. The loads imposed on the model for the finite element analyses are significantly more severe than any service to date or proposed for the future. The material properties were selected to be lower bound and in the most severe combinations.

7.1 Reinforced Concrete

The reinforced concrete structure was evaluated in the manner required by ACI 349 (ACI 1990). Load combinations 1, 4 (which includes the seismic load), and 9 of the ACI code were evaluated for each combination of soil and concrete properties. The axial load and moment were evaluated on the load-moment interaction diagram for each individual cross section. The demand was demonstrated to be lower than the capacity at all locations for all load combinations. The cross-section shear demand was less than the capacity for all sections. The in-plane shear demand/capacity ratios were evaluated for the seismic loads and showed low values.

7.2 Primary Tank

The primary tank is governed by ASME B&PV Code, Section III, Division 1 (ASME 1992a). The allowable stress value, $S_m$, is provided by the code at operating temperature, which is defined to be 210°F for operating loads. This value at this temperature was used for all the stress intensity code checks regardless of temperature. All sections of the primary tank were checked to Service Level D requirements with $k = 2.0$. In all instances the factored inelastic general primary membrane stress intensity remained below the yield stress (which is lower than the allowable $2S_m$). The primary local membrane plus bending stress intensity remained below the code allowable value of $1.5 kS_m$, and the primary + secondary (thermal) stress intensity range remained below the code allowable value of $3.0 S_m$. Therefore, the primary tank is acceptable according to the established criteria.

7.3 Stress Corrosion Cracking

The use of the criterion limiting the primary tank principal stress on the inside surface to 90% of the yield strength of the steel to prevent stress corrosion cracking was discontinued with this analysis. The SCC report (Rinker et al. 2005) discouraged further use of this criterion, citing the lack of a technical basis. The fracture mechanics method developed in that report was extended to evaluate the bounding tank under the thermal and operating loads. The results when considered with the current crack growth rate testing show that SCC is unlikely if the present operating requirements are maintained. Analysis also showed that the propensity for SCC would not be increased after a seismic event.

7.4 Primary Tank Buckling

A large displacement finite element analysis method was developed to evaluate the potential for buckling of the primary tank. The method was shown to have good correlation with the ASME code case N-284 method. The primary tank buckling evaluation showed the current limit on demand of 12 inch w.g.
vacuum to exceed the ASME allowable of 10.4 inch. This determination was based on analysis at the full 60-year corrosion allowance on the tank wall of 0.060 inch. However, analysis at a corrosion allowance of 0.025 inch results in an acceptable demand/capacity ratio. Therefore, the current limit of 12 inches w.g. for the AP tanks is acceptable given the current lack of corrosion in the tanks. It should be noted that, as a result of the anchor bolt analysis, the maximum tank waste bulk temperature is reduced to 135°F. Therefore, the buckling analysis is now more conservative, which would allow for a corrosion allowance higher than 0.025 inch.

7.5 Concrete-Backed Liner

The evaluation criteria for the secondary steel liner are strain-based and taken from the ASME B&PV Code, Section III, Division 2, Subsection NC (ASME 1992a) for normal service loads. The results in all cases demonstrate that the secondary liner strains are all well below the allowable strain levels. Therefore, the secondary liner is judged to be adequate.

7.6 Anchor Bolts

Evaluation of the anchor bolts in the dome was conducted with the ACI/AISC strength reduction factor of 0.75. The combination of thermal and seismic loads was evaluated using a displacement-based criterion. In all cases the anchor bolts were within the allowable range for an operating waste temperature range of 80°F to 135°F. Therefore, the dome anchor bolts are considered to be satisfactory.
8.0 References


ACI. 1977. *American Concrete Institute Building Code Requirements for Structural Concrete*. ACI 318-77, American Concrete Institute, Detroit, Michigan.

ACI. 1990. *American Concrete Institute Code Requirements for Nuclear Safety Related Concrete Structures*. ACI 349-90, American Concrete Institute, Detroit, Michigan.

ACI. 2001. *American Concrete Institute Code Requirements for Nuclear Safety Related Concrete Structures*. ACI 349-01, American Concrete Institute, Detroit, Michigan.


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Appendix A

Reviewer Comments and Resolution
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Appendix A

A.1 Introduction

A series of project technical reviews were conducted subsequent to the initial Rev. 0 release of this report. These reviews raised a number of issues, including the anchor bolt evaluation and the primary tank lower knuckle mesh resolution. This appendix provides a chronological account of the reviewer comments and analytical responses.

At the June 2007 review meeting of the analyses on the Effect of Increased Liquid Level in 241-AP Tank Farms, the reviewers (RP Kennedy and AS Veletsos) raised concerns primarily with the anchor bolt evaluation. Changes to the anchor bolt modeling and evaluation were suggested and subsequently implemented. Further questions regarding the new anchor bolt modeling were raised at the March 2008 review. These comments were addressed and a further review was conducted by RE Klingner.

A.2 Reviewer Comments – Kennedy and Veletsos, July 2007

Comments Regarding Seismic Evaluation of Hanford Double-Shell Tanks and Effect of Increased Liquid Level in 241-AP Tank Farms

by

R. P. Kennedy and A. S. Veletsos
July 2007

A.2.1 Introduction

Based on our review of the seismic response analyses of the Hanford Double-Shell Tanks (DSTs) reported through February 2006, we provided in Ref. A.2.1 comments on the reported information and recommendations for requisite additional studies. In response to this input, previously reviewed reports (Refs. A.2.2, A.2.4, and A.2.5) have been modified and comprehensive Appendices have been added to them. In addition, a benchmark study (Ref. A.2.3) of seismically induced fluid-structure interaction in flat-top tanks has been performed using the DYTRAN computer program. Lastly, two reports (Refs. A.2.6 and A.2.7) evaluating the effects of increasing the waste in the 241-AP tanks to the 460-inch level have been prepared.

Our present input refers to the additional studies conducted since then, and it is based on:

- Our review of Refs. A.2.2 through A.2.7; and
The presentations and ensuing discussions at the Review Meeting of June 7 and 8, 2007, in which we participated to provide an independent oversight and comment on the adequacy and completeness of the approach being used.

Our views and recommendations are presented under the following six topic headings.

A.2.2 Fluid-Structure Interaction Analyses of Primary Tanks

A.2.2.1 DYTRAN Analyses

Refs. A.2.2 and A.2.3 present a series of fluid-structure interaction analyses performed using computer program DYTRAN. The problem with the DYTRAN solution identified in Section 3.3 of Ref. A.2.1 has been addressed by using a more refined mesh in the tank region for which the fluid comes in contact with the roof.

We consider the DYTRAN fluid-structure interaction solutions obtained with the refined mesh to represent a good representation of the behavior of a homogeneous, incompressible, practically inviscid liquid in the tanks.

A.2.2.2 ANSYS Analyses

The ANSYS model continues to be used for the combined soil-structure-fluid interaction seismic evaluation of the tanks. As previously noted in Section 3.1 of Ref. A.2.1, this model conservatively overestimates the impulsive mode component of the hydrodynamic effects on the primary tank and underestimates the convective component of the effects. Because the impulsive mode of response dominates the fluid effects on the primary tank and because the ANSYS results are generally slightly higher than the DYTRAN results, we concur that the ANSYS model can continue to be used for the seismic evaluation of the soil-structure-fluid system. However, wherever critical, the convective and dome constrained fluid pressures near the surface of the liquid should be obtained from the DYTRAN solutions.

A.2.2.3 Modeling of Waste

In the seismic analyses of the Hanford DSTs conducted so far – as in all previous analyses of waste-containing tanks that we are aware of – the waste was effectively modeled as a homogeneous, incompressible, practically inviscid liquid. There are fundamental uncertainties in this idealization, and it would be highly desirable to assess their effect on critical responses.

We recommend that, as a minimum, a qualitative discussion be provided as to why it is considered acceptable to model the waste as a homogeneous liquid. From discussions on this issue during the June 7 and 8 meetings, we understand that the waste may appropriately be represented as:

1. Liquid with a specific gravity (SG) of 1.3 to 1.5 over at least the upper 2/3 of the waste height; and
2. Sludge with the consistency of over-saturated soil with a low angle of repose and a SG of 1.5 to 1.83 over the lower portion of the tank.

Based on this description, we concur that it is probably reasonable, as a first approximation, to model the waste as an incompressible liquid with a SG of at least 1.7. However, this aspect of the system modeling is likely to continue being of concern to some, especially in light of the currently available computational capabilities.

In defense of criticism that may legitimately be voiced on this issue, it is recommended that the critical responses of a simplified model of the tank-waste system (for example, one that does not provide for the effects of soil-structure interaction or the impact effects of the sloshing surface of the waste with the superimposed dome) be evaluated by representing the waste as a uniform, deformable solid with the properties of the lower portion of the waste. The computed responses must then be compared with those obtained for the liquid-like idealization of the waste.

A more realistic modeling of the waste and of the tank itself would be warranted only if the differences in the critical responses computed for the liquid-like and proposed representations of the waste are shown to be of practical significance.

A.2.2.4 Comparison of DYTRAN Results With Approximate Results Obtained Using Method of BNL Tank Report (Ref. A.2.8)

For the condition under which the sloshing liquid impacts the tank roof, Refs. A.2.2 and A.2.3 compare the DYTRAN-computed pressures and reactions with those estimated by the approximate method presented in Appendix D of the BNL tank report (Ref. A.2.8). However, both in Refs. A.2.2 and A.2.3, this appendix, particularly in sections dealing with wall pressures, has been misinterpreted.

Appendix D of Ref. A.2.8 provides the following equations for estimating the hydrodynamic pressures induced on the tank wall:

- Constrained impulsive pressure $p_{ci}$ defined by Equation (D.5)
- Unconstrained impulsive pressure $p_{ui}$ defined by Equation (D.6)
- Unconstrained convective pressure $p_{cu}$ defined by Equation (D.7)

For liquid that is constrained by the roof within the angle $|\theta| \leq \theta_0$, Appendix D approximates the hydrodynamic wall pressure $p$ by:

$$ p = p_{ci} \quad \text{for} \quad |\theta| \leq \theta_0 \quad (A.2.1) $$

$$ p = \left[ p_{ui}^2 + p_{cu}^2 \right]^{0.5} \quad \text{for} \quad |\theta| > \theta_0 \quad (A.2.2) $$

Instead, Refs. A.2.2 and A.2.3 have incorrectly used the expression:
\[ P = P_i + P_{iu} + P_{cu} \]  

(A.2.3)

which leads to a substantial overestimation of the wall pressures.

For example, for the 480-inch liquid level results shown in Figure 4-9 of Ref. A.2.3, the correct values of the maximum absolute pressures determined by the approach of Appendix D of Ref. A.2.8 vary from 54.3 psi at the bottom to 23.9 psi at the top of the waste height. Similarly, the maximum gage pressure on the wall determined by this approach is 39.6 psi, which is in close agreement with the DYTRAN result of 37.8 psi. These results are only slightly greater than the DYTRAN computed maximum pressures.

Ref. A.2.3 also incorrectly computes the minimum pressures corresponding to \( \theta = 180^\circ \) by subtracting the incorrectly defined pressure \( p \) obtained by application of Equation (A.2.3) from the hydrostatic pressure. The correct hydrodynamic pressure that must be subtracted from the static pressure is given by Equation (A.2.2). The resulting minimum pressure determined by the approach of Appendix D of Ref. A.2.8 is identical to the open top minimum pressure. Again, there is close agreement between the results computed by DYTRAN and those obtained by the approach of Appendix D.

A lesser problem exists with the peak horizontal reaction forces \( P \) reported in Refs. A.2.2 and A.2.3 based on the approach of Appendix D of Ref. A.2.8. The reaction forces, in the later approach should be determined from the expressions:

\[ P_{ic} = \varepsilon \left( \frac{H_t}{H_t} \right) m_i (S_A) \]  

(A.2.4)

\[ P_{iu} = (1 - \varepsilon) P_i \]  

(A.2.5)

\[ P_{cu} = (1 - \varepsilon) P_c \]  

(A.2.6)

\[ P = \left[ (P_{ic} + P_{iu})^2 + P_{cu}^2 \right]^{0.5} \]  

(A.2.7)

where \( m_i \) is the total liquid mass, \((S_A)\) is the spectral acceleration for the impulsive mode of response, \( H_t \) is the roof height, \( H_t \) is the liquid height, \( \varepsilon \) is the fraction of the liquid that is constrained by the roof, and \( P_i \) and \( P_c \) are respectively the impulsive and convective components of the reactions for an open top (unconstrained) liquid surface.

For example, for the 480-inch liquid level, the peak horizontal reaction force \( P \) obtained by the approach of Appendix D should be \( 4.14 \times 10^6 \) lbs as opposed to the \( 4.47 \times 10^6 \) lbs reported in Figure 4.1 and Table 4.1 of Ref. A.2.3.

Furthermore, Appendix D of Ref. A.2.8 does not provide a method for estimating the peak value of the convective component of the reaction following the decay of the impulsive component. Neither \( P_{cu} \) (shown in Refs. A.2.2 and A.2.3) nor \( P_c \) are intended to represent the peak horizontal convective reaction.
force. It is therefore recommended that no results be reported in tables such as Table 4-1 and figures such as Figure 4-2 of Ref. A.2.3 for the peak value of the convective component of the horizontal force obtained by the approach of Appendix D.

The maximum roof pressure of 16.2 psi gage reported in Table 4-1 of Ref. A.2.3 for the DYTRAN results is believed to be for the midheight of the top outermost fluid element closest to the wall-roof junction. However, in Figure 4-9 of Ref. A.2.3, the corresponding wall pressure for the same element is only about 26.7 psi absolute (corresponding to about 12.0 psi gage). Please explain why there is such a large difference between the roof pressure and wall pressure for this same fluid element.

We recommend that the results obtained by the approach of Appendix D of Ref. A.2.8 shown in Sections 4 and 5 and Appendix B of Ref. A.2.3, and in Appendices C and D of Ref. A.2.2 be corrected so as not to lead others astray when using the approximate method. Correcting these results will also help to demonstrate the reasonableness of the DYTRAN results.

A.2.3 Anchorage of Primary Tank Steel Dome to Concrete Vault Dome

Shearing forces and tensile forces between the primary tank steel dome and the concrete vault dome are transferred by 2-inch diameter anchors. These anchors consist of either 6-inch long headed anchor bolts or 6-inch long J-bolts with a 180° J-hook at their upper end. These anchor bolts are screwed into 3/4-inch diameter by 1.375-inch high Nelson tapped welding studs welded to the steel dome.

The tensile loads on these anchors are small. However, the shear loads are significant.

In Ref. A.2.1 we stated that:

Neither of us is familiar with the basis of the acceptance criteria for the reported allowables. Furthermore, we do not have sufficient information regarding the Nelson Internally Threaded Studs used to attach the J-bolts to the steel tank so that we may assess the appropriateness of the indicated allowables.

The basis for the tension and shear allowables for these anchors has now been provided in Section 6.1 of Ref. A.2.4 and Section E.3 of Ref. A.2.5.

Based on our review of these sections, we have concerns about the allowable capacities assigned to the anchors. We also wish to comment on the demands computed for these anchors.

A.2.3.1 Allowable Anchor Bolt Capacities

From Table 6-3 of Ref. A.2.4, the allowable anchor tension \( T_a \) and shear \( V_a \) are defined by the following expressions:

For Normal (Operating) Loads

\[
T_a = 0.33 T_u \\
V_a = 0.33 V_u
\]  

(A.2.8a)  

(A.2.8b)
For Abnormal (Operating + Seismic) Loads

\[ T_a = 0.5 T_u \]  \hspace{1cm} (A.2.9a)
\[ V_a = 0.5 V_u \]  \hspace{1cm} (A.2.9b)

where \( T_u \) and \( V_u \) represent the nominal ultimate tensile and shear capacities of the anchors, respectively. We understand that the tank criteria document specifies the use of these ASME code factors of 0.33 and 0.5. These factors are lower (more conservative) than the strength reduction factors \( \phi \) in both the AISC Code (Ref. A.2.9) for steel and the ACI Code (Ref. A.2.10) for concrete.

**A.2.3.1.1 Nominal Ultimate Tensile Strength for Headed Bolts**

Table 6-3 of Ref. A.2.4 bases the nominal ultimate tensile capacity of the anchors on:

\[ T_u = \frac{2}{3} A_b f_u \]  \hspace{1cm} (A.2.10)

where \( A_b = 0.1963 \text{ inch}^2 \) is the cross-sectional area of the bolt shank, and \( f_u = 60 \text{ ksi} \) is the ultimate strength of the bolt material. Thus:

\[ T_u = 7.85 \text{ kips} \]  \hspace{1cm} (A.2.11)

which is slightly less (more conservative) than the nominal \( T_u \) computed in accordance with AISC (Ref. A.2.9) or ACI (Ref. A.2.10).

However, Refs. A.2.4 and A.2.5 do not check the anchor tensile capacity as governed by the concrete breakout strength \( T_{ub} \):

\[ T_{ub} = 24 \left( f'_c \right)^{0.5} h^{1.5} \]  \hspace{1cm} (A.2.12)

where \( f'_c = 4860 \text{ psi} \) is the concrete strength, and \( h = 6 \) inches is the bolt length. Neither is the concrete pullout strength, \( T_{up} \), defined by:

\[ T_{up} = 8f'_c A_{brg} \]  \hspace{1cm} (A.2.13)

checked, where \( A_{brg} = 0.2959 \text{ inch} \) is the bearing area of the head on a ½ inch bolt. The values obtained from Equations (A.2.12) and (A.2.13) are:

\[ T_{ub} = 24.6 \text{ kips} \]  \hspace{1cm} (A.2.14)
\[ T_{up} = 11.5 \text{ kips} \]  \hspace{1cm} (A.2.15)

These concrete failure modes do not control the nominal ultimate tensile capacity \( T_u \) for the headed anchor bolts. Even so, these concrete failure mode tensile capacities should be computed.
In conclusion, the tensile capacity $T_u=7.85$ kips presented in Table 6-3 of Ref. A.2.4 is considered to be reasonable for the headed anchor bolts.

A.2.3.1.2 Nominal Ultimate Tensile Strength for J-Bolt Anchors

J-Bolt anchors are not permitted by either AISC or ACI for positive tensile anchorage. See, for example, page 14-10 of Ref. A.2.9. Therefore, no approach is provided in either Ref. A.2.9 or A.2.10 for computing the ultimate tension capacity of J-Bolt anchors.

A criterion for determining the nominal ultimate capacity of J-Bolt anchors is provided in older versions of the British Standard CP110 (Ref. A.2.11). Based on this Standard, the ultimate bond tensile capacity $T_{ub}$ for J-Bolt anchors is defined by:

$$T_{ub} = \pi d_b f_{bs} \ell_e$$

where $d_b$ is the bar diameter, $f_{bs}$ is the concrete bond strength for a smooth-bar, and $\ell_e$ is the effective bar length given by:

$$\ell_e = \ell_a + \ell_h$$

$$\ell_h \leq 24 d_b$$

where $\ell_a$ is the straight bar length to the start of the hook, and $\ell_h$ is the inside radius length of the hook plus any straight extension beyond the hook, provided $\ell_h$ is limited to not more than $24 d_b$. For concrete with $f'_c$ greater than 4600 psi, CP110 limits the smooth-bar bond-strength to:

$$f_{bs} = 275 \text{ psi}$$

We suggest that the bond-slip capacity of the J-Bolt anchors might control their ultimate tensile capacity $T_u$ rather than the steel bolt shank capacity $T_u=7.85$ kips given by Equation (A.2.11). One possible approach for estimating the bond-slip capacity is to use Equations (A.2.16) through (A.2.19).

A.2.3.1.3 Nominal Ultimate Shear Strength for Anchor Bolts

In Table 6-3 of Ref. A.2.4, ultimate shear strength values $V_u$ based both on a steel failure limit and on a concrete failure limit were computed using the following expressions:

For Steel Failure Limit

$$V_{us} = 0.9 A_s f_u$$

(A.2.20)

For Concrete Failure Limit
\[ V_{uc} = 5.66 A \sigma_f^{0.3} E_c^{0.44} \quad \text{(A.2.21)} \]

In Table 6-3 of Ref. 4 the full cross-sectional area \( A_s = 0.442 \text{ in}^2 \) of the \( \frac{5}{6}\)-inch diameter Nelson tapped welding stud was used in both Equations (A.20) and (A.21) to obtain:

\[ V_{us} = 23.86 \text{ kips} \quad \text{(A.2.22)} \]

\[ V_{uc} = 23.42 \text{ kips} \quad \text{(A.2.23)} \]
In our judgment, it is inappropriate to use $A_s=0.442 \text{ in}^2$ in Equation (A.2.21) for the concrete failure limit $V_{uc}$. This equation was based on extensive test data for headed studs with a length of at least four stud diameters and is unconservative for lesser bearing lengths. For a ¾-inch diameter stud, the required length is 3.0 inches. However, the Nelson tapped welding stud is only 1.375 inch long. Over the remainder of the required 3.0 inch length, the concrete bears against a ½ inch bolt instead of a ¾ inch stud.

The required bearing area $A_{bear}$ to obtain the $V_{uc}$ capacity is:

**Required**

$$A_{bear} = 4\left(\frac{3}{4} \text{ in}\right)^2 = 2.25 \text{ in}^2$$  \hspace{1cm} (A.2.24)

However, the available bearing area in the 3 inch length is only:

**Available**

$$A_{bear} = 1.375 \text{ in (3/4 in)} + 1.625 \text{ in (1/2 in)} = 1.844 \text{ in}^2$$  \hspace{1cm} (A.2.25)

Conservatively assuming a uniform bearing pressure over the required 3 inch length, $V_{uc}$ should be reduced to:

$$V_{uc} = (1.844/2.25)(23.42) = 19.19 \text{ kips}$$  \hspace{1cm} (A.2.26)

for an average bearing pressure on the concrete of:

$$f_{bear} = \frac{19.19}{1.844} = 10.4 \text{ ksi}$$  \hspace{1cm} (A.2.27)

It is undoubtedly conservative to assume a uniform bearing pressure over the 3-inch length. In reality, bearing pressure will be concentrated closer to the base and this concentration will lead to in a higher $V_{uc}$ than that given by Equation (A.2.26). However, for a 4.86 ksi concrete, it is not clear how much higher than 10.4 ksi the bearing pressure can become without crushing the concrete.

It is also not appropriate to use the full $A_s=0.442 \text{ in}^2$ to determine the steel failure limit $V_{us}$. Immediately above the base, the cross-sectional area of the ¾-inch Nelson tapped welding stud is reduced by the tapped threaded hole. Using the diameter midway between the minor and pitch diameter of the threaded hole, the reduction in cross-sectional area becomes 0.1416 inch. Thus, the effective shear area $A_{se}$ of the welding stud is:

$$A_{se} = 0.4418 - 0.1416 = 0.300 \text{ in}^2$$  \hspace{1cm} (A.2.28)

and with $f_u=60 \text{ ksi}$, Equation (A.2.20) yields:

$$V_{us} = 0.9(0.300)(60) = 16.2 \text{ kips}$$  \hspace{1cm} (A.2.29)
Another location that might control the ultimate shear capacity of the anchorage is the ½ inch anchor bolt shaft at its junction with the Nelson tapped welding stud. Based on Equation (A.2.20), the shear capacity \( V_{ub} \) for the bolt shank is:

\[
V_{ub} = 0.9(0.1963 \text{ in}^2)(60 \text{ ksi}) = 10.60 \text{ kips}
\]  

(A.2.30)

Conservatively assuming a uniform bearing pressure \( f_{bear} = 10.4 \text{ ksi} \) and a bearing area \( A_{bear} = 1.375(3/4) = 1.031 \text{ in}^2 \) for the welding stud, the corresponding ultimate shear capacity at the base of the welding stud is:

\[
V_{ub} + f_{bear} A_{bear} = 21.3 \text{ kips}
\]  

(A.2.31)

which is not the controlling capacity.

The ultimate shear capacity, \( V_u \), of the anchors seems to be controlled by the \( V_{us} \) value determined from Equation (A.2.20). Thus:

\[
V_u = 16.2 \text{ kips}
\]  

(A.2.32)

which is only 69\% of the value reported in Table 6-3 of Ref. 4 for these anchors.

**A.2.3.2 Recommendation for Finite Element Analysis of Anchor Bolts**

We recommend that a detailed nonlinear finite element model be developed for an anchor in the concrete dome so as to determine its load-deformation relationship in shear. The model must include: (1) a realistic stress-strain relationship for the Nelson welding stud and stud bolt, (2) realistic nonlinear constitutive properties for compression, shear, and tension in the concrete, (3) a bond shear limit between the anchor and concrete of no more than 250 psi, and (4) a coefficient of friction between the anchor and concrete of no more than 0.2, with friction induced stresses not being additive to the bond induced stresses since friction activates after the bond is broken.

It is unlikely that this finite element analysis would justify the use of an ultimate shear strength higher than the 16.2 kips value, since the shear area is reduced by the tapped hole in the Nelson welding stud and the bolt does not extend to the bottom of this tapped hole. However, the analysis is likely to show significant shear distortions at an allowable shear load \( V_a = 0.5V_u = 8.1 \text{ kips} \). The results of this analysis could be then used to determine if a lower shear stiffness than that currently considered for the anchors would be appropriate to use in the demand analyses.

As shown in Figures 6-25 and 6-26 of Ref. 4, the reported demand analyses indicate the total shear between the primary tank steel dome and the concrete vault roof is heavily concentrated on the outermost anchor bolts. We expect that reducing the shear stiffness of the anchors below the level used in the demand evaluations presented so far will redistribute the shear to more anchors and will reduce the shear demands on the outermost anchors.
A.2.3.3 Other Comments on Anchor Bolt Demand

A.2.3.3.1 Anchor Bolt Demand for 422 Inch Waste Level

In Ref. 12, the shear demand in the outermost anchor bolts for the combination of gravity and seismic loads was reported to be:

\[ V_{bs} = 5.4 \text{ kips/bolt} \]  

(A.2.33)

for the ‘Best Estimate Soil-Fully Cracked Concrete’ (BES-FCC) Case. This value was obtained from an analysis in which the coefficient of friction, COF, between the steel and concrete was taken as 0.4.

In Ref. 1 we commented that a COF value of 0.4 was too high to use once sliding was initiated and the anchor bolts begin to pick-up shear load. Therefore, the seismic analysis was rerun with COF=0 for ‘Best-Estimate Soil-Best Estimate Concrete’ (BES-BEC) Case which is not the critical BES-FCC Case that we had recommended to be considered. For the BES-BEC Case, the shear \( V_{bs} \) increased from 4.052 kips for COF=0.4 to 4.591 kips for COF=0, or by a factor of 1.133. Applying the same amplification factor to the BES-FCC Case leads to:

BES-FCC Case (COF=0)

\[ V_{bs} = 5.4 \times 1.133 = 6.1 \text{ kips} \]  

(A.2.34)

However, in Section 6.3 of Ref. 4 the seismically induced shear demand \( V_{bs}=4.6 \text{ kips} \) was used to evaluate the Demand to Capacity ratio (D/C) of the anchors. We believe that the appropriate seismic shear demand should have been \( V_{bs}=6.1 \text{ kips} \).

The seismic shear demand \( V_{bs}=4.6 \text{ kips} \) in Ref. 4 was then combined with the shear demand \( V_{bc} \) on the outermost anchor induced by axial compression in the tank wall resulting from thermal expansion of the steel tank and axial shortening of the concrete vault due to concrete creep. The maximum permissible axial compressive force was then determined from the permissible \( V_{bc}=V_{a}-V_{bs}=11.7 \text{ kips}-4.6 \text{ kips}=7.1 \text{ kips} \).

Increasing \( V_{bs} \) from 4.6 kips to 6.1 kips and decreasing \( V_{a} \) from 11.7 kips to 8.1 kips will substantially reduce the allowable axial compression in the tank wall due to temperature and creep effects since \( V_{bc} \) is reduced to 8.1 kips-6.1 kips=2.0 kips.

However, the temperature and creep induced axial compression in the tank wall occurs only when significant compressive normal forces exist between the primary tank dome and the concrete vault roof. Under these conditions, even a low COF value of 0.2, which we previously accepted in Ref. 1, is likely to reduce the \( V_{bc} \) demand.
In summary, we do not concur with the D/C evaluation of the J-Bolt anchors presented in Sections 6.1 through 6.3 of Ref. 4 and summarized in Section 6.6 of Ref. 5 because:

1. The reported ultimate shear capacity $V_u$ of the anchors appears to be significantly unconservative; and

2. Both conservative and unconservative aspects appear to exist in the anchorage demand evaluations.

A.2.3.3.2 Anchor Bolt Demand for 460 Inch Waste Level

For the anchorage of the steel dome to the concrete roof and the combination of gravity and seismic loads, Ref. 6 reports a shear demand $V_{bS}$ in the outermost anchors of 9.0 kips. This $V_{bS}$ represents an approximate factor of 1.5 increase resulting from increasing the waste height from 422 inches to 460 inches and increasing the waste SG from 1.7 to 1.83. This increase seems reasonable, because with the increased waste level, a greater fraction of the total seismically induced horizontal reaction gets transferred to the concrete vault roof.

For the waste level considered, it is not clear how the temperatures and creep induced shear, $V_{bC}$, is combined with $V_{bS}$ in Section 6.6 of Ref. 7. No explanation is provided on how the total shear demand $V_b$ on the outermost anchor bolts was obtained. However, based on an allowable $V_a=11.7$ kips, the maximum D/C ratio is shown in Figure 6-86 of Ref. 7 to be about 0.88, which would correspond to a combined total shear demand:

$$V_b = 0.88(11.71 \text{ kips}) = 10.3 \text{ kips} \quad (A.2.35)$$

This combined shear demand is only 1.3 kips higher than the value of $V_{bS}=9.0$ kips obtained for gravity and seismic loads only. The small effect of the $V_{bC}$ in this case does not appear to be consistent with the result reported in Section 6.3 of Ref. 4 for the 422 inch waste level.

A seismic shear demand of $V_{bS}=9.0$ kips compounds the issues that arise if the ultimate shear capacity $V_u$ is reduced to 16.2 kips and the allowable shear capacity $V_a$ is reduced to 8.1 kips. The computed seismic shear demand alone for the outermost anchor exceeds this allowable shear capacity.

One should reconsider whether it is really necessary to define the allowable shear:

$$V_a = 0.5 V_u \quad (A.2.36)$$

as is currently required by the project criteria for Abnormal (Operating + Seismic) Loads. Both AISC (Ref. 9) and ACI (Ref. 10) would permit the use of a strength reduction factor $\phi=0.75$, which would increase the allowable $V_a$ for a given $V_u$ by a factor of 1.5.
A.2.4 Buckling Evaluations

We concur with the approach for the buckling evaluation of the tank wall presented in Ref. 4 and summarized in Section 6.4 of Ref. 5 for a generic tank. The same approach and results are summarized in Section 6.4 of Ref. 7 for the AP tanks with the increased waste height.

A.2.5 Seismic Induced Stressed in Lower Knuckle of Primary Tank

The lower knuckle of the primary tank is too crudely modeled in the global analysis of the soil-structure-waste system to accurately define the peak values of the stresses induced in it. To provide for this inadequacy, the maximum values of the stresses determined in the global analysis for this region were increased by a factor of 2.0. We understand that this factor was based on the increase in maximum stresses determined for a refined model of the knuckle considering the effects of the hydrostatic pressures only.

While this amplification factor may indeed be adequate for the hydrostatic effects, we are concerned that it may not be adequate for the seismically induced effects. As the seismic loading, unlike the hydrostatic, induces a substantive axial force in the tank-wall, we expect the increase of the bending stresses in the knuckle to be larger for the seismic loading than for the hydrostatic.

We recommend that the stresses in the refined local model of the lower knuckle be determined using the maximum values of the boundary forces and of the associated pressures computed in the seismic analysis of the global model. A comparison of the absolute maximum values of the resulting stresses with those obtained by the global model would then provide a more defensible estimate of the amplification factor that should be applied to the seismically induced effects determined with the global model.

Alternatively – although this option is not as desirable – an approximate estimate of the requisite amplification factor may be determined by a static analysis similar to the one used, provided the vertical and circumferential distributions of the pressures considered are representative of those of the impulsive component of the seismically induced pressures.

Considering that some of the reported analyses indicate the absolute maximum stresses to occur in the base plate, slightly beyond the lower end of the knuckle, it is important that the local model does include this region.

A.2.6 Comments in Inelastic Factor and Nonlinear Response

So long as these tanks are considered to be PC#2 structures, we concur with the use of a Response Modification Factor \( R = 2.5 \) coupled with an Importance Factor \( I = 1.5 \) which results in an Inelastic Factor:

\[
F_{\mu} = \frac{R}{I} = 1.67
\]  
(A.2.37)
For ductile failure modes, the computed seismic demands can be reduced by $F_{\mu}=1.67$ before being combined with non-seismic demands. For brittle failure modes such as J-bolt anchorage failure and buckling, no credit should be taken for the Inelastic Factor (i.e., $F_{\mu}=1.0$).

In addition, wherever credit is taken for the Inelastic Factor $F_{\mu}=1.67$, the ASME Code allowable stresses defined by Equations (A.37) through (A.40) of Ref. 5 should be limited to:

\[
\begin{align*}
     kS_m & \leq S_y \\
     1.5k S_m & \leq 1.5 S_y \\
     3S_m & \leq 1.5 S_y
\end{align*}
\]  

where $S_y$ is the yield stress. These limits should be applied to insure that the effect of inelastic behavior is not double-counted.

However, we are concerned with the statements on Pages i, 6.16, and 7.1 that primary stresses remain below yield, and that gross plastic deformation does not occur. The use of $F_{\mu}=1.67$ automatically implies that gross plastic deformation has occurred during the transient seismic response. In fact, in order to develop an $F_{\mu}$ of 1.67, the gross deformation (elastic + plastic) during transient seismic response needs to be about 1.5 to 2.0 times the yield deformation of the structure (i.e., transient gross plastic deformations are about 0.5 to 1.0 times the yield deformation). At the end of the seismic event some residual stresses will remain in the yielding elements of the structure. However, it is not expected that the further operability or future seismic margin will appreciably be impaired by this level of inelastic response, although the potential for future stress-controlled cracking may increase.

If it is necessary to prevent gross plastic deformation, a value of $F_{\mu}=1.0$ should be used. In this case, the limits imposed by Equations (A.2.38) through (A.2.40) would no longer be necessary.

Lastly, we do not recommend the use of the $R=3$ factor discussed in the second paragraph on Page 6.17 of Ref. 5. We consider $R=2.5$ to be reasonable, but not conservative. We further believe that it would be difficult to defend the view that there is sufficient inelastic energy dissipation capability in these tanks so as to justify the use of $R=3$ (i.e., $F_{\mu}=2.0$).

### A.2.7 References


A.3 Anchor Bolt Modeling and Evaluation

Reevaluation of the DST Anchor Bolts for the Increased Waste Level in AP Tanks

by

M. W. Rinker, J. E. Deibler, K. I. Johnson, and F. G. Abatt
PNNL and M&D
December 17, 2007

A.3.1 Introduction

At the June 2007 review meeting of the PNNL analyses on the Effect of Increased Liquid Level in 241-AP Tank Farms, the reviewers raised concerns with the anchor bolt evaluation. In particular, “we do not concur with the D/C evaluation of the J-bolt anchors presented in Sections 6.1 through 6.3 of Ref. 4 and summarized in Section 6.6 of Ref. 5 because:

3. The reported ultimate shear capacity \( V_u \) of the anchors appears to be significantly unconservative; and

4. Both conservative and unconservative aspects appear to exist in the anchorage demand evaluations.”

The reviewers’ recommendation and arguments are as follows:

“We recommend that a detailed nonlinear finite element model be developed for an anchor in the concrete dome so as to determine its load-deformation relationship in shear. The model must include: (1) a realistic stress-strain relationship for the Nelson welding stud and stud bolt, (2) realistic nonlinear constitutive properties for compression, shear, and tension in the concrete, (3) a bond shear limit between the anchor and concrete of no more than 250 psi, and (4) a coefficient of friction between the anchor and concrete of no more than 0.2, with friction induced stresses not being additive to the bond induced stresses since friction activates after the bond is broken.

It is unlikely that this finite element analysis would justify the use of an ultimate shear strength higher than the 16.2 kips value, since the shear area is reduced by the tapped hole in the Nelson welding stud and the bolt does not extend to the bottom of this tapped hole. However, the analysis is likely to show significant shear distortions at an allowable shear load \( V_a = 0.5 V_u = 8.1 \) kips. The results of this analysis could be then used to determine if a lower shear stiffness than that currently considered for the anchors would be appropriate to use in the demand analyses.
As shown in Figs. 6-25 and 6-26 of Ref 4, the reported demand analyses indicate the total shear between the primary tank steel dome and the concrete vault roof is heavily concentrated on the outermost anchor bolts. We expect that reducing the shear stiffness of the anchors below the level used in the demand evaluations presented so far will redistribute the shear to more anchors and will reduce the shear demands on the outermost anchors.

This document summarizes our responses to the reviewer's comments regarding the anchor integrity and describes the resolution to the issues raised. Briefly, we concur that the anchor shear capacity used in the previous analyses is unconservative. However, we will demonstrate that by

1) adopting the ACI 349 evaluation criteria for the AP tanks
2) limiting the temperature range (ΔT) to 55°F based on reduced tank temperature ranges and an anchor bolt stress-free temperature of 80°F
3) using an equivalent linear shear stiffness (secant modulus) to represent the shear response of the anchor bolts in the finite element models to allow limited shear deformation,

the anchor bolt capacity is greater than the demand for the AP tanks at the 460 inch waste depth.

A.3.2 Background

The anchor bolts are used to attach the steel primary tank in the tank dome and the steel secondary liner in the wall to the secondary concrete tank. The anchor bolts take several different forms, depending on the tank family. The AY, AZ, and SY tanks use J-bolts (or hooked bolts with 180 degree bend to use the terminology of ACI-318). The AN and AW tanks use L-bolts (hooked bolts with 90 degree bend). The AP tanks use headed studs. The original thermal and operating loads analysis (TOLA) report (RPP-RPT-23308) appropriately used the terminology "J-Bolts" as that model was largely based on the AY tank. However, that nomenclature was inadvertently preserved in the 241-AP Increased Liquid Level reports. This will be corrected in the future revision to these reports.

Common to all the tanks is the use of a 3/4 inch external diameter by 1-3/8 inch long internally threaded weld stud (Nelson TBL shown in Figure A.3-1) that is welded onto the steel tank or liner. The 1/2 inch anchor bolt, whether J, L, or headed stud is then threaded into this stud. A cursory review of the stud geometry as shown in Figure A.3-1 suggests that there may be adequate material at the 3/4 inch diameter at the base of the stud to transfer the shear load.

Figure A.3-1. Nelson TBL Internally Threaded Stud
Table A.3-1a. Nelson TBL Weld Stud Dimensions

<table>
<thead>
<tr>
<th>Stud Diameter</th>
<th>Maximum Tap Size C</th>
<th>Minimum Values</th>
<th>Burn Off</th>
<th>E</th>
<th>F</th>
<th>Flash Clearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/4</td>
<td>5/8-11</td>
<td>0.750 0.937 0.406 0.250 0.187 1.062 0.250</td>
<td>1.125</td>
<td>19</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table A.3-1b. Nelson TBL Thread Dimensions

<table>
<thead>
<tr>
<th>Thread Size</th>
<th>Minimum OD</th>
<th>Length of Engagement for Full Strength</th>
<th>Imperfect Thread Depth</th>
<th>Solid Weld Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2-13</td>
<td>0.625</td>
<td>0.750</td>
<td>0.319</td>
<td>0.218</td>
</tr>
</tbody>
</table>

The nominal 3/4 inch diameter stud dimensions listed in Table A.3-1a were extracted from the Nelson Stud Welding (NSW) catalog. The additional thread dimensions listed in Table A.3-1b were obtained from NSW in response to questions arising from the initial uncertainty in the dimensions of the as-installed stud. The 1-3/8 inch (1.375) length TBL stud with a 1/2-13 thread requires 0.75 inch thread length. The remaining 0.625 inch length also includes 0.319 inch imperfect thread length. The final 0.306 inch length of the solid weld base exceeds the NSW specified minimum of 0.218 inch. The welding process consumes 0.187 inch of the base leaving 0.119 inch solid material. These dimensions formed the basis of the finite element model described below.

A.3.2.1 Correlation of Finite Element Models with Anchor Bolt Shear Tests

A combined experimental and modeling study (Lam and El-Lobody 2005) by the University of Leeds provided a convenient benchmark for developing finite element models of anchor bolts loaded in shear. An ANSYS model of the Leeds anchor bolt test was constructed and compared with the experimental and ABAQUS results reported in the Leeds paper. This comparison validates the selection of element type, mesh resolution and material models. Once confidence in the method was obtained, a model of a standard 3/4 inch headed stud was constructed. This was followed by a model of the AP configuration anchor bolt with the internally threaded weld stud and headed anchor bolt.

The shear strength predicted by the model was compared with the values recommended by the reviewers. The load-displacement response of the ANSYS model established the shear stiffness response of the anchor bolt. As suggested by the reviewers, this nonlinear stiffness can be used in the TOLA and seismic models to evaluate the potential redistribution of shear loads.

The ABAQUS model from the Leeds paper is shown in Figure A.3-2. The corresponding ANSYS model is shown in Figure A.3-3. The shear connector (anchor) is 19 mm (3/4 inch) diameter and 100 mm (4 inch) length. The push-off test specimen is similar to the standard test established by the British Standards Institution.
Figure A.3-2. ABAQUS Model

Figure A.3-3. ANSYS Model
A key feature of the ABAQUS analysis is the use of a simple elastic-plastic material model for the concrete. The yield strength was taken as the compressive strength of the concrete. The Leeds paper mentions 3 different concrete strengths: cube strength, compressive strength and cylinder compressive strength. The interplay between the different strengths was not precisely defined, but running the model with the various values helped narrow the definition. Four different concrete slab strengths were tested.

Figure A.3-4 shows the load-displacement curve for the SP-3 concrete, which is closest in strength to the Hanford AP concrete ($f_c = 5$ ksi). The plot includes curves for the experimental tests, the ABAQUS results and the ANSYS results. Note that quite good correlation is achieved between the experimental test, the ABAQUS results and the ANSYS results. Results from the other models with different concrete strengths showed similar good correlation.

![Load-Displacement Curve](image)

**Figure A.3-4.** SP-3 Load-Displacement Results

With satisfactory results from the comparison to the Leeds experimental and modeling results, the FE modeling progressed to a standard 3/4 inch Nelson headed stud for which published test data exists. A standard 3/4 inch headed anchor bolt model is shown in Figure A.3-5. The length was taken as the minimum required of 4 times the diameter, or 3 inches. Figure A.3-6 shows the comparison with the Ollgaard (1971) data.
Figure A.3-5. 3/4 Inch Headed Stud Anchor Bolt Model

Figure A.3-6. 3/4 Inch Headed Stud Load-Displacement Results

Figure A.3-7 shows the AP anchor bolt model. As described earlier, the solid region at the base of the stud is defined to be 0.119 inch high. The annular region is defined to be 0.406 inch high. The dimensions of the weld flash are taken from NSW specifications.
Figure A.3-7. AP Anchor Bolt Model
Figure A.3-8 shows the load-displacement response. The annular area of the TBL stud results in a lower strength than the full 3/4 inch stud. Figure A.3-9 shows the shear deformation that occurs in the TBL stud.

Figure A.3-10 shows results from several additional analyses that were conducted to gain an understanding of the effect of the length of the solid section at the base of the weld stud. The AP 1" curve and AP 2" curve are models with the solid base height increased to 1 inch and 2 inches, respectively. The overall anchor bolt embedment was maintained at 6 inches. Note that the load carrying ability increases but remains below the standard 3/4 inch headed stud even with a 2 inch base. The conclusion from the finite element anchor bolt study is that an ultimate shear load, $V_{UN} = 14.3$ kips, is appropriate for the welded/threaded anchor studs used in the AP tanks. This is compared to the 16.2 kip shear strength that was estimated by the reviewers. The more conservative 14.3 kip value is used later in this section to calculate the equivalent secant modulus for the equivalent linear modulus of the anchor studs.

![ANSYS Results](image)

Figure A.3-8. AP – 3/4 Inch Headed Stud Comparison
Figure A.3-9. Anchor Bolt Shear Deformation

Figure A.3-10. Load-Displacement Results
A.3.2.2 AP Anchor Bolt Shear Displacement Allowable and Secant Modulus Stiffness

In discussions held with the reviewers subsequent to the June review meeting, it was suggested that consideration be given to using an anchor bolt shear stiffness corresponding to a secant modulus that credits the finite shear deformation that occurs under higher load. The finite element anchor bolt modeling (Figures A.3-8 though A.3-10) and experimental data (Ollgaard et al. 1971; Lam and El-Lobody 2005) clearly shows the expected nonlinear response with significant softening prior to reaching the ultimate load.

The ASME evaluation makes a distinction between an anchor bolt force allowable and a displacement allowable based on the different response to force limited and displacement limited loading configurations. Use of the linear secant makes the anchor shear force and displacement allowables equivalent because the secant stiffness is defined as the ultimate anchor shear force divided by the corresponding anchor shear displacement. The secant stiffness also softens the initial portion of the load-deflection curve allowing some shear load redistribution between the anchors.

The DST Evaluation Criteria document (Day et al. 1995) specifies Ultimate Displacements for Nelson Studs (Table 4.1.4-3). The recommended allowable shear displacements for 1/2 inch and 5/8 inch Headed-Threaded Studs are 0.167 inch and 0.22 inch, respectively. The footnote states that test data are not available for this configuration, and that the recommended values are conservative. Indeed, the local nonlinear anchor bolt model that was calibrated against test data shows that the effective diameter of the anchor bolt and welded stud combination is greater than the nominal 1/2 inch diameter of the headed studs, indicating an ultimate shear displacement greater than 0.167 inch.

The ultimate shear displacement for the AP anchor bolts was established using the experimentally determined anchor bolt slip capacities reported by Oehlers and Sved (1995) and the experimentally determined load-slip relationship documented by Ollgaard et al. (1971). Oehlers reported good correlation with the following equation of slip capacity:

\[ S_f/d_s = 0.45 - 0.0021f_c \quad (A.3.1) \]

where \( S_f \) is the slip at fracture, \( d_s \) is the anchor bolt shank diameter and \( f_c \) is the concrete strength in N/mm\(^2\). This gives an allowable shear displacement of 0.285 inch for a 3/4 inch anchor bolt and 0.188 inch for a 1/2 inch anchor bolt.

Ollgaard (1971) reported an empirical formula for shear load-slip response as:

\[ Q = Q_u(1 - e^{-18A})^{0.4} \quad (A.3.2) \]

The load-slip curves for 1/2 and 3/4 inch anchor bolts defined by this relationship are shown in Figure A.3-11. The displacement capacity of these size anchor bolts is also identified on the plot. The AP anchor bolt response as determined by the finite element model is also shown in this figure. The AP anchor bolt ultimate shear displacement is established as 0.22 inch, which is the intersection of the line joining the 1/2 and 3/4 inch capacities with the AP response. The corresponding ultimate shear force is \( V_{UN} = 14.34 \) kips for the AP anchors.
Figure A.3-11. AP Anchor Bolt Secant Modulus and Allowable Displacement

This point also defines the secant modulus for use in the TOLA and seismic finite element models. The secant shear modulus, $k_s$, is calculated as:

$$k_s = \frac{V}{\delta} = \frac{14.34kip}{0.22\text{in}} = 65,187\text{lbf/in}$$

(A.3.3)

The value of 65,000 lbf/in was selected for both the TOLA and seismic models.

A.3.2.3 Establishing Rational Concrete Curing and Tank Operating Temperatures from the Available Tank Data Records

The primary contributor to the anchor bolt demand from the thermal and operating loads analysis (Deibler et al. 2007) is the mismatch between thermal expansion coefficients of the concrete and steel liner in conjunction with the specified temperature range. The original analysis very conservatively defined the maximum waste temperature at the design limit of 210°F even though the maximum waste temperatures had never come close to the design limit. In addition, the stress-free temperature for the differential thermal expansion stresses was taken as 50°F, which is conservatively low considering the natural heat of hydration that occurs during concrete curing. Therefore, the available data records on concrete curing temperatures and the historical waste temperature in the AP tanks were reviewed to define more realistic values for the stress-free and maximum waste temperature limits.
A review of the construction records found only one example of curing temperatures. It was for tank 241-AP-104, which had temperature of 81°F, 78°F, and 64°F for thermocouples embedded in the haunch during the pour. This pour coincided with coldest temperatures experienced in the 241-AP during construction. All three thermocouples showed a similar temperature rise during curing. Based on this information, the baseline (stress-free) temperature for the anchor bolts was selected as 80°F.

A review of the operating temperatures back to completion of the 241-AP Tank Farm in 1986 showed that the tanks normally operated at 80°F ± 10°F. Two exceptions to this temperature range were 241-AP-104 and 241-AP-108 when the received waste from the 242-A Evaporator raised the temperature in the lower portions of the tank to between 120°F and 130°F and the dome temperature to approximately 100°F. The heat from these transfers quickly dissipated from the tank with the temperatures returning to the previously stated range. From this review it was estimated that a maximum dome temperature of 110°F conservatively bounds the operating history of all the AP tanks.

Discussions were also held with tank farm operations staff to determine if the current operating temperature (210°F) could be reduced without impacting the future waste retrieval and treatment operations. It was concluded that a maximum waste temperature limit of 135°F is sufficiently high to not limit operations.

A.3.2.4 Thermal and Operating Loads Analysis

The primary contributor to the anchor bolt demand from the thermal and operating loads analysis (Deibler et al. 2007) is the mismatch between thermal expansion coefficients of the concrete and steel liner in conjunction with the specified temperature range ΔT = 160°F = (210°F - 50°F). The review of construction records and operational data suggests a more historically realistic range to be ΔT = 30°F (110°F – 80°F). A 60-year analysis was conducted with this temperature range.

The apparent margin for the anchor bolts with this temperature range suggested there is sufficient capacity to accommodate a wider temperature range. Another analysis, based on more realistic yet conservative tank bulk waste temperature of 135°F yielding the following ΔT = 55°F (135°F – 80°F), was conducted.

All the other model parameters – loads and material models (including concrete creep and cracking) are as documented in the Increased Liquid Level report (Deibler et al. 2007).

The secant stiffness of 65,000 lbf/in was used for the spring elements that represent the anchor bolts in shear.

A.3.2.5 Seismic Analysis

The earlier reported anchor evaluation was based on a shear response that did not credit the finite shear deformation that is known to occur in such anchor bolts under higher loads. The current approach uses the secant modulus of 65,000 lbf/in in both the TOLA and seismic analyses.
The same combinations of soil properties and concrete properties used for the initial AP level rise and baseline analysis were used for the re-analysis of the anchor bolts. That is, the four combinations to be evaluated are BES-BEC, UBS-BEC, LBS-BES, and BES-FCC.

A.3.2.6 Shift from ASME to ACI 349 Evaluation Criteria for the AP Tank Anchor Bolts

The current evaluation of the AP anchor bolts follows the procedure given in ACI 349-01, which was the original concrete code of record for the AP tanks. The initial evaluation of the AP anchor bolts was performed using ASME B&PVC evaluation criteria as recommended in Day et al. (1995). The ASME B&PVC criteria are intended for the design of concrete containments in nuclear facilities. Since 1995, the DSTs have been downgraded from PC-3 to PC-2 structures, and the application of the concrete containment code to the anchor bolt evaluation is viewed as unnecessarily restrictive. The change of criteria from ASME (specifying a 0.50 load reduction factor on ultimate) to ACI 349-01 (0.75 load reduction factor) has the effect of increasing the capacity of the AP anchors by 50%.

A.3.2.7 Combined TOLA and Seismic Results:

The maximum anchor shear deflections in both the TOLA and seismic analyses occur at the outer-most row of anchors near the transition between the dome and the haunch regions of the tank. The anchor shear deflections from the TOLA and seismic analyses were added and compared against shear displacement allowables based on both the ASME and ACI evaluation criteria. The TOLA results (with 55°F temperature range) were combined with full time history seismic results. Based on the ultimate shear deformation of 0.22 inch (Figure A.3-11), the allowable shear deformation per the ASME and ACI 349 criteria are $(0.5)(0.22 \text{ inch}) = 0.11 \text{ inch}$, and $(0.75)(0.22 \text{ inch}) = 0.165 \text{ inch}$, respectively. Table A.3-2 shows demand-to-capacity ratios using the ASME and ACI 349 criteria for the worst case Upper Bound Soil analysis. Using the ACI criteria, the demand-to-capacity ratios are below 1.0 for each of the 4 soil/concrete cases.

<table>
<thead>
<tr>
<th>Run</th>
<th>Maximum Deflection (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOLA – 55°F temp. range</td>
<td>0.068</td>
</tr>
<tr>
<td>Seismic – full time history UBS/BEC</td>
<td>0.096</td>
</tr>
<tr>
<td>Total Shear Deformation</td>
<td>0.164</td>
</tr>
<tr>
<td>ACI 349 D/C Ratio</td>
<td>0.99</td>
</tr>
<tr>
<td>ASME D/C Ratio</td>
<td>1.49</td>
</tr>
</tbody>
</table>

A.3.2.8 Sources of Analytical Conservatism

- So far, a simplified routine that smears spatial and temporal results has been used to calculate peak seismic demands. Use of a more refined methodology is estimated to reduce the seismic demand by approximately 5-10%.
• The TOLA and seismic demands reported for the AP tanks do not credit any friction between the concrete dome and the steel tank. Initial indications are that the benefit of friction may reduce the demands by approximately 5%.

• The use of the nonlinear load-displacement response of the anchor bolt as predicted by the ANSYS finite element model resulted in an allowable ultimate shear load of 14.5 kip. This is conservative in comparison to the 16.2 kip load based on the annular region of the anchor bolt as recommended by the reviewers.

• The most recent site response analyses performed at the Hanford Site Waste Treatment Plant (WTP) Site show that the currently published design spectra for the WTP Site are significantly lower than the interim spectra published in 2005 (PNNL 2007). This indicates that the governing spectra being used for the DST analysis are likely to be conservative.

A.3.2.9 Additional Considerations

• The project team has sought technical support from ACI 349 Code Committee member Richard E. Klingner. Professor Klingner is an expert in anchorage to concrete and will be contracted to assist in questions of ACI code interpretation and treatment of thermal demands on the anchor bolts. In the interim, the evaluation of the AP Tanks will proceed using conservative assumptions for the treatment of thermal demands on the anchor bolts.

• The focus so far has been on calculating the demand-to-capacity ratios for the anchor bolts. The larger question of the safety function that is performed by the anchor bolts and the degree of structural stability provided by the anchor bolts has not been addressed. If it can be shown that the system remains stable with some or all of the anchor bolts removed from the load path, this will add defense-in-depth to the arguments supporting the evaluation of the anchor bolts.

A.3.3 Conclusion

1. Due to the lower temperature ranges used to calculate the thermal demands and the switch to the ACI 349-01 code criteria the anchor bolts in the AP tank farm have adequate capacity at the 460 inch waste level.

A.3.4 References


A.4 Reviewer Comments – Kennedy, December 2007

Comments Regarding Revised
Anchor Bolt Evaluation for
241-AP Tanks with Increased Liquid Level

by

R. P. Kennedy
December 2007

A.4.1 Introduction

I have reviewed Sections 3 (Seismic Model) and 6 (Analysis Results), and Appendix B (Anchor Bolt Evaluation) of the revised Diebler, J.E., et al., Hanford Double-Shell Tank Thermal and Seismic Project-Increased Level Analysis for 241-AP Tank Farms, RPP-RPT-32237, Rev. 1, Pacific Northwest National Laboratory, December 2007. The purpose of my review was to review the revised anchor bolt evaluation of the 241-AP tanks with increased liquid level.

A.4.2 Overall Comment

I concur with the revised anchor bolt evaluation. Therefore, I concur that the Demand/Capacity (D/C) ratio for the 241-AP tank anchor bolts does not exceed unity so long as:

1. Liquid level does not exceed 460 inches,
2. Thermal increase (ΔT) of primary tank in dome region does not exceed 55°F, and
3. Seismic input does not exceed the level defined in Section 3.5 of the reviewed report

A few specific comments follow.

A.4.3 Specific Comments

A.4.3.1 Comment on Section 3.2.5 of Reviewed Report

No basis is presented on Page 3.14 for the use of an anchor bolt stiffness of 65.0 kips/inch in the seismic and thermal evaluations. This section should refer to Page B.11 of Appendix B where this shear stiffness is defined. I concur that the secant shear stiffness of 65.0 kips/inch defined on Page B.11 is reasonable.

A.4.3.2 Comment on Section 6.6 of Reviewed Report

Section 6.6 of the reviewed report does not define either the nominal ultimate shear capacities or the factored ultimate shear capacities used for the anchor bolt D/C ratios reported in this section. Based on
my understanding of Appendix B, I believe that the nominal ultimate shear displacement, \( \delta_{UN} \), and the
nominal ultimate shear capacity, \( V_{UN} \), used are:

\[
\delta_{UN} = 0.22 \text{ inch} \quad (A.4.1)
\]

\[
V_{UN} = (65 \text{ kip/in})(0.22 \text{ inch}) = 14.3 \text{ kips} \quad (A.4.2)
\]

Thus, based on a strength reduction factor \( \phi = 0.75 \), the factored \( \delta_{UF} \) and \( V_{UF} \) are:

\[
\delta_{UF} = 0.165 \text{ inch} \quad (A.4.3)
\]

\[
V_{UF} = 10.7 \text{ kips} \quad (A.4.4)
\]

I consider these values of \( \delta_{UN}, V_{UN}, \delta_{UF}, \) and \( V_{UF} \) to be reasonable based upon the material presented in
Appendix B.

Section 6.6 should explicitly define the factored \( \delta_{UF} \) and \( V_{UF} \) used in the anchor bolt D/C ratios presented
in this sections. Furthermore, Section 6.6 should refer to the sections in Appendix B where the basis for
\( \delta_{UN}, V_{UN}, \delta_{UF}, \) and \( V_{UF} \) are explicitly presented.

**A.4.3 Comments on Appendix A.3**

I concur with the anchor bolt model shown in Figure A.3-7 which was used in the finite element analysis
to determine the nominal ultimate capacity of the AP anchor bolts.

I concur that the nominal ultimate shear displacement, \( \delta_{UN} \), of 0.22 inch reported on Page B.11 is
reasonable.

I concur that the use of the strength reduction factor \( \phi = 0.75 \) discussed on Pages B.13 and B.14 is
appropriate for defining the factored load capacity.

However, I found the last paragraph on Page B.7 discussing the nominal ultimate shear capacity, \( V_{UN} \), and
the last paragraph on Page B.11 defining the secant stiffness \( k_s \), to be confusing and mutually
contradictory.

Page B.7 reports a 14 kip “plateau” shear strength which is then increased by a factor of 1.17 to obtain a
shear strength of 16.4 kips. The basis for the 1.17 increase factor is not convincingly discussed. I
presume that this increase is to account for strain hardening effects. Lastly, what is the \( V_{UN} \) being defined
at the end of the last paragraph on Page B.7?

The secant stiffness, \( k_s \), defined on Page B.11 should be based on:

\[
k_s = \frac{V_{UN}}{\delta_{UN}} \quad (A.4.5)
\]
If $V_{UN}=16.4 \text{kips}$ and $\delta_{UN}=0.22 \text{ inch}$, then:

$$k_s = \frac{16.4 \text{kips}}{0.22 \text{inch}} = 74.5 \text{ kips/\text{inch}}$$  \hspace{1cm} (A.4.6)

which is larger than the $k_s$ reported on Page B.11. If $k_s=65 \text{ kip/inch}$ and $\delta_{UN}=0.22 \text{ inch}$, then:

$$V_{UN} = (65 \text{ kips/inch})(0.22 \text{ inch}) = 14.3 \text{ kips}$$  \hspace{1cm} (A.4.7)

The problem is that $V_{UN}, \delta_{UN}$, and $k_s$ need to be mutually consistent in accordance with Equation (C.5). Since $k_s=65 \text{ kips/inch}$ was used in the Demand analyses, I recommend that $V_{UN}$ be taken as 14.3 kips in accordance with Equation (C.7). Otherwise, if $V_{UN}=16.4 \text{ kips}$ then $k_s=74.5 \text{ kips/\text{inch}}$ in accordance with Equation (C.6) and the Demand analyses should be revised using this revised $k_s$.

Finally, a consistent set of $V_{UN}, \delta_{UN}$, and $k_s$ should be defined in Appendix B and repeated in Section 6.6.
A.5 Reviewer Comments – Veletsos, March 2008

Comments Regarding Revised
Anchor Bolt Evaluation for
241-AP Tanks with Increased Liquid Level

by

A.S. Veletsos
March 2008

A.5.1 Scope of Comments

The following comments relate mainly to Sections 2.2.4.2, 2.4.1, 3.2.5, 3.5, 6.6 and Appendices A.3 and A.4 of the report by Deibler, J.E. et al, Hanford Double-Shell Tank Thermal and Seismic Project, Increased Level Analysis for 241-AP Tank Farms, RPP-RPT-32237, Rev. 1, Pacific Northwest National Laboratory, January 2008. These are the sections that deal with the demand and capacity evaluation of the anchor bolts connecting the primary tank to the concrete dome. The remaining sections of the Report are identical to those of its initial version, Rev. 0, and, with one exception, are not commented on.

A.5.2 General Comments

As previously indicated, I cannot claim any in-depth expertise on the characteristics and behavior of the type of anchor bolts used in this project. The comments that follow represent simply my best effort and judgment on the issues involved.

I concur with Dr. Kennedy’s conclusion in Appendix A.4 of the Report to the effect that the revised anchor bolt evaluation is acceptable subject to the conditions enumerated in Section A.4.2. I further concur with the view that the basis and values of the ultimate shear strength and displacement of the bolts, and of the associated stiffness used in the evaluation of their demand/capacity ratio should clearly be identified in Section 6.6 of the Report.

A.5.3 Additional Comments

A.5.3.1. On the third paragraph of p. 6.54 of the Report, the strength reduction factor specified by ACI 349 is incorrectly listed as 0.50 rather than 0.75, the latter value being correctly reported on p. 13 of Appendix A.3. This typographical error should be corrected.

A.5.3.2. The nonlinear, hysteretic, nearly elastoplastic resistance-deformation diagram of the anchor bolts in the reported analyses was approximated by a linear relationship with a stiffness equal to the secant stiffness of the actual diagram corresponding to the maximum resisting force and permissible deformation. In the evaluation of the seismic effects, I would have definitely preferred the use of the actual, nonlinear relationship. I would also have liked to see the relevant resistance-deformation diagram presented for both increasing and decreasing cycles of loading. I do realize, of course, that the analysis of
A.5.3.3. The information regarding the maximum force and deformation demands for the anchor bolts presented in the Report is not sufficiently detailed in my view. I strongly recommend that the relevant demands for both the seismic effect and the combination of the seismic and other effects be identified for at least the most highly deformed bolts at the bottom and next to the bottom rings of the dome. Additionally, to provide some insight into the sensitivity of these demands to the stiffness of the linearized version of the resistance-deformation relationship of the bolts, it is recommended that they are also evaluated and reported for a higher bolt stiffness, such as their low-amplitude, initial stiffness.

A.5.3.4. It is not clear if the value of approximately 65 kips/in for the stiffness of the linearized version of the resistance-deformation relationship of the anchor bolts was used for all bolts, or only for those on the bottom ring of the dome which will experience the largest deformations. This issue needs to be clarified. The use of the secant stiffness for all bolts has the undesirable effect of underestimating the force and deformation demands for the bolts at or near the bottom rings of the dome.

A.5.3.5. I am perplexed by the comments on pages A.4.2 and A.4.3 of Dr. Kennedy's review regarding the shear strength and secant stiffness values of the bolts used in the reported analyses. My own understanding is that the reported solutions are indeed for an ultimate shearing strength of 14.3 kips (as noted on page 10 of Appendix A.3) and for a secant stiffness of 780 kips/ft − 65 kips/in (as noted on pages 3.14 and A.3.11 of the Report). It appears that this information needs to be emphasized, preferably in the body of the Report. If, however, my interpretation is not correct, I would concur with Dr. Kennedy's recommendation.

A.5.3.6. On the issue of the uncertainties and potential conservatism involved in the reported analyses (listed on pages 6.58 and A.3.14 of the Report), I wish to note that I fully agree that the design response spectra used in the study are likely to be conservative. As previously indicated, this is expected to be especially true of the spectrum for the vertical component of shaking, the peak segment of which is considered to be much broader than that for the horizontal component (see Figs. 3-34 and 3-35 of the Report).

A.5.4 Comment on Another Issue

In Section A.5 of the Reviewer Comments presented in Appendix A of the Report, concern was expressed about the accuracy of the maximum seismic stresses reported previously for the lower knuckle of the primary tank, and some additional studies were recommended to clarify matters. Based on the information presented in Section 6.2.1 of the Report, however, this concern does not appear to have yet been addressed. If this is indeed true, it is strongly recommended that it be given the appropriate attention.
A.6 Anchor Bolt Modeling and Evaluation

DST Anchor Bolt Modeling and Evaluation
July 14, 2008
PNNL and M&D
MW Rinker, JE Deibler, KI Johnson and FG Abatt

A.6.1 Introduction

At the June 2007 review of the DST analyses, the reviewers raised concerns with the anchor bolt evaluation. The ultimate shear capacity used in the original evaluation reported in Deibler et al. (2007) was judged to be unconservative. In response, the secant stiffness representation of the anchor bolts was developed and an evaluation method based on allowable shear displacements was identified. Complete details are given in Appendix A.3 of the Increased Liquid Level report, Rev. 1 (Deibler et al. 2008).

Additional comments by the reviewers in March 2008 raised concerns over the use of a uniform anchor bolt shear stiffness over the entire radius of the dome. It was postulated that in some locations, credit was being taken for unrealized ductility. An iterative procedure that converges on matching the secant stiffness to the actual shear displacement was recommended. A representative analysis that demonstrates the use of location specific shear stiffness anchor bolts is described in this report.

A.6.2 Location Specific Anchor Bolt Stiffness

The 65 kip/in value of the secant shear stiffness of the AP anchor bolts reported in Rev. 1 of the Increased Liquid Level report (Deibler et al. 2008) was based on the estimated failure point on the shear load-deformation diagram and is a lower bound for possible secant shear moduli. Generally, the shear demand on the DST anchor bolts in the dome increases as radial distance from the dome apex increases. The use of a uniform value of the secant shear modulus that is based on the failure point of the anchors means that all anchors are assigned a lower bound shear stiffness. The difference between the assigned value of 65 kip/in and the expected value based on realized shear deformations increases for anchors closer to the dome apex.

During the March 2008 review a question was raised as to whether the above approach would provide conservative estimates of the anchor shear displacements. From a static point of view, lower shear stiffnesses will produce higher shear displacements that conservatively bound the actual displacements. However, the concern raised during the review was if an increase in anchor bolt stiffness could cause a frequency shift in the system dynamic response that could amplify the anchor bolt response.

To investigate this possibility, the reviewers recommended an iterative procedure to more accurately match the shear stiffness with the actual shear deformation in the anchor bolts on a row-by-row basis.

One iteration towards the radial location specific anchor stiffness was conducted to evaluate the use of uniform stiffness anchor bolts. The combined TOLA + seismic shear displacements for each row of
anchor bolts from the uniform 65 kips/in stiffness analysis of the Upper-Bound Soil, Best Estimate Concrete were overlaid on the predicted shear load-displacement curve for the AP anchor bolts. The secant modulus for each point is then used as the shear stiffness at that location for the next iteration of the analysis. Figure A.6-1 illustrates the procedure graphically.

The stiffness at each location is greater than the nominal 65 kips/in. As expected, the resulting combined shear displacements decrease. This procedure could be repeated until convergence of the anchor bolt stiffness is achieved at each specific location. However, a demand/capacity evaluation at the end of this first iteration demonstrates the conservative results given by the uniform 65 kips/in shear stiffness. Figure A.6-2 shows the demand/capacity evaluation for the nominal and first iteration shear stiffness. The anchor bolts pass the evaluation at the nominal 65 kips/in shear stiffness (D/C ratio equal to 0.99 at the outer-most anchor). The more refined analysis gives a maximum D/C ratio of 0.53. If a second iteration were analyzed this ratio would drop even further.
A.6.3 Conclusion

The secant modulus anchor bolt modeling is a viable method of accommodating the nonlinear load-displacement response. The assignment of a uniform lower bound secant shear modulus to all of the anchor bolts provided a very conservative estimate of the shear deformations relative to a more refined row-by-row assignment of shear stiffnesses based on actual deformations. The higher location specific shear stiffnesses resulted in a decrease in shear deformation under dynamic seismic loading.

A.6.4 References

A.7 Seismic Model Primary Tank Lower Knuckle Mesh Resolution

Seismic Model Primary Tank Knuckle Stress Evaluation

May 15, 2008
M&D Professional Services, Inc
KL Stoops, FG Abatt, M Meyer

A.7.1 Introduction and Purpose
The complexity of the global DST seismic model required that some mesh resolution be sacrificed in the lower knuckle region of the primary tank. The purpose of this appendix is to establish a factor that will be applied to the global seismic model lower knuckle stress components to account for loss of accuracy due to the limited mesh resolution (discretization error). This factor can be applied to the lower knuckle stress components from the global seismic model before combining the results with the TOLA model stresses and performing the primary tank ASME code evaluation. Although this Appendix focuses on the AY configuration, both AY and AP tank are addressed using a common methodology.

A.7.2 Background
A study of the effect of mesh resolution on the stresses in the lower knuckle of the primary tank in the seismic model was documented in Appendix A of Deibler et al. (2008). The important conclusions of that study were that increasing the mesh resolution in the lower knuckle from two elements to eight elements produced sufficiently accurate stresses, and that a single factor of 2.0 applied to the meridional and hoop stress components was more than enough to account for loss of mesh resolution in the global model.

Further investigation was motivated by a comment from reviewers R.P. Kennedy and A.S. Veletsos during a July 2007 project review meeting. The text of the comment appears below in italics.

The lower knuckle of the primary tank is too crudely modeled in the global analysis of the soil-structure-waste system to accurately define the peak values of the stresses induced in it. To provide for this inadequacy, the maximum values of the stresses determined in the global analysis for this region were increased by a factor of 2.0. We understand that this factor was based on the increase in maximum stresses determined for a refined model of the knuckle considering the effects of the hydrostatic pressures only.

While this amplification factor may indeed be adequate for the hydrostatic effects, we are concerned that it may not be adequate for the seismically induced effects. As the seismic loading, unlike the hydrostatic, induces a substantive axial force in the
tank-wall, we expect the increase of the bending stresses in the knuckle to be larger for the seismic loading than for the hydrostatic.

We recommend that the stresses in the refined local model of the lower knuckle be determined using the maximum values of the boundary forces and of the associated pressures computed in the seismic analysis of the global model. A comparison of the absolute maximum values of the resulting stresses with those obtained by the global model would then provide a more defensible estimate of the amplification factor that should be applied to the seismically induced effects determined with the global model.

Alternatively—although this option is not as desirable—an approximate estimate of the requisite amplification factor may be determined by a static analysis similar to the one used, provided the vertical and circumferential distributions of the pressures considered are representative of those of the impulsive component of the seismically induced pressures.

Considering that some of the reported analyses indicate the absolute maximum stresses to occur in the base plate, slightly beyond the lower end of the knuckle, it is important that the local model does include this region.

The approach to the evaluation differs from that reported in Revision 0 of this Appendix in the following important aspects:

1. The focus of the evaluation is the differences in results between the global seismic model (with two elements in the knuckle) and the results the global seismic model would have if a more accurate eight element mesh had been used in the knuckle.
2. The axisymmetric study model used in Revision 0 was abandoned in favor of a slice model so that the global model and study model used the same element types. The slice study model is based directly on the global seismic model.
3. The adjustment factor is based on the differences in results between the slice study model with two elements in the knuckle vs. with eight elements in the knuckle. The previous approach compared the results from two different models: the global seismic model, and the TOLA model.
4. Because the slice study model is based directly on the global seismic model and uses the same element types, it was judged to be unnecessary to “benchmark” the study model against the thermal and operating loads analysis (TOLA) model. Thus, the TOLA model is no longer referenced in this evaluation.
5. Based on the results from Revision 0 and the mesh refinement in the thermal and operating loads analysis (TOLA) model, it was determined that having eight elements in the knuckle provides sufficient mesh refinement.
6. The comparisons between the global seismic model and slice study model are performed using loads representative of seismic loads only in the absence of gravity, since these are the loads that will be combined with the TOLA results.
7. The effects of axial loads in the tank will be included in the evaluation.
8. The configuration of the AP tanks as well as the AY-based baseline model will be addressed in this evaluation.
A.7.3 References


A.7.4 Methodology

A set of load cases will be indentified to satisfy the comments (above). The load cases will apply representative seismic axial force and waste pressure loads. To speed runtime and reduce postprocessing, the loads will be applied statically to a simplified model. The seismic only results will be obtained through the same procedure as for the global seismic model, which is to solve with combined gravity + seismic and then subtract the gravity portion (solved independently) via postprocessing. The differences in the results between the different mesh densities will be examined and an adjustment factor (ratio) will be determined. The method of combination of the global seismic model results to the TOLA model results will be prescribed, and a single bounding adjustment factor will be determined for use in the combination.

A.7.5 Model Descriptions

A.7.5.1 DST Primary Tank Knuckle Geometry

The DST primary tanks have a 12-inch radius knuckle region that joins the tank cylindrical sidewalls to the tank bottom plates. The bottom of the primary tank is supported below by insulating concrete. The insulating concrete extends past the bottom tangent of the knuckle, although the knuckle will not contact the insulating concrete outside of the tangent unless significant deflection occurs. Typical knuckle geometry is shown in Figure 0.7-3.
A.7.5.2 Global Seismic Model Description

A complete description of the AY-based generic seismic model can be found in Section 3.0 of Abatt (2008). A view of the primary tank knuckle and insulating concrete from the global model is shown as Figure 0.7-4.
Figure 0.7-4. Primary Tank Knuckle and Insulating Concrete from Global Seismic Model.

The property configuration used for this evaluation is AY tank Best Estimate Soil, Best Estimate Concrete, Lower Bound Anchor Bolt Secant Modulus (AY-BES-BEC-LBmod).

A.7.5.3 Slice Study Model

The slice model is based directly on the global seismic model, but with the following simplifications and modifications:

- To create the study model, the global seismic model is generated, and then a 1 element wide slice is selected for the solution.
- To improve element aspect ratios in the primary tank knuckle at higher mesh resolutions, the mesh is modified to provide an element width of 2 degrees, instead of 9 degrees. The free mesh in the center region of the model is also adjusted to accommodate the narrower slice. Other than the knuckle itself, this is the only mesh change.
- The waste is removed from the study model. Loads from the waste will be simulated as pressures on the inner surface of the primary tank.
- Symmetry boundary conditions are applied at the slice sides (circumferential) and at the center of the tank (radial).
- The soil boundary conditions are distributed among nodes that were previously coupled to a master node.
- The solution is performed statically.
The purpose of this investigation is to address the local response of the knuckle, not global behavior of the tank. Although the slice model does not capture full three-dimensional effects, it is sufficient for studying the effects of mesh resolution in the lower knuckle.

Figure 0.7-5 shows a full element plot of the study model, and Figure 0.7-6 shows a close-up view of the knuckle region of the study model.
A.7.6 Load Application and Load Case Definition

Per the comments made by Kennedy and Veletsos (see 0), seismically induced axial and waste pressure loads on the primary tank will be addressed. These loads will be addressed in the following load cases:

1) Seismic waste pressure on primary tank. Waste pressure is taken from the tables of theoretical waste pressure found in Section 8.2 of Abatt (2008). The theoretical values are used for simplicity (e.g. actual results are non-uniform and harder to apply). The theoretical values are compared to the global seismic model results in Abatt (2008), and are found to be similar to the global seismic model FEA results.

2) Axial loads in the primary tank wall. The axial load is applied to the model based on the meridional midplane stress values found in Deibler et al (2007). A vertical force will be applied at approximately half height on the primary tank wall such that the resulting stress in the primary tank wall is similar to the meridional midplane stress values found in Deibler et al (2007). The meridional stress is assumed to be completely caused by the seismic structural forces (e.g. overturning). The values reported in Deibler et al (2007) are absolute value; therefore the range of loads is potentially reversing. Two opposing axial load subcases will be considered:
   a. Axial up, based on positive maximum global seismic model stress results (Abatt 2008) from the primary tank wall.
   b. Axial down, based on negative maximum global seismic model stress results (Abatt 2008) from the primary tank wall.

An additional gravity case considering dead weight with waste hydrostatic fluid effects due to gravity will be run as a non-seismic baseline. The load cases will be run with gravity effects (dead weight and waste...
hydrostatic fluid effects due to gravity) included, and the results of the gravity case will be subtracted from the seismic results. This methodology is the same approach used for producing the global seismic results.

All loads will be applied statically as either a surface pressure or point forces resulting in membrane stress.

A.7.6.1 Limit of Knuckle Mesh Influence

Results will be presented in the knuckle region and adjacent elements. The limits of influence from the knuckle mesh will be demonstrated by convergence in the results. Convergence is defined as when the relative difference is small, or the overall magnitude is small compared to the maximum values used for calculation of the factor. Beyond the zone of influence no adjustment factor is required.

A.7.6.2 Methodology Differences and Sensitivity to Applied Loading

The global seismic model is evaluated with dynamic loading, and the study model is evaluated with statically applied loads. For a single load state (as defined by the load cases above), a set of static solutions provide sufficient data on the response of the model to determine the relative differences due to the knuckle mesh.

The loads used in the study model are based on the results provided in Abatt (2008). Those results are maximum absolute values taken from the global seismic model time history analysis. Therefore, the following variations are inherent to this bounding value approach:

- The tank experiences a range of loads that are not reported in detail (absolute maximums only)
- Co-existence of multiple loads (e.g. waste pressure and axial loading) at any place or time cannot be determined without more extensive investigation and correlation

The variations are addressed by determining the sensitivity of the model to the loading. The load will be varied to demonstrate the applicability of the adjustment factor over the expected range of magnitude for the given load type. If the response to the applied loads is nearly linear then the adjustment factor is largely independent of the applied load magnitude. The adjustment factor may then be applied to a range of loads, encompassing the variations.

A.7.7 Definition of Adjustment Factor

The global seismic model has inadequate mesh resolution in the primary tank knuckle. In order to make sure that conservative stresses are presented for the seismic analyses, a scaling factor needs to be determined to account for the lower mesh resolution in the global seismic model.

In Deibler et al 2008, the seismic results from the 2 element global seismic model are combined with the results from the 8 element TOLA model to perform an ASME code evaluation of the primary tank. In this process, an adjustment factor must be applied to the global seismic model results to compensate for the lack of mesh resolution in the global seismic model.
A.7.7.1 Calculation of the adjustment factor

The factor is based on the maximum of the absolute values of meridional and hoop stresses from the study model with 2 and 8 element meshes. The factor is determined by the following steps (performed in a spreadsheet):

1. List stress results by element
2. The knuckle zone of influence is determined by reviewing convergence of the different mesh results.
3. Only results within the zone of influence are applicable for factor use. However, to compare the full range of knuckle results, calculation of the factor must include an element at a common location on each end, regardless of the elements to which the factor is to be applied. See the example below for further explanation.
4. Take the absolute value of the results.
5. Find the maximum of the absolute values for both 2 element and 8 element results (independent of location)
6. Divide the pair of results found above: 8 element divided by 2 element (independent of location)

It is also recognized that other comparison algorithms could be used, but this recommendation uses the method described here.

The calculation of the adjustment factors for each load case is summarized in a table following the graphical presentation of the results.

The adjustment factor and the zone of influence will be determined for each load case. After that, a single bounding factor and zone of influence will be concluded.

A.7.7.2 Example factor calculation using identical results:

In this example, and in the actual results following, the results used are obtained from elements, and therefore located at the element centroid. The plots will show straight line interpolation between data points to aid comparison and reveal trends. The X-axis on all plots is an arbitrary sequence that indicates the progression of elements from the wall to the floor, where the knuckle extends from element 1 to 8. Additional data points on either side of the knuckle are included to show the limits of the knuckle mesh influence.
Knuckle elements are highlighted. The 2 element mesh does not align with the 8 element mesh, therefore the location is noninteger. Elements 0 and 9 (and beyond) have the same location.

<table>
<thead>
<tr>
<th>8 element</th>
<th>Stress</th>
<th>2 element</th>
<th>stress</th>
</tr>
</thead>
<tbody>
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<td>element</td>
<td>0</td>
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<tr>
<td></td>
<td>1</td>
<td>1</td>
<td>2.5</td>
</tr>
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<td>6.5</td>
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<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
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<td></td>
</tr>
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</tr>
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</tr>
<tr>
<td></td>
<td>9</td>
<td>9</td>
<td>&lt;- max</td>
</tr>
</tbody>
</table>

Max abs value 9.00  Max abs value 9.00  Factor

The factor is $\frac{8e}{2e} = \frac{9}{9} = 1.0$.

Note that if the common element at each end is not included, the factor is $\frac{8}{6.5} = 1.23$, which is clearly incorrect, since the data trend is identical. The common element must be included to ensure that no difference in alignment of the element centroids inadvertently leads to a different range of data being considered (in this example 1 to 8 vs 2.5 to 6.5).
A.7.7.3 Application of the adjustment factor

The method of combining the results must be consistent with the method of calculating the adjustment factor. The adjustment factor must be applied to the global seismic model results within the knuckle zone of influence. The single bounding factor and zone of influence must be used when the loading involves an indeterminate combination of the load types addressed in the load cases.

The dead weight portion of the seismic load from the global seismic model is subtracted from the results before combination; therefore an adjustment factor is applied to seismic loads for a consistent approach.

The recommended method for mapping the global seismic model results to the TOLA model is outlined below. This simplified, conservative method is consistent with the use of a single bounding factor. Follow the process for each stress component (hoop, meridional, top/bottom/membrane, etc.)

1. List the results for the global seismic model elements
2. Determine the maximum stress within the given zone of influence
3. Multiply the above maximum stress by the adjustment factor
4. Add the resulting single value to the TOLA model elements within a location range equal to the zone of influence.

A.7.8 Results

A.7.8.1 Format for presentation of results

Results will be summarized and presented in plots showing primary tank meridional and hoop stresses in the knuckle region. Meridional and hoop stresses will be labeled SM and SH, respectively. The top, middle, and bottom shell surface from which the results are retrieved will be identified by _T, _M, and _B respectively. The stress label will be followed by an indicator of the number of elements (e.g. “2e”) and a label for the load case. Finally, an additional number (if present) at the end indicates a multiplier on the nominal load. For example, the label “SM_T 8e Pseis_AY 2” represents meridional stress at the top surface on a model with a 8 element mesh, under seismic waste pressure for the AY configuration, using twice the nominal load.

A.7.8.2 Load Case 1: Pressure Loading

The study model was subjected to a pressure load to simulate the effect of the waste during a seismic event. The pressures are taken from the tables of theoretical waste pressure found in Section 8.2 of Abatt (2008). The pressures used the AY tank waste depth of 422 inches with a specific gravity of 1.7. The pressure is applied to the primary tank as a pressure gradient over the depth of the waste. To show the sensitivity of the model to the load, additional loads of one-half and double the nominal loading are applied to the study model. The load case also includes gravity effects (dead weight and waste hydrostatic fluid effects due to gravity), which will be subtracted in post processing.
Table A.7 -1. Theoretical Waste Pressures, BES-BEC (copied from Section 8.2 of Abatt (2008))

<table>
<thead>
<tr>
<th>Waste Height Ratio</th>
<th>Waste Height</th>
<th>Hydrostatic (psi)</th>
<th>Imp (psi)</th>
<th>Conv (psi)</th>
<th>Vert (psi)</th>
<th>Dyn (psi)</th>
<th>Dyn (SRSS) (psi)</th>
<th>Theor Max</th>
<th>Theor Min</th>
<th>Theor Max (SRSS)</th>
<th>Theor Min (SRSS)</th>
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<td>0.97</td>
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<td>1.38</td>
<td>0.26</td>
<td>2.01</td>
<td>1.77</td>
<td>2.70</td>
<td>-1.32</td>
<td>2.46</td>
<td>-1.08</td>
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<tr>
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<td>1.43</td>
<td>4.51</td>
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<td>2.05</td>
<td>5.76</td>
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<td>7.99</td>
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<td>0.80</td>
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<td>1.57</td>
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<td>23.86</td>
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<td>20.69</td>
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<td>0.52</td>
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<td>6.81</td>
<td>0.6</td>
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<td>12.94</td>
<td>9.16</td>
<td>36.74</td>
<td>9.57</td>
<td>31.97</td>
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<td>24.40</td>
<td>6.86</td>
<td>0.49</td>
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<td>9.26</td>
<td>37.48</td>
<td>11.32</td>
<td>33.66</td>
<td>15.14</td>
</tr>
</tbody>
</table>

Figure 0.7-5. Element Plot Showing Applied Loads
A.7.8.3 Results

The meridional and hoop stresses for the study model with several mesh refinements are presented in Figure 0.7-7 through Figure 0.7-12.

Figure 0.7-7: Knuckle Meridional Stress – Outside Surface (Away from Waste)
Figure 0.7-8. Knuckle Meridional Stress – Mid-plane Surface

Knuckle elements (wall to floor), and 3 adjacent elements at each end

Pseis M_M

Stress (KSF)

Knuckle elements (wall to floor), and 3 adjacent elements at each end

SM_M2e Pseis_AY

SM_M8e Pseis_AY
Figure 0.7-9. Knuckle Meridional Stress – Inside Surface (Near Waste)
Figure 0.7-10. Knuckle Hoop Stress – Outside Surface (Away from Waste)
Figure 0.7-11. Knuckle Hoop Stress – Mid-plane Surface

Knuckle elements (wall to floor), and 3 adjacent elements at each end.
A.7.8.4 Seismic Pressure Stress Factors

As shown in Figure 0.7-7 through Figure 0.7-12, the results converge at the first element outside the knuckle. The zone of influence is thus limited to the knuckle itself.

Table A.7-2. List of results for 2x load with scale factor calculation

<table>
<thead>
<tr>
<th></th>
<th>SM_T</th>
<th>SM_M</th>
<th>SM_B</th>
<th>SH_T</th>
<th>SH_M</th>
<th>SH_B</th>
</tr>
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<tbody>
<tr>
<td>8e Pseis_AY 2</td>
<td>2883.80</td>
<td>43.96</td>
<td>2795.90</td>
<td>2895.90</td>
<td>2482.30</td>
<td>2068.80</td>
</tr>
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<td>8e Pseis_AY 2X (scaled)</td>
<td>2883.60</td>
<td>43.99</td>
<td>2795.80</td>
<td>2895.20</td>
<td>2481.40</td>
<td>2067.60</td>
</tr>
<tr>
<td>Scale factor</td>
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<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Table A.7-3. List of results for 0.5x load with scale factor calculation

<table>
<thead>
<tr>
<th></th>
<th>SM_T</th>
<th>SM_M</th>
<th>SM_B</th>
<th>SH_T</th>
<th>SH_M</th>
<th>SH_B</th>
</tr>
</thead>
<tbody>
<tr>
<td>8e Pseis_AY .5</td>
<td>720.90</td>
<td>10.98</td>
<td>698.95</td>
<td>723.80</td>
<td>620.35</td>
<td>516.80</td>
</tr>
<tr>
<td>8e Pseis_AY .5X (scaled)</td>
<td>720.90</td>
<td>11.00</td>
<td>698.95</td>
<td>723.80</td>
<td>620.35</td>
<td>516.80</td>
</tr>
<tr>
<td>Scale factor</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>
The stress scales linearly with the load. Thus, a single adjustment factor may be used, according to methodology described in 0.

Table A.7-4. List of results with adjustment factor calculation

<table>
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<tr>
<th>Study</th>
<th>Pseis_AY</th>
<th>Element</th>
<th>SM_T</th>
<th>SM_M</th>
<th>SM_B</th>
<th>SH_T</th>
<th>SH_M</th>
<th>SH_B</th>
</tr>
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<tbody>
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<td>2.50</td>
<td>7917</td>
<td>997.6</td>
<td>20.984</td>
<td>-955.6</td>
<td>1091.5</td>
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<td>6.50</td>
<td>8007</td>
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<td>21.013</td>
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<td>561.6</td>
<td>110.34</td>
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<tr>
<td></td>
<td>value</td>
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<td>21.20</td>
<td>1353.30</td>
<td>1091.50</td>
<td>778.40</td>
<td>628.80</td>
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</table>

<table>
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<tr>
<th>Study</th>
<th>Pseis_AY</th>
<th>Element</th>
<th>SM_T</th>
<th>SM_M</th>
<th>SM_B</th>
<th>SH_T</th>
<th>SH_M</th>
<th>SH_B</th>
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<th>factors (max)</th>
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<tr>
<td>8e</td>
<td></td>
<td>1.03, 1.33, 1.59, 1.64</td>
</tr>
</tbody>
</table>

For seismic meridional stresses in the knuckle, the ratio of the 8 element mesh to the 2 element mesh produces a correction factor of 1.04. For seismic hoop stresses in the knuckle, the ratio of 8 element mesh to the 2 element mesh produces a correction factor of 1.64. To ensure conservative analyses, the primary tank knuckle seismic meridional and hoop stresses should both receive a stress factor of at least 1.64.

A.7.8.5 Load Case 2: Upward Axial Force

A positive vertical force will be applied at approximately midway up the primary tank wall such that the resulting stress in the primary tank wall is similar to the meridional midplane stress values found in
Deibler et al 2008. To show the sensitivity of the model to the load, additional loads of one-half and double the nominal loading are applied to the study model. The load case also includes gravity effects (dead weight and waste hydrostatic fluid effects due to gravity), which will be subtracted in post processing.

The wall extends from path location 508” to 851”. At the nominal load magnitude, the meridional midplane stress in the five primary tank wall elements above the knuckle in the study model is 90 ksf, which is a reasonable match within the range of values shown in Table A.7-5 for that location.

Table A.7-5. Excerpt from Appendix F AY-2D-NL-BES-BEC Pri Tank Stress Seismic Only.xls

<table>
<thead>
<tr>
<th>M&amp;D Starting Element No.</th>
<th>Path (in.)</th>
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A.7.8.6 Results

The meridional and hoop stresses for the study model with several mesh refinements are presented in Figure 0.7-14 through Figure 0.7-19.
Figure 0.7-14. Knuckle Meridional Stress – Outside Surface (Away from Waste)
Figure 0.7-15. Knuckle Meridional Stress – Mid-plane Surface
Figure 0.7-16. Knuckle Meridional Stress - Inside Surface (Near Waste)
Figure 0.7-17. Knuckle Hoop Stress – Outside Surface (Away from Waste)
Figure 0.7-18. Knuckle Hoop Stress – Mid-plane Surface

Knuckle elements (wall to floor), and 3 adjacent elements at each end.
A.7.8.7 Seismic Axial Force Stress Factors

As shown in Figure 0.7-14 through Figure 0.7-19, the results converge at the first element outside the knuckle. The zone of influence is thus limited to the knuckle itself.

Table A.7-6. List of results for 2x load with scale factor calculation

<table>
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<th>SH_M</th>
<th>SH_B</th>
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<td>3878.14</td>
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<td>6093.20</td>
<td>165.26</td>
<td>6282.00</td>
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<td>1.04</td>
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Table A.7-7. List of results for 0.5x load with scale factor calculation

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<th>SH_M</th>
<th>SH_B</th>
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<td>1525.20</td>
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<td>1572.30</td>
<td>727.50</td>
<td>842.80</td>
<td>958.00</td>
</tr>
<tr>
<td>8e Forc+ AY .5X(scaled)</td>
<td>1523.30</td>
<td>41.32</td>
<td>1570.50</td>
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The stress scales approximately linearly with the load. Thus, a single adjustment factor may be used, according to methodology described in 0.

Table A.7-8. List of results with adjustment factor calculation

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<th>SM_B</th>
<th>SH_T</th>
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<th>SH_B</th>
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<td>521.8</td>
<td>82.169</td>
<td>-357.5</td>
<td>-1064.7</td>
<td>-1170.6</td>
<td>-1276.63</td>
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Max abs value  1591.40  92.51  1722.20  1368.20  1170.60  1422.57

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<th>SM_B</th>
<th>SH_T</th>
<th>SH_M</th>
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<td>-1394.9</td>
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<td>1448.2</td>
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</table>

Max abs value 3046.60  92.11  3141.00  1456.30  1687.00  1917.60

For seismic meridional stresses in the knuckle, the ratio of the 8 element mesh to the 2 element mesh produces a correction factor of 1.91. For seismic hoop stresses in the knuckle, the ratio of 8 element mesh to the 2 element mesh produces a correction factor of 1.44. To ensure conservative analyses, the primary tank knuckle seismic meridional and hoop stresses should both receive a stress factor of at least 1.91.

A.7.8.8 Load Case 3: Downward Axial Force

The loading is the same as for upward axial force, except the sign of the vertical force is negative.
A.7.8.9 Results

The meridional and hoop stresses for the study model with several mesh refinements are presented in Figure 0.7-14 through Figure 0.7-19.
Figure 0.7-21. Knuckle Meridional Stress – Outside Surface (Away from Waste)
Figure 0.7-22. Knuckle Meridional Stress – Mid-plane Surface
Figure 0.7-23. Knuckle Meridional Stress - Inside Surface (Near Waste)
Figure 0.7-24. Knuckle Hoop Stress – Outside Surface (Away from Waste)
Figure 0.7-25. Knuckle Hoop Stress – Mid-plane Surface
A.7.8.10 Seismic Axial Force Stress Factors

As shown in Figure 0.7-21 through Figure 0.7-26, the results converge at the first element outside the knuckle. The zone of influence is thus limited to the knuckle itself.

Table A.7-9. List of results for 2x load with scale factor calculation

<table>
<thead>
<tr>
<th></th>
<th>SM_T</th>
<th>SM_M</th>
<th>SM_B</th>
<th>SH_T</th>
<th>SH_M</th>
<th>SH_B</th>
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</thead>
<tbody>
<tr>
<td>8e Forc-_AY 2</td>
<td>6079.50</td>
<td>165.20</td>
<td>6269.10</td>
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<td>3376.90</td>
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<td>8e Forc-_AY 2X (scaled)</td>
<td>6102.00</td>
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Table A.7-10. List of results for 0.5x load with scale factor calculation

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<th>SM_B</th>
<th>SH_T</th>
<th>SH_M</th>
<th>SH_B</th>
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</thead>
<tbody>
<tr>
<td>8e Forc-_AY .5</td>
<td>1523.20</td>
<td>41.31</td>
<td>1575.40</td>
<td>726.60</td>
<td>841.60</td>
<td>956.60</td>
</tr>
<tr>
<td>8e Forc-_AY .5X (scaled)</td>
<td>1525.50</td>
<td>46.05</td>
<td>1572.70</td>
<td>727.20</td>
<td>842.40</td>
<td>957.60</td>
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<td>1.00</td>
<td>1.00</td>
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The stress scales linearly with the load. Thus, a single adjustment factor may be used, according to methodology described in 0.

Table A.7-11. List of results with adjustment factor calculation

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<tr>
<td>6.50</td>
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<tr>
<td>9</td>
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</table>

Max abs value: | 1592.2 | 92.51 | 1723.00 | 1365.10 | 1169.60 | 1420.70 |

<table>
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<th>Study 8e Forc_AY</th>
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<tr>
<td>7</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>9</td>
</tr>
</tbody>
</table>

Max abs value: | 3051.00 | 92.11 | 3145.40 | 1454.40 | 1684.60 | 1915.20 |

| Forc_AY factors | 1.92 | 1.00 | 1.83 | 1.07 | 1.44 | 1.35 |

For seismic meridional stresses in the knuckle, the ratio of the 8 element mesh to the 2 element mesh produces a correction factor of 1.92. For seismic hoop stresses in the knuckle, the ratio of 8 element mesh to the 2 element mesh produces a correction factor of 1.44. To ensure conservative analyses, the primary tank knuckle seismic meridional and hoop stresses should both receive a stress factor of at least 1.92.

A.7.9 AY vs. AP

The AP tank configuration is examined using the same methodology as AY tank. The applied loads are derived from AP tank waste properties (Abatt 2008) and AP tank global seismic model results (Abatt...
2008. In the interest of brevity, only tabular results with adjustment factor calculation are presented for the AP tank configuration.

### A.7.9.1 Load Case 1: Pressure Loading

#### Table A.7-12. List of results for 2x load with scale factor calculation

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<th>SH_T</th>
<th>SH_M</th>
<th>SH_B</th>
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<tr>
<td>8e Pseis_AP 2</td>
<td>671.90</td>
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#### Table A.7-13. List of results for 0.5x load with scale factor calculation

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#### Table A.7-14. List of results with adjustment factor calculation

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## Study 8e Pseis _AP

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<th>Forc_AP factors (max)</th>
<th>Forc_AP factors (max)</th>
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### A.7.9.2 Load Case 2: Upward Axial Force

Table A.7-15. List of results for 2x load with scale factor calculation

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Table A.7-16. List of results for 0.5x load with scale factor calculation

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### A.7.9.3 Load Case 3: Downward Axial Force

#### Table A.7-18. List of results for 2x load with scale factor calculation

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Table A.7-19. List of results for 0.5x load with scale factor calculation

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Table A.7-20. List of results with adjustment factor calculation

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A.7.9.4 Summary of AP tank configuration

The general trend for AP tank results is similar to AY tank. The AP tank does not reach convergence of the 2 element and 8 element results until the second element outside of the knuckle.

The stress scales approximately linearly with the load. Thus, a single adjustment factor may be used, according to methodology described in 0.

For seismic meridional stresses in the knuckle, the ratio of the 8 element mesh to the 2 element mesh produces a correction factor of 2.0. For seismic hoop stresses in the knuckle, the ratio of 8 element mesh to the 2 element mesh produces a correction factor of 1.97. To ensure conservative analyses, the primary tank knuckle seismic meridional and hoop stresses should both receive a stress factor of at least 2.0.

A.7.10 Summary and Conclusion

This appendix establishes a factor that will be applied to the global seismic model lower knuckle stress components to account for loss of accuracy due to the limited two element mesh resolution. This factor will be applied to the lower knuckle stress components from the global seismic model before combining the results with the TOLA model stresses, which uses a more accurate eight element mesh resolution.

In comments on the previous revision of this appendix, reviewers R.P. Kennedy and A.S. Veletsos recommended that the adjustment factor consider seismically-induced effects, specifically seismic waste pressure and axial loads in the primary tank wall. This revision is substantially rewritten based upon the comments.

The effects of the knuckle mesh and seismic loading are evaluated using a simplified slice model based directly on the global seismic model. Two instances of the study model were used; a two element and an eight element knuckle mesh resolution. Three load cases were defined to evaluate the load conditions indicated in the above comments. The load cases are run with a range of load magnitudes found in the global seismic model.

The results of the evaluation showed:

- The knuckle zone of influence is limited to the knuckle itself (AY) or within 1 element of the knuckle (AP). Thus, the effect of the knuckle mesh resolution (and the adjustment required) is localized.
- The stress scales approximately linearly with the load. Thus, a single adjustment factor may be used because the single factor is applicable over the entire range considered. The broad applicability of the factor covers uncertainties in the magnitude of the load.

The adjustment factor is based on the maximum of the absolute values of meridional and hoop stresses from the study model with 2 and 8 element meshes.

An adjustment factor of at least 2.0 is recommended to be applied to the meridional and hoop stresses for the primary tank lower knuckle of the global seismic model. The adjustment factor need only be applied
to the knuckle zone of influence elements, which is at most one element beyond the knuckle. The applicable elements are list below:

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A.7.11 Application to Increased Liquid Level Analysis for AP Tanks

There are differences in the interpretation of the results of the primary tank lower knuckle study. While the study concluded that “An adjustment factor of at least 2.0 is recommended to be applied” to the seismic results of the primary tank stress in the lower knuckle, a factor of 3.0 was used for combining with the TOLA results for the subsequent ASME evaluation.
A.8 Reviewer Comments – Veletsos, August 2008

Comments Regarding Revised
Anchor Bolt Evaluation for
241-AP Tanks with Increased Liquid Level

by

A.S. Veletsos
Via e-mail
August 12 2008

Following, at long last, are my comments on the report on Anchor Bolts Modeling.

The issuance of this report in its present form would be totally acceptable to me. I would, however, like to add the following remarks, and leave it up to you and your associates to decide if any adjustments would be desirable in response to them.

There were two issues mentioned on this topic in our teleconference of March 25, 2008: First, that increasing the flexibility of the anchor bolts may decrease rather than increase their maximum dynamic deformations; and second, that considering the stiffness or flexibility of all bolts to be the same is likely to underestimate the maximum deformations of those in the lower rows compared to those in the upper rows.

For reasons that I do not quite understand but I fully accept, the results of the more extensive study of anchor bolts had already demonstrated that, at least for the conditions relevant to the project, my view on the first issue was not correct. On the other hand, the view on the second issue is demonstrated to have been right by the results of the present study. It is worth noting in this regard that, although of significantly lower values, the ordinates of the curve in Fig. 2 of the Report for bolts with the realistic, differing effective stiffness increase much more rapidly with increasing distance from the crown than do those of the curve for bolts of the same stiffness. Specifically, whereas the ratio of the ordinates of the curves for bolts of the same effective stiffness at distances of roughly 260 in. and 50 in. from the crown is approximately 0.38 / 0.12 = 3.2, for the bolts of variable stiffness, it is 0.1 / 0.02 = 5. More importantly, at the distances of about 440 in. and 50 in. from the crown, the corresponding ratios are approximately 1.0 / 0.12 = 8.3 and 0.52 / 0.02 = 26, respectively.

I hope that these brief comments prove helpful.
A.9 Reviewer Comments – Klingner, September 2008

COMMENTS ON THE TREATMENT OF ANCHORS IN ANALYSES OF HANFORD DOUBLE-SHELL TANKS

Richard E. Klingner, PE
Austin, TX
September 2008

A.9.1 Introduction

Pacific Northwest National Laboratories (PNNL) and M&D Professional Services (M&D) are conducting analyses of the Hanford Site Double-Shell Tanks (DSTs) as part of the DST Integrity Project. The thermal and operating loads (TOLA) analysis is being performed by PNNL and the seismic analysis is being performed by M&D. The computer models used for the seismic analyses are distinct from the computer models used for the TOLA analyses, and results from the two models have been superposed.

Among the critical components of the DST structure are the anchors that connect the steel dome of the primary tank to the concrete dome of the vault. For the analyses noted above, the nonlinear response of these embedded anchors has been simulated using an equivalent linear elastic modulus (secant modulus) that is based on the estimated maximum deformation capacity of the anchors. Of particular interest is the development of the equivalent linear elastic modulus representing the shear response of the anchors.

The equivalent linear elastic moduli in shear and tension that were used in the evaluation of the DST anchor bolts were developed based on a combination of test results, extrapolations of test results, and analytical predictions. This paper has three purposes. The first is to review and assess the underlying technical justification for the combination of TOLA and seismic demands on the anchors when those anchors are simulated using an equivalent linear modulus in the separate models. The second is to assess the ultimate shearing deformation capacity used in the DST anchor evaluation. The third is to comment on the relationship between the approach used in the DST anchor evaluation and the current activity of ACI Committee 349 (Concrete Nuclear Structures).

A.9.2 Superposition of Seismic and TOLA Results

Because the goals and technical constraints of the seismic and TOLA models were significantly different, the two analyses have been conducted separately using distinct models and the results then combined. Such superposition is convenient because it reduces computational effort. It also eliminates the possibility of numerical instability associated with spurious coupling of seismic and TOLA solutions that might in fact be uncoupled.

Such superposition is valid, provided that the following conditions are met:
1) The seismic and TOLA responses must each be essentially linear elastic;

2) The secant stiffnesses used for the anchor bolts in the seismic and TOLA analyses must be consistent with the range of deformations experienced by those anchor bolts in the seismic and the TOLA responses; and

3) The secant stiffnesses used for the anchors in the seismic and TOLA analyses must be consistent with the ranges of deformations experienced by those anchors in the superposed seismic and TOLA analyses.

The above assertion is clearly valid if each anchor remains linear elastic throughout the seismic and TOLA responses, and also throughout the superposition of those responses. The assertion remains reasonable provided that each of the seismic and TOLA responses, as well as their superposition, is essentially represented by the equivalent linearization. This particular point is addressed below.

A.9.3 Technical Justification for Equivalent Linear Analyses

The biggest question regarding the use of equivalent linear models in the seismic and TOLA analyses for elements whose behavior is actually nonlinear is, “Is equivalent linearization safe?” This question becomes especially complex when the loading comes from restrained thermal deformations in addition to applied gravity loads or seismic inertial forces.

A fundamental approach to this question is probably best. The solution to a structural analysis problem must satisfy equilibrium, constitutive relationships, and kinematics. The collapse load predicted by such a solution is in principle exact if the model is correct. According to the lower-bound theorem of structural mechanics (Hodge 1958, Neal 1963), a collapse load predicted using a solution that satisfies equilibrium and constitutive relationships, but not necessarily kinematics, is a lower bound to the true collapse load. Analytical solutions that satisfy the lower-bound theorem are therefore in principle safe for the design, because the true collapse load is always greater than or equal to that predicted.

In structural design for applied loads, the lower-bound theorem is applied by selecting a force path from the point of load application to the foundation, and by providing along that force path sufficient strength to resist the resulting actions, under the deformations associated with those actions. The force path does not have to be that corresponding to elastic analysis. Examples of the lower-bound approach to structural design are the idealization of reinforced concrete slabs with plan dimensional ratios of 2:1 or greater as one-way slabs spanning in the shorter direction, and the idealization of complex reinforced concrete assemblages using strut-and-tie models. Lower-bound models satisfy equilibrium of applied forces and corresponding internal actions, and they satisfy constitutive relationships because yield is not exceeded along the designated load path.

Under applied loads from gravity or ground shaking, an analytical approach that uses equivalent linearization with a secant modulus based on a deformation greater than or equal to the calculated deformation, is in principle consistent with the lower-bound theorem of structural mechanics, and is in principle therefore safe.
To see why this is so, consider the hypothetical structural system whose force-deformation behavior is shown in Figure 27. Units of load and displacement are arbitrary. For discussion purposes, the curve on the figure represents the system’s true force-deformation behavior, while the upper and lower straight lines represent equivalent linearizations of that behavior using secant stiffnesses evaluated between zero and a deformation of 0.01, and between zero and a deformation of 0.02, respectively.

Suppose that the system is analyzed using an equivalent linearization with the secant stiffness evaluated between zero and a deformation of 0.01. Provided that the deformation experienced by the system is less than or equal to 0.01, the results of the analysis will satisfy the lower-bound theorem: equilibrium is satisfied, and so are constitutive relationships, because the force consistent with the secant stiffness is always less than or equal to the true force.

If the calculated deformation exceeds 0.01, then constitutive relationships are no longer necessarily satisfied, and the analysis should be repeated using a secant stiffness evaluated between zero and a greater deformation (for example, 0.02).

This logic is valid provided that the system is a softening system, and provided that its behavior is ductile rather than brittle, so that there is no sudden release of energy at failure. It also applies to the seismic response, which is essentially elastic.

The logic remains valid even when the load on the system comes from restrained internal deformations, because any such load case can be interpreted as the summation of two load cases: the first is the combination of thermal deformations plus the external loads (nodal loads) necessary to give zero nodal displacements; and the second is the opposite of those nodal loads. In addition, it is useful to remember that in principle, a ductile anchor embedded in concrete that is subjected to thermal deformations cannot
fail as a result of those deformations, because as the stiffness of the anchor approaches zero, so does the change in anchor force resulting from thermal deformations of the concrete. This presumes, of course, that the deformation limit of the anchor is not exceeded.

Finally, it is worthwhile to discuss briefly the probable effects of two other possible behaviors in the concrete surrounding the anchors: tensile cracking and creep (or relaxation). Both of these decrease the effective elastic modulus of the concrete, and therefore decrease the forces imposed on the anchors by restrained thermal deformations. Provided that cracking of the concrete does not degrade the performance of the tank in other ways, it does not affect the validity of the lower-bound approach presented above.

A.9.4 Development of Equivalent Linear Elastic Models for Anchors

In terms of the above example, it is necessary to have a reliable force-deformation curve in order for the equivalent secant linearization to satisfy the lower-bound theorem. Such force-deformation curves can be obtained by test or by analysis. The process used to develop them in this case is reported in pp. 10-13 of Appendix B of Deibler (2008), and is corroborated by Figure 28 (Nelson 1961), which shows force-deformation curves for plain headed bolts loaded in shear. Behavior is ductile, and the maximum deformations reported in Nelson (1961) for 1/2-, 5/8-, and 3/4-in. diameter studs are 0.167 in., 0.299 in., and 0.341 in., respectively. The reported deformations are for concrete compressive strengths between approximately 3,800 and 4,200 psi. The deformations at failure are consistent with those reported by Hungerford (2004) in tests of single welded studs embedded in concrete and loaded in shear. Hungerford reports deformations at failure of 0.6 in. for 3/4-in. welded studs.

![Figure 28: Force-deformation curves for headed bolts (Figure 13 of Nelson [1961]).](image)
Figure 29 and Figure 30, taken from Hungerford (2004), show a load-slip curve for a cast-in-place, 3/4-in. diameter welded stud, 5-in. long, loaded in shear. The concrete in that test series had a strength of 3,500 psi at time of test, and showed some hairline cracks.

Figure 29  Load-slip curve for 3/4-in., cast-in-place welded stud, 0 to 0.8 in.  (Hungerford 2004)

Deformations at failure will be less for smaller studs, but are still expected to be considerably above 0.2 in. for studs with an effective diameter of at least 9/16 in., which was shown in Appendix B of Deibler et al. (2008) to be the effective diameter of the DST anchor bolts.

Figure 30  Load-slip curve for 3/4-in., cast-in-place welded stud, 0 to 0.3 in.  (Hungerford 2004)
A.9.5 The Proposed Approach and ACI349 Loading Combinations

This paper is the work of an individual, and does not represent an official interpretation of any document authored by ACI Committee 349 (Concrete Nuclear Structures). Nevertheless, the approach discussed here (equivalent linearization, direct combination of thermal and seismic effects, and a check that the calculated anchor deformations do not exceed the limits of the experimental and analytical results used to establish the linearization) is consistent with the current work of ACI349. Also, the procedure used to combine non-thermal and thermal effects is consistent and conservative. In this section, each of these points is discussed further.

As discussed in Deibler et al. (2008), the DST anchor bolts were evaluated according to ACI349-01 (ACI 2001). That standard treats combinations of thermal and seismic loads quite briefly. Of the eleven factored loading combinations given in Section 9.2.1 of that document, only two address combinations of thermal loads and design-basis earthquake; both combinations simply add their effects. This point is discussed further below.

Further guidance is given in the Committee's Reinforced Concrete Design for Thermal Effects on Nuclear Power Plant Structures (ACI349.1R-07). As stated in Section 1.3 (General Guidelines) of that document,

Stresses resulting from thermal effects are generally self-relieving, that is thermal forces and moments are greatly reduced or completely relieved once concrete cracks or reinforcement yields; as a result, thermal effects do not reduce the strength of a section for mechanical loads.

Informal Committee discussions reflect agreement that thermal loads cannot produce failure of an element, provided that deformation limits are not exceeded.

Given the limited guidance from ACI349 regarding appropriate combinations of thermal and earthquake effects, it is necessary to use professional judgment to establish appropriate combinations of thermal and seismic effects from consistent linearizations, and to establish appropriate ways of comparing those combinations against available capacities.

Of the loading combinations given in Section 9.2.1 of ACI349-01, only one (Loading Combination 4) involves thermal effects plus design-basis earthquake. That combination is repeated below in Eq. (1), with the factored loading combination \( U \) on the right-hand side of the equation:

\[
D + F + L + H + T_o + R_o + E_{as} = U \\
\text{Eq. (1)}
\]

Consider first a combination of load effects not involving thermal effects. The design criterion is given in Eq. (2):

\[
\sum_{i=1}^{N} \text{Non-thermal Effect}_i = U \leq \phi (\text{no minimal resistance})
\text{Eq. (2)}
\]
If consistent linearizations are used, so that deformations are proportional to actions, then for the case of shearing loads and deformations, this design criterion can be expressed directly in terms of deformations, as in Eq. (3):

\[
\sum_{i=1}^{n} \left( \Delta_{\text{non-thermal}} \right)_i \leq \phi \left( \Delta_{\text{ultimate}} \right)
\]

*Eq. (3)*

where

\[ \Delta_{\text{non-thermal}} = \text{shearing deformations from non-thermal effects}; \]

\[ \Delta_{\text{ultimate}} = \text{ultimate shearing deformation capacity} \]

The \( \phi \)-factor is intended to address the statistical dispersion of load effects, and possibly the statistical dispersion of ultimate shearing deformations. The ultimate shearing deformations used in the evaluation of the DST anchor bolts are based on the ultimate deformations reported in Oehlers and Sved (1995), which have a coefficient of variation of only 0.048. Thus, in the case of the DST anchor bolts, the primary purpose of the \( \phi \)-factor is to address the statistical dispersion of load effects.

According to Appendix B4.4 of ACI349-01, the \( \phi \)-factor corresponding to failure of a ductile steel element is 0.75 in shear. Based on this evaluation, it would be justifiable to use a \( \phi \)-factor of 0.75 in Eq. (3), leading to Eq. (4):

\[
\sum_{i=1}^{n} \left( \Delta_{\text{non-thermal}} \right)_i \leq 0.75 \left( \Delta_{\text{ultimate}} \right)
\]

*Eq. (4)*

Now consider combinations of loads involving thermal loads only. Because thermal loads cannot in principle produce failure provided that the ultimate shearing deformation is not exceeded, there is no need to use a \( \phi \)-factor to account for the statistical dispersion of thermal effects. The appropriate loading combination is therefore as shown in Eq. (5):

\[
\sum_{i=1}^{n} \left( \Delta_{\text{thermal}} \right)_i \leq 1.0 \left( \Delta_{\text{ultimate}} \right)
\]

*Eq. (5)*

where

\[ \Delta_{\text{thermal}} = \text{shearing deformations from thermal effects}; \]

\[ \Delta_{\text{ultimate}} = \text{ultimate shearing deformation capacity} \]

Finally, consider combinations of non-thermal and thermal effects. To combine those appropriately, both sides of the above equation involving thermal effects only should be factored by 0.75. The equation
involving non-thermal effects only and the factored equation involving thermal effects only can then be combined as in Eq. (6).

\[ \sum_{i=1}^{n} (\Delta_{\text{non-thermal}}^i) + 0.75 (\Delta_{\text{thermal}}) \leq 0.75 (\Delta_{\text{ultimate}}) \]  
Eq. (6)

If desired, Eq. (6) can be simplified (very conservatively) as Eq. (7):

\[ \sum_{i=1}^{n} (\Delta_{\text{non-thermal}}^i) + (\Delta_{\text{thermal}}) \leq 0.75 (\Delta_{\text{ultimate}}) \]  
Eq. (7)

A.9.6 Concluding Remarks

These “Comments” have three purposes. The first is to review and assess the underlying technical justification for the combination of TOLA and seismic demands on the anchors when those anchors are simulated using an equivalent linear modulus in the separate models. The second is to assess the value of the ultimate shearing deformation used to evaluate the DST anchors. The third is to comment on the relationship between the approach used in the DST anchor evaluation and the current activity of ACI Committee 349 (Concrete Nuclear Structures), particularly with respect to loading combinations involving non-thermal plus thermal effects.

In the above sections, that underlying technical justification is assessed, and is judged valid, because the following conditions are met:

1) The seismic and TOLA responses are each essentially linear elastic;

2) The secant stiffnesses used for the anchor bolts in the seismic and TOLA analyses are consistent with the range of deformations experienced by those anchor bolts in the seismic and the TOLA responses; and

3) The secant stiffnesses used for the anchors in the seismic and TOLA analyses are consistent with the ranges of deformations experienced by those anchors in the superposed seismic and TOLA analyses.

In the above sections, the probable ultimate shear deformation capacity of the DST anchors is shown to considerably exceed the approximately 0.2 in. used in the DST evaluation.

Although ACI Committee 349 (Concrete Nuclear Structures) gives little direct guidance on how to combine thermal effects with those from design-basis earthquakes, it does give general guidance on the interaction of thermal and seismic effects. That guidance is consistent with the general approach used here. Because thermal effects cannot in principle produce failure provided that the ultimate deformation
capacity is not exceeded, it is appropriate to compute the summation of shearing deformations from non-thermal effects, plus 0.75 times the shearing deformations from thermal effects, and to compare that summation with 0.75 times the ultimate deformation capacity. In this case, shearing deformations from non-thermal and thermal effects were summed directly, and were compared with 0.75 times the ultimate deformation capacity. This is very conservative.

I therefore conclude that the methodology used to evaluate the DST anchor bolts is technically justified, safe, and consistent with the current activity of ACI Committee 349.

A.9.7 References

ACI 2001, *Code Requirements for Nuclear Safety Related Concrete Structures (ACI 349-01) and Commentary (ACI 349R-01)*, American Concrete Institute, Farmington Hills, Michigan.


Appendix B

Software Acceptance
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Appendix B

Software Acceptance

1) Project Title and Number: DST Thermal and Seismic Analyses 48971
2) Software Name and Version: ANSYS 7.0 (Rev. 11)
3) Computer and Property Number: Dell PWS 530 WD39892
5) Scope of Testing: Software reinstallation (XP SP2)
6) Tests: Execute ANSYS Verification Testing Package
7) Discrepancies:
   a) c0231. These differences are acceptable per the ANSYS Verification Package User’s Guide - ANSYS Release 7.0 (AVPUG).
   b) vm184. These differences occur at the 5th significant figure.
   c) vm198. This difference is the reporting of the customer number for this installation.
   d) vmc8. These differences are acceptable as noted in the output because of the difference in number of iterations and accuracy.
   e) cyc-177s. This difference is acceptable due to the handling of the QAEND macro (see AVPUG).
   f) cyc-178s. This difference is acceptable due to the handling of the QAEND macro (see AVPUG).
   g) dds-13s. This test case requires the “Parallel Performance Module” which is not part of this software installation and is not required for the DST analyses.
   h) dds-17s. This test case requires the “Parallel Performance Module” which is not part of this software installation and is not required for the DST analyses.
   i) evl73-53s. This difference is acceptable due to the handling of the QAEND macro (see AVPUG).
   j) evl75-20s. This difference is acceptable due to the handling of the QAEND macro (see AVPUG).
   k) evl75-21s. This test case requires the “Parallel Performance Module” which is not part of this software installation and is not required for the DST analyses.
1) int-16s. This difference is acceptable due to the handling of the QAEND macro (see AVPUG).

m) sx120-1s. This test case requires the “Frequency Sweep Module” which is not part of this
software installation and is not required for the DST analyses.

8) Finding: This installation of ANSYS is acceptable.

Certified by:

JE Deibler
Code Custodian

Reviewed by:

KI Johnson
Lead Engineer

B.2
Notes for test case c0231.

Test case c0231 may show considerable differences for the Phase Angle value that is part of the Post1 Nodal Degree of Freedom Listing (PRNS command) output. Any such differences do not indicate a problem with this test case's results and should be considered acceptable. The output items of significance for this test case are the UZ values in the Post1 Nodal Degree of Freedom Listing. Machine precision differences in the form of small numerical differences that are trivial with respect to the test's output items of significance may also show for this test case in the compare output for this test. Please see Verifying ANSYS and Evaluating COMPARE Differences in Chapter 2 of the ANSYS Verification Testing Package User's Guide for more information on evaluating COMPARE differences. The following is an example of acceptable COMPARE differences for test case c0231:

```
COMPARE DIFFERENCE FOUND AT G= NODAL RESULTS ARE FOR CYCLIC SECTOR T= NODAL RESULTS ARE FOR CYCLIC SECTOR
COMPARE DIFFERENCE FOUND AT G= NODAL RESULTS ARE FOR CYCLIC SECTOR T= NODAL RESULTS ARE FOR CYCLIC SECTOR
COMPARE DIFFERENCE FOUND AT G= NODAL RESULTS ARE FOR CYCLIC SECTOR T= NODAL RESULTS ARE FOR CYCLIC SECTOR
```

```
COMPARE DIFFERENCE FOUND AT G= NODAL RESULTS ARE FOR CYCLIC SECTOR T= NODAL RESULTS ARE FOR CYCLIC SECTOR
```

```
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COMPARE DIFFERENCE FOUND AT G= VALUE -9.7579 0.53293 0.39419 0.39425 10. T= VALUE -9.7581 0.53297 0.39419 10.
```

```
COMPARE DIFFERENCE FOUND AT G= 10 0.53495 0.39569 9. T= 10 0.52497 0.39562 9.
```

```
COMPARE DIFFERENCE FOUND AT G= 259 NT= 259 G= 12 0.50435 0.40268 8.6483 6.6723 T= 12 0.50435 0.40268 8.6471 6.6711
```

```
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COMPARE DIFFERENCE FOUND AT G= 260 NT= 260 G= 14 0.48186 0.41201 7.8730 7.8565 T= 14 0.48186 0.41196 7.8700 7.8655
```

```
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```

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```

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G= 272 NT= 272 G= 31 0.19366 0.41245 23.013 21.413 T= 31 0.19366 0.41245 23.010 21.410
```

```
G= 273 NT= 273 G= 33 0.15542 0.41245 26.113 21.413 T= 33 0.15542 0.41245 26.110 21.410
```

```
Notes for Test Case vm212
Test case vm212 may produce an expected compare difference due to an inconsequential warning message that appears in the ANSYS, Inc. supplied output file that may not appear in the output file generated by your system for this test case. This compare difference should be considered acceptable. The following is an example of this compare difference.

```
COMPARE DIFFERENCE FOUND AT NG= 445 NT= 436
G= NUMBER OF WARNING MESSAGES ENCOUNTERED= 1
T= NUMBER OF WARNING MESSAGES ENCOUNTERED= 0
```

Notes for Test Cases cyc-177s, cyc-178s, ev-173-53s, ev-175-20s, inrt-16s, and inrt-9s
Test cases cyc-177s, cyc-178s, ev-173-53s, ev-175-20s, inrt-16s, and inrt-9s may produce expected compare differences due to the use of a macro named qaend. The method that is used in the verification procedure (runqa) to handle this macro may cause one or more comparison differences. Any such compare differences are inconsequential and should be considered acceptable. The following is an example of such a compare difference.

```
EXTRA DATA SKIPPED ON TEST FILE NG= 1033 NT= 1030
T= USE COMMAND MACRO qaend
T= ARGS= 137 00
END OF SKIPPED DATA NG= 1033 NT= 1033
```

Notes for test Cases dds-13s, dds-17s, and ev175-21s
The test cases dds-13s, dds-17s, and ev175-21s will run to completion only if the "Parallel Performance for ANSYS" product (DDS and AMG solvers) is included in your ANSYS installation.
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**UP20020121 WINDOWS**

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- SP Version: 70SP20030909
- Compare Rel: 3.8
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**Note:** The table data appears to be a log of test runs with various IDs and dates, likely related to software testing or debugging. The columns include VM IDs, date and time of the test run, file or test name, compare version, REL, evaluation details, and date and time of the evaluation.
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<td>19</td>
<td>19</td>
<td>7020021010</td>
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<td>20</td>
<td>20</td>
<td>QA70-1</td>
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<td>inrt-16s</td>
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<td>inrt-9s</td>
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<td>24</td>
<td>QA70-1</td>
<td></td>
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<tr>
<td>mvhy-bk501</td>
<td>25</td>
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<td>7020021010</td>
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<tr>
<td>INTEL NT</td>
<td>26</td>
<td>26</td>
<td>QA70-1</td>
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<td>mvhy-gt202</td>
<td>27</td>
<td>27</td>
<td>7020021010</td>
<td></td>
</tr>
<tr>
<td>INTEL NT</td>
<td>28</td>
<td>28</td>
<td>QA70-1</td>
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<td>mvve-cr003</td>
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<td>30</td>
<td>30</td>
<td>QA70-1</td>
<td></td>
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<td>mvve-cr804</td>
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<td>INTEL NT</td>
<td>32</td>
<td>32</td>
<td>QA70-1</td>
<td></td>
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<tr>
<td>se-1s</td>
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<td>7020021010</td>
<td></td>
</tr>
<tr>
<td>INTEL NT</td>
<td>34</td>
<td>34</td>
<td>QA70-1</td>
<td></td>
</tr>
<tr>
<td>se-20s</td>
<td>35</td>
<td>35</td>
<td>7020021010</td>
<td></td>
</tr>
<tr>
<td>INTEL NT</td>
<td>36</td>
<td>36</td>
<td>QA70-1</td>
<td></td>
</tr>
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<td>sxl20-1s</td>
<td>37</td>
<td>37</td>
<td>7020021010</td>
<td></td>
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<tr>
<td>NOT AVAILABLE</td>
<td>38</td>
<td>38</td>
<td>QA70-1</td>
<td></td>
</tr>
<tr>
<td>tbc-155s</td>
<td>39</td>
<td>39</td>
<td>7020021010</td>
<td></td>
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<tr>
<td>INTEL NT</td>
<td>40</td>
<td>40</td>
<td>QA70-1</td>
<td></td>
</tr>
</tbody>
</table>
Comparison differences found at NG= 113 NT= 113
G= CURRENT JOBNAME=c0231 10:37:04 OCT 15, 2002 CP= 0.219
T= CURRENT JOBNAME=c0231 11:04:48 FEB 12, 2005 CP= 0.156

0 /verify,c0231
0 /title, c0231 (fsk) Unmatched nodes mapping

Comparison differences found at NG= 114 NT= 114
G= NODAL RESULTS ARE FOR CYCLIC SECTOR 1 - PHASE ANGLE = 30.580
T= NODAL RESULTS ARE FOR CYCLIC SECTOR 1 - PHASE ANGLE = 237.330

Comparison differences found at NG= 192 NT= 192
G= NODAL RESULTS ARE FOR CYCLIC SECTOR 2 - PHASE ANGLE = 30.580
T= NODAL RESULTS ARE FOR CYCLIC SECTOR 2 - PHASE ANGLE = 237.330

Comparison differences found at NG= 219 NT= 219
G= NODAL RESULTS ARE FOR CYCLIC SECTOR 3 - PHASE ANGLE = 30.580
T= NODAL RESULTS ARE FOR CYCLIC SECTOR 3 - PHASE ANGLE = 237.330

Comparison differences found at NG= 246 NT= 246
G= NODAL RESULTS ARE FOR CYCLIC SECTOR 3 - PHASE ANGLE = 30.580
T= NODAL RESULTS ARE FOR CYCLIC SECTOR 3 - PHASE ANGLE = 237.330

Bottom of good file reached at line 289
G= | ANSYS RUN COMPLETED |

--------------
NOTE- NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED
NUMBER OF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) - 0
NUMBER OF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) - 0
NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT - 0
NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT - 0
--------------

Comparison errors = 3

--------------
NOTE- NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED
NUMBER OF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) - 0
NUMBER OF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) - 0
NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT - 0
NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT - 0
--------------

Comparison options

Problem: c0231

<table>
<thead>
<tr>
<th>Comparison Options</th>
<th>Comparison Rel</th>
<th>Windows</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALMOST ZERO (GOOD)</td>
<td>1.0000E-006</td>
<td>KROUND (DROP LAST DIGIT)= 1</td>
</tr>
<tr>
<td>ALMOST ZERO (TEST)</td>
<td>1.0000E-006</td>
<td>KABSPP (0=SUMMARY 1=ALL)= 1</td>
</tr>
<tr>
<td>ABSOLUTE VALUE TOL</td>
<td>1.0000E-010</td>
<td>KSkip (SKIP=ERR 0=Y, 1=N)= 0</td>
</tr>
<tr>
<td>FRACTIONAL DIFFERENCE</td>
<td>1.0000E-004</td>
<td>MAXERR (STOP WHEN ERRS )= 100</td>
</tr>
<tr>
<td>ABSOLUTE DIFFERENCE</td>
<td>1.0000E-006</td>
<td>MAXBUF (# LINES TO SCAN)= 6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>KNOWN (# OF KNOWN ERRS)= 0</td>
</tr>
</tbody>
</table>
GREAD, TREAD = 1, 1

LINES ON GOOD FILE = 304
LINES ON TEST FILE = 304

*************************************************************************
EXPECTED COMPARE DIFFERENCE FOUND AT NG= 113 NT= 113
G= 00000000 VERSION=INTEL NT RELEASE= 7.0 UP20021010
T= 00292062 VERSION=INTEL NT RELEASE= 7.0SP11 UP20030909

EXPECTED COMPARE DIFFERENCE FOUND AT NG= 114 NT= 114
G= CURRENT JOBNAME=vm184 20:46:18 OCT 15, 2002 CP= 0.250
T= CURRENT JOBNAME=vm184 11:27:32 FEB 12, 2005 CP= 0.297

0 /VERIFY,VM184
0 /TITLE, VM184, STRAIGHT CANTILEVER BEAM
0 /stitle,1,Reason COMPARE differences are acceptable:
0 /stitle,2, mesh error - element number on warning; near-zero values
0 /TITLE, VM184, STRAIGHT CANTILEVER BEAM

NOW COMPARING LINES FROM ***** ANSYS ANALYSIS DEFINITION (PREP7) *****

NOW COMPARING LINES FROM ***** ANSYS RESULTS INTERPRETATION (POST1) *****

ABSOLUTE VALUE DIFFERENCE FOUND AT NG= 926 NT= 926
G= VALUE -0.24849E-01 0.98917 -0.43696E-05 0.98848
T= VALUE -0.24849E-01 0.98917 0.43696E-05 0.98848

ABSOLUTE VALUE DIFFERENCE FOUND AT NG= 926 NT= 926
G= VALUE -0.53544E-02 -0.26671E-05 0.42554 0.42557
T= VALUE -0.53544E-02 0.26671E-05 0.42554 0.42557

ABSOLUTE VALUE DIFFERENCE FOUND AT NG= 1011 NT= 1011
G= VALUE -0.12394E-01 -0.61739E-05 0.98504 0.98511
T= VALUE -0.12394E-01 0.61739E-05 0.98504 0.98511

NOW COMPARING LINES FROM ***** ANSYS ANALYSIS DEFINITION (PREP7) *****

NOW COMPARING LINES FROM ***** ANSYS RESULTS INTERPRETATION (POST1) *****

COMPARE DIFFERENCE FOUND AT NG= 1580 NT= 1580
G= VALUE 0.24811E-01 0.98813 -0.43696E-05 0.98844
T= VALUE 0.24811E-01 0.98813 0.43696E-05 0.98844

ABSOLUTE VALUE DIFFERENCE FOUND AT NG= 1639 NT= 1639
G= VALUE -0.53533E-02 -0.30755E-05 0.42553 0.42556
T= VALUE -0.53533E-02 0.30756E-05 0.42553 0.42556

ABSOLUTE VALUE DIFFERENCE FOUND AT NG= 1673 NT= 1673
G= VALUE -0.12392E-01-0.71193E-05 0.98502 0.98510
T= VALUE -0.12392E-01 0.71194E-05 0.98502 0.98510

NOW COMPARING LINES FROM ***** ANSYS ANALYSIS DEFINITION (PREP7) *****

NOW COMPARING LINES FROM ***** ANSYS RESULTS INTERPRETATION (POST1) *****

NOW COMPARING LINES FROM ***** ANSYS ANALYSIS DEFINITION (PREP7) *****

NOW COMPARING LINES FROM ***** ANSYS RESULTS INTERPRETATION (POST1) *****

BOTTOM OF GOOD FILE REACHED AT LINE 3147
G= | ANSYS RUN COMPLETED |

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
NOTE- NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED
NUMBER OF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) = 0
NUMBER OF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) = 0
NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT = 0
NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT = 0
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

*********************************************************
COMPARE ERRORS = 1 *
*********************************************************

*********************************************************
WARNING - 5 ABSOLUTE VALUE DIFFERENCE(s) FOUND.
*********************************************************

*********************************************************
NOTE - 1 summary line(s) contained absolute value differences.
*********************************************************

PROBLEM: vm184

ALMOST ZERO (GOOD) = 1.0000E-006 KROUND (DROP LAST DIGIT)= 1
ALMOST ZERO (TEST) = 1.0000E-006 KABSPR (O=SUMMARY 1=ALL)= 1
ABSOLUTE VALUE TOL = 1.0000E-010 KSKIP(SKIP=ERR 0=Y, 1=N)= 0
FRACTIONAL DIFFERENCE= 1.0000E-004 MAXERR (STOP WHEN ERRORS)= 100
ABSOLUTE DIFFERENCE = 1.0000E-006 MAXBUF (# LINES TO SCAN)= 6
KNOWN (# OF KNOWN ERRORS)= 0

B.23
GREAD, TREAD = 1, 1

LINES ON GOOD FILE = 3162
LINES ON TEST FILE = 3162
**Expected Compare Difference Found At**

G= 00000000  
T= 00292062

**Version=INTEL NT**  
**Release= 7.0 UP20021010**

**Expected Compare Difference Found At**

G= CURRENT JOBNAME=vml98  20:50:49 OCT 15, 2002 CP= 0.266
T= CURRENT JOBNAME=vml98  11:29:13 FEB 12, 2005 CP= 0.172

0 /VERIFY,VM198
0 /TITLE, VM198, LARGE STRAIN IN-PLANE TORSION TEST (%EL%)

Now comparing lines from

***** ANSYS ANALYSIS DEFINITION (PREP7) *****

Now comparing lines from

***** ANSYS RESULTS INTERPRETATION (POST1) *****

Now comparing lines from

***** TIME-HISTORY POSTPROCESSOR (POST26) *****

Now comparing lines from

***** ANSYS ANALYSIS DEFINITION (PREP7) *****

Compare difference found at

G= RELEASE 0.0 UPDATE  
T= RELEASE 0.0 UPDATE

Now comparing lines from

***** ANSYS RESULTS INTERPRETATION (POST1) *****

Now comparing lines from

***** TIME-HISTORY POSTPROCESSOR (POST26) *****

Now comparing lines from

***** ANSYS ANALYSIS DEFINITION (PREP7) *****

Compare difference found at

G= RELEASE 0.0 UPDATE  
T= RELEASE 0.0 UPDATE

Now comparing lines from

***** ANSYS RESULTS INTERPRETATION (POST1) *****

Now comparing lines from

***** TIME-HISTORY POSTPROCESSOR (POST26) *****

Now comparing lines from

***** ANSYS ANALYSIS DEFINITION (PREP7) *****

Compare difference found at

G= RELEASE 0.0 UPDATE  
T= RELEASE 0.0 UPDATE

Now comparing lines from

***** ANSYS RESULTS INTERPRETATION (POST1) *****

Now comparing lines from

***** TIME-HISTORY POSTPROCESSOR (POST26) *****
NOTE - NONSTANDARD COMPARE - DIPOPT NAME QA70-1 HAS BEEN USED

| NUMBER OF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) | 2 |
| NUMBER OF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) | 2 |
| NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT | 0 |
| NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT | 0 |

--------------

**COMPARE ERRORS = 2**
--------------

<table>
<thead>
<tr>
<th>PROBLEM: vm198</th>
<th>COMPARE OPTIONS</th>
<th>COMPARE_REL 3.8 UP20020121</th>
<th>WINDOWS</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALMOST ZERO (GOOD) = 1.0000E-006</td>
<td>KROUND (DROP LAST DIGIT) = 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ALMOST ZERO (TEST) = 1.0000E-006</td>
<td>KABSPR (0=SUMMARY 1=ALL) = 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABSOLUTE VALUE TOL = 1.0000E-010</td>
<td>KSKIP (SKIP=ERR 0=Y, 1=N) = 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRACTIONAL DIFFERENCE = 1.0000E-004</td>
<td>MAXERR (STOP WHEN ERRS ) = 100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABSOLUTE DIFFERENCE = 1.0000E-006</td>
<td>MAXBUF (# LINES TO SCAN) = 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>KNOWN (# OF KNOWN ERRS) = 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>GREAD, TREAD = 1, 1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

--------------

LINES ON GOOD FILE = 1208
LINES ON TEST FILE = 1208

---------
Expected Compare Difference Found at NG= 113 NT= 113
G= 00000000 VERSION=INTEL NT RELEASE= 7.0 UP20021010
T= 00292062 VERSION=INTEL NT RELEASE= 7.0SP11 UP20030909
Expected Compare Difference Found at NG= 114 NT= 114
G= CURRENT JOBNAME=vmc8 21:52:06 OCT 15, 2002 CP= 0.219
T= CURRENT JOBNAME=vmc8 12:22:49 FEB 12, 2005 CP= 0.188

0 /VERIFY,VMC8
0 /TITLE, VMC8, ALUMINUM BAR IMPACTING A RIGID BOUNDARY
0 /stitle,1,Reason COMPARE differences are acceptable:
0 /stitle,2, number of iterations, accuracy

PLAN2
0 /title, VMC8, ALUMINUM BAR IMPACTING A RIGID BOUNDARY -

PLAN42
0 /title, VMC8, ALUMINUM BAR IMPACTING A RIGID BOUNDARY -

PLAN82
0 /title, VMC8, ALUMINUM BAR IMPACTING A RIGID BOUNDARY -

VISCO106
0 /title, VMC8, ALUMINUM BAR IMPACTING A RIGID BOUNDARY -

SOLID45
0 /title, VMC8, ALUMINUM BAR IMPACTING A RIGID BOUNDARY -

SOLID95
0 /title, VMC8, ALUMINUM BAR IMPACTING A RIGID BOUNDARY -

VISCO107
0 /TITLE, VMC8, ALUMINUM BAR IMPACTING A RIGID BOUNDARY

Now comparing lines from ***** ANSYS Analysis Definition (PREP7) *****

Now comparing lines from ***** ANSYS Results Interpretation (POST1) *****

Compare Difference Found at NG= 880 NT= 880
G= SET COMMAND GOT LOAD STEP= 2 SUBSTEP= 320 CUMULATIVE ITERATION= 3255
T= SET COMMAND GOT LOAD STEP= 2 SUBSTEP= 320 CUMULATIVE ITERATION= 3240
NOW COMPARING LINES FROM
***** TIME-HISTORY POSTPROCESSOR (POST26)

NOW COMPARING LINES FROM
***** ANSYS ANALYSIS DEFINITION (PREP7) *****

NOW COMPARING LINES FROM
***** ANSYS RESULTS INTERPRETATION (POST1)

NOW COMPARING LINES FROM
***** ANSYS ANALYSIS DEFINITION (PREP7) *****

NOW COMPARING LINES FROM
***** ANSYS RESULTS INTERPRETATION (POST1)

NOW COMPARING LINES FROM
***** TIME-HISTORY POSTPROCESSOR (POST26)

NOW COMPARING LINES FROM
***** ANSYS ANALYSIS DEFINITION (PREP7) *****

NOW COMPARING LINES FROM
***** ANSYS RESULTS INTERPRETATION (POST1)

NOW COMPARING LINES FROM
***** ANSYS ANALYSIS DEFINITION (PREP7) *****

NOW COMPARING LINES FROM
***** ANSYS RESULTS INTERPRETATION (POST1)

NOW COMPARING LINES FROM
***** TIME-HISTORY POSTPROCESSOR (POST26)

NOW COMPARING LINES FROM
***** ANSYS ANALYSIS DEFINITION (PREP7) *****

NOW COMPARING LINES FROM
***** ANSYS RESULTS INTERPRETATION (POST1)

NOW COMPARING LINES FROM
***** ANSYS ANALYSIS DEFINITION (PREP7) *****

NOW COMPARING LINES FROM
***** ANSYS RESULTS INTERPRETATION (POST1)

COMPARE DIFFERENCE FOUND AT NG= 1227 NT= 1227
G= 3 ESOL 1 EPP EQV EPP EQV 0.7401E-16 0.000 3.410 0.000
T= 3 ESOL 1 EPP EQV EPP EQV 0.2694E-35 0.000 3.422 0.000
NOW COMPARING LINES FROM
****** TIME-HISTORY POSTPROCESSOR |POST2>

BOTTOM OF GOOD FILE REACHED AT LINE 1879
G= | ANSYS RUN COMPLETED |

-------------------------------------------------------------------------------------------------------------------
NOTE- NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED
NUMBER OF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) = 0
NUMBER OF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) = 0
NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT = 0
NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT = 0
-------------------------------------------------------------------------------------------------------------------
COMPARE ERRORS = 2 *

-------------------------------------------------------------------------------------------------------------------
PROBLEM: vmc8

ALMOST ZERO (GOOD) = 1.0000E-006
ALMOST ZERO (TEST) = 1.0000E-006
ABSOLUTE VALUE TOL = 1.0000E-010
FRACTIONAL DIFFERENCE = 1.0000E-004
ABSOLUTE DIFFERENCE = 1.0000E-006
KROUND (DROP LAST DIGIT) =
KABSPR (0 = SUMMARY, 1 = ALL) =
KSKIP (SKIP = ERR 0 = Y, 1 = N) =
MAXERR (STOP WHEN ERRS ) =
MAXBUF (# LINES TO SCAN) =
KNOWN (# OF KNOWN ERRS) =
GREAD, TREAD = 1, 1

-------------------------------------------------------------------------------------------------------------------
LINES ON GOOD FILE = 1894
LINES ON TEST FILE = 1894

-------------------------------------------------------------------------------------------------------------------
**Problem:** cyc-177s

**Compare Options:**

- **Almost Zero (Good):** 1.0000E-006
- **Almost Zero (Test):** 1.0000E-006
- **Absolute Value TOL:** 1.0000E-010
- **Fractional Difference:** 1.0000E-004
- **Absolute Difference:** 1.0000E-006

**Remarks:**

- **KROUND (Drop Last Digit):** 1
- **KSKIP (SKIP=ERR 0=Y, 1=N):** 0
- **MAXERR (STOP WHEN ERRORS):** 100
- **MAXBUF (# LINES TO SCAN):** 6
- **KNOWN (# OF KNOWN ERRORS):** 0
- **GREAD, TREAD:** 1, 1

**ANSYS Run Completed**
LINES ON GOOD FILE = 1219
LINES ON TEST FILE = 1222

********************************************************************************
**Comparison Results**

**Expected Compare Difference Found At**

NG= 113 NT= 113

G= CURRENT JOBNAME=cyc-178s 11:48:41 OCT 15, 2002 CP= 0.250
T= CURRENT JOBNAME=cyc-178s 13:01:42 FEB 12, 2005 CP= 0.234

0 /verify,cyc-178s
0 /TITLE, ceb,cyc-178s, Test cyc symm Buckling element 182
0 /title,1,Full Results to Sector Results!
0 /stitle,Reason Compare differences are acceptable:

**Extra Data Skipped On Test File**

NG= 1202 NT= 1194

T= USE COMMAND MACRO QAEND
T= ARGS= 289.00

**End Of Skipped Data**

NG= 1202 NT= 1199

**Bottom Of Good File Reached At Line** 1204

G= | ANSYS RUN COMPLETED

---

**Note**

Nonstandard compare - DIOPT NAME QA70-1 has been used

**Compare Errors** = 1

---

**Problem**

**cyc-178s**

**Compare Options**

**Compare Rel** 3.8 UP20020121 Windows

**Almost Zero (Good)** = 1.0000E-006
**Almost Zero (Test)** = 1.0000E-006
**Absolute Value TOL** = 1.0000E-010
**Fractional Difference** = 1.0000E-004
**Absolute Difference** = 1.0000E-006

---

B.32
<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lines on Good File</td>
<td>1219</td>
</tr>
<tr>
<td>Lines on Test File</td>
<td>1222</td>
</tr>
</tbody>
</table>
*** ERROR -- (VERSION=) was not found anywhere in the "TEST" file. ***
*** Comparison was supposed to start at this string, specified in CMPOPT. ***

NOTE- NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED
NUMBER OF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) = 0
NUMBER OF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) = 0
NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT = 0
NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT = 0

COMPARE ERRORS = -8 8 *

---

PROBLEM: dds-13s

COMPARISON OPTIONS

- ALMOST ZERO (GOOD) = 1.0000E-006
- ALMOST ZERO (TEST) = 1.0000E-006
- ABSOLUTE VALUE TOL = 1.0000E-010
- FRACTIONAL DIFFERENCE = 1.0000E-004
- ABSOLUTE DIFFERENCE = 1.0000E-006

- KROUND (DROP LAST DIGIT) = 1
- KABSPR (0=SUMMARY 1=ALL) = 1
- KSKIP(SKIP=ERR 0=Y, 1=N) = 0
- MAXERR (STOP WHEN ERR) = 100
- MAXBUF (# LINES TO SCAN) = 6
- KNOWN (# OF KNOWN ERRS) = 0
- GREAD, TREAD = 1, 1

---

LINES ON GOOD FILE = 402
LINES ON TEST FILE = 146
*** ERROR -- (VERSION=) was not found anywhere in the "TEST" file. ***
*** Comparison was supposed to start at this string, specified in CMPOPT. ***

NOTE- NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED
NUMBER OF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) = 0
NUMBER OF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) = 0
NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT = 0
NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT = 0

COMPARE ERRORS = -88

-----
PROBLEM: dds-17s
PROBLEM OPTIONS: COMPARE_REL 3.8 UP20020121  WINDOWS

ALMOST ZERO (GOOD) = 1.0000E-006
ALMOST ZERO (TEST) = 1.0000E-006
ABSOLUTE VALUE TOL = 1.0000E-010
FRACTIONAL DIFFERENCE = 1.0000E-004
ABSOLUTE DIFFERENCE = 1.0000E-006
KROUND (DROP LAST DIGIT) = 1
KABSPR (0=SUMMARY 1=ALL) = 1
KSKIP (SKIP=ERR 0=Y, 1=N) = 0
MAXERR (STOP WHEN ERRS ) = 100
MAXBUF (# LINES TO SCAN) = 6
KNOWN (# OF KNOWN ERRS) = 0
GREAD, TREAD = 1, 1

LINES ON GOOD FILE = 746
LINES ON TEST FILE = 146
**RPP-RPT-32237, Rev. 1**

***

**00000000** **VERSION=INTEL NT** **RELEASE= 7.0** **UP20021010**

**EXPECTED COMPARE DIFFERENCE FOUND AT** **NG= 113 NT= 113**

**G= 00000000** **VERSION=INTEL NT** **RELEASE= 7.0** **UP20021010**

**T= 00292062** **VERSION=INTEL NT** **RELEASE= 7.0** **UP20021010**

**EXPECTED COMPARE DIFFERENCE FOUND AT** **NG= 114 NT= 114**

**G= CURRENT JOBNAME=evl73-53s 14:02:31 OCT 15, 2002 CP= 0.234**

**T= CURRENT JOBNAME=evl73-53s 13:10:45 FEB 12, 2005 CP= 0.172**

- /verify,evl73-53s
- /title,evl73-53s,mfquresh,Test to verify PSOVLE,ELFORM for 171-175 (3D) with FENE

**EXTRA DATA SKIPPED ON TEST FILE** **NG= 1409 NT= 1401**

**T= USE COMMAND MACRO QAEND** **NG= 1409 NT= 1406**

**END OF SKIPPED DATA** **NG= 1409 NT= 1405**

**BOTTOM OF GOOD FILE REACHED AT LINE 1411**

**G= I ANSYS RUN COMPLETED**

---

**NOTE- NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED**

**NUMBER OF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) = 2**

**NUMBER OF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) = 2**

**NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT = 0**

**NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT = 0**

---

**COMPARE ERRORS = 1**

---

**PROBLEM: evl73-53s**

**COMPARE OPTIONS**

- **ALMOST ZERO (GOOD) = 1.0000E-006**
- **ALMOST ZERO (TEST) = 1.0000E-006**
- **ABSOLUTE VALUE TOL = 1.0000E-010**
- **FRACTIONAL DIFFERENCE = 1.0000E-004**
- **ABSOLUTE DIFFERENCE = 1.0000E-006**

---

**LINES ON GOOD FILE - 1426**

**LINES ON TEST FILE - 1429**

---

B.36
EXPECTED COMPARE DIFFERENCE FOUND AT NG= 113 NT= 113
G= 00000000 VERSION=INTEL NT RELEASE= 7.0 UP20021010
T= 00292062 VERSION=INTEL NT RELEASE= 7.0 UP20030909

EXPECTED COMPARE DIFFERENCE FOUND AT NG= 114 NT= 114
G= CURRENT JOBNAMES=evl75-20s 14:22:02 OCT 15, 2002 CP= 0.250
T= CURRENT JOBNAMES=evl75-20s 13:11:18 FEB 12, 2005 CP= 0.156

0 /verify,evl75-20s
0 /title,evl75-20s,mfq, Check real constant FKN and FTOLN and

KEYOPT(2)=0,1

NOW COMPARING LINES FROM ***** ANSYS ANALYSIS DEFINITION (PREP7) *****

EXTRA DATA SKIPPED ON TEST FILE
T= USE COMMAND MACRO QAEND
T= ARGS= 3.0000
END OF SKIPPED DATA
NG= 521 NT= 513
NG= 521 NT= 5 IS
BOTTOM OF GOOD FILE REACHED AT LINE 523
G= | ANSYS RUN COMPLETED

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

NOTE- NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED
NUMEROF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) - 2
NUMEROF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) - 2
NUMEROF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT - 0
NUMEROF LINES ON TEST FILE WITH STRINGS CONDENSED OUT - 0
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

COMPARE ERRORS = 1 *
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

PROBLEM: evl75-20s COMPARE OPTIONS COMPARE REL 3.8 UP20020121 WINDOWS

ALMOST ZERO (GOOD) = 1.0000E-006 KROUND (DROP LAST DIGIT)= 1
ALMOST ZERO (TEST) = 1.0000E-006 KASFR (0=SUMMARY 1=ALL)= 1
ABSOLUTE VALUE TOL = 1.0000E-010 KSKIP (SKIP=ERR 0=Y, 1=N)= 0
FRACTIONAL DIFFERENCE= 1.0000E-004 MAXERR (STOP WHEN ERRS)= 100
ABSOLUTE DIFFERENCE = 1.0000E-006 MAXBUF (# LINES TO SCAN)= 6

KNOWN (# OF KNOWN ERRS)= 0
GREAD, TREAD = 1, 1

B.37
LINES ON GOOD FILE = 538
LINES ON TEST FILE = 541

*****************************************************************************
*** ERROR — (VERSION=) was not found anywhere in the "TEST" file. ***
*** Comparison was supposed to start at this string, specified in CMPOPT. ***

NOTE- NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED

NUMBER OF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) = 0
NUMBER OF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) = 0
NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT = 0
NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT = 0

COMPARE ERRORS = -88

<table>
<thead>
<tr>
<th>PROBLEM: evl75-21s</th>
<th>COMPARE OPTIONS</th>
<th>COMPARE_REL 3.8 UP20020121</th>
<th>WINDOWS</th>
</tr>
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<td>ALMOST ZERO (GOOD) = 1.0000E-006</td>
<td>KROUND (DROP LAST DIGIT)= 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ALMOST ZERO (TEST) = 1.0000E-006</td>
<td>KABSQR (0=SUMMARY 1=ALL)= 1</td>
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<td></td>
</tr>
<tr>
<td>ABSOLUTE VALUE TOL = 1.0000E-010</td>
<td>KSKIP (SKIP=ERR 0=Y, 1=N)= 0</td>
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<tr>
<td>FRACTIONAL DIFFERENCE = 1.0000E-004</td>
<td>MAXERR (STOP WHEN ERRS)= 100</td>
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</tr>
<tr>
<td>ABSOLUTE DIFFERENCE = 1.0000E-006</td>
<td>MAXBUF (# LINES TO SCAN)= 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>KNOWN (# OF KNOWN ERRS)= 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>GREAD, TREAD = 1, 1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

LINES ON GOOD FILE = 566
LINES ON TEST FILE = 146
**RPP-RPT-32237, Rev. 1**

---

**G00000000**  
VERSION=INTEL NT  
RELEASE= 7.0  
UP200221010

EXPECTED COMPARE DIFFERENCE FOUND AT  
NG= 113 NT= 113

G= 00000000  
VERSION=INTEL NT  
RELEASE= 7.0  
UP200221010

T= 00292062  
VERSION=INTEL NT  
RELEASE= 7.0  
UP20030909

EXPECTED COMPARE DIFFERENCE FOUND AT  
NG= 114 NT= 114

G= CURRENT JOBNAME=inrt-16s 16:14:59 OCT 15, 2002 CP= 0.219

T= CURRENT JOBNAME=inrt-16s 13:13:40 FEB 12, 2005 CP= 0.188

0 /VERIFY,INRT-16S

0 /TITLE, INRT-16S, ceb, component omega loading and layer elements

0 /TITLE, INRT-16S, BENDING OF A COMPOSITE BEAM

EXTRA DATA SKIPPED ON TEST FILE  
NG= 462 NT= 459

T= USE COMMAND MACRO QAEND

END OF SKIPPED DATA

BOTTOM OF GOOD FILE REACHED AT LINE 469

G= | ANSYS RUN COMPLETED |

---------------------------------------------------------------------

NOTE- NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED

NUMBER OF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) = 1

NUMBER OF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) = 1

NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT = 0

NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT = 0

---------------------------------------------------------------------

COMPARE ERRORS = 1 *

---------------------------------------------------------------------

PROBLEM: inrt-16s  
COMPARE OPTIONS COMPARE_REL 3.8 UP20020121 WINDOWS

ALMOST ZERO (GOOD) = 1.0000E-006  
KROUND (DROP LAST DIGIT)= 1

ALMOST ZERO (TEST) = 1.0000E-006  
KAESFR (0=SUMMARY 1=ALL)= 1

ABSOLUTE VALUE TOL = 1.0000E-010  
KSKIP (SKIP=ERR 0=Y, 1=N)= 0

FRACTIONAL DIFFERENCE = 1.0000E-004  
MAXERR (STOP WHEN ERRS )= 100

ABSOLUTE DIFFERENCE = 1.0000E-006  
MAXBUF (# LINES TO SCAN)= 6

KNOWN (# OF KNOWN ERRS)= 0

GREAD, TREAD = 1, 1

---------------------------------------------------------------------

LINES ON GOOD FILE = 484

LINES ON TEST FILE = 486

---------------------------------------------------------------------

B.40
*** ERROR -- (VERSION=) was not found anywhere in the "TEST" file. ***

NOTE- NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED

NUMBER OF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) = 0
NUMBER OF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) = 0
NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT = 0
NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT = 0

COMPARE ERRORS = -88

PROBLEM: sx120-1s

COMPARE OPTIONS COMPARE REL 3.8 UP20020121 WINDOWS

ALMOST ZERO (GOOD) = 1.0000E-006
ALMOST ZERO (TEST) = 1.0000E-006
ABSOLUTE VALUE TOL = 1.0000E-010
FRACTIONAL DIFFERENCE = 1.0000E-004
ABSOLUTE DIFFERENCE = 1.0000E-008
KROUND (DROP LAST DIGIT) = 1
KABSPR (0=SUMMARY 1=ALL) = 1
KSKIP (SKIP=ERR 0=Y, 1=N) = 0
MAXERR (STOP WHEN ERRS ) = 100
MAXBUF (# LINES TO SCAN) = 8
KNOWN (# OF KNOWN ERRS) = 0
GREAD, TREAD = 1, 1

LINES ON GOOD FILE = 248
LINES ON TEST FILE = 146
Software Acceptance

1) Project Title and Number: DST Thermal and Seismic Analyses  48971

2) Software Name and Version: ANSYS 7.0 (Rev. 11)

3) Computer and Property Number: Dell DHM WD44879


5) Scope of Testing: Software reinstallation (XP SP2)

6) Tests: Execute ANSYS Verification Testing Package

7) Discrepancies:

   n)  c0231. These differences are acceptable per the ANSYS Verification Package User’s Guide—ANSYS Release 7.0 (AVPUG).

   o)  vml84. These differences occur at the 5th significant figure.

   p)  vml98. This difference is the reporting of the customer number for this installation.

   q)  vme8. These differences are acceptable as noted in the output because of the difference in number of iterations and accuracy.

   r)  cyc-177s. This difference is acceptable due to the handling of the QAEND macro (see AVPUG).

   s)  cyc-178s. This difference is acceptable due to the handling of the QAEND macro (see AVPUG).

   t)  dds-13s. This test case requires the “Parallel Performance Module” which is not part of this software installation and is not required for the DST analyses.

   u)  dds-17s. This test case requires the “Parallel Performance Module” which is not part of this software installation and is not required for the DST analyses.

   v)  evl73-53s. This difference is acceptable due to the handling of the QAEND macro (see AVPUG).

   w)  evl75-20s. This difference is acceptable due to the handling of the QAEND macro (see AVPUG).

   x)  evl75-21s. This test case requires the “Parallel Performance Module” which is not part of this software installation and is not required for the DST analyses.

   y)  inrt-16s. This difference is acceptable due to the handling of the QAEND macro (see AVPUG).

   z)  sx120-1s. This test case requires the “Frequency Sweep Module” which is not part of this software installation and is not required for the DST analyses.

8) Finding: This installation of ANSYS is acceptable.
Notes for test case c0231

Test case c0231 may show considerable differences for the Phase Angle value that is part of the Post1 Nodal Degree of Freedom Listing (PRNS command) output. Any such differences do not indicate a problem with this test case's results and should be considered acceptable. The output items of significance for this test case are the UZ values in the Post1 Nodal Degree of Freedom Listing. Machine precision differences in the form of small numerical differences that are trivial with respect to the test's output items of significance may also show for this test case in the compare output for this test. Please see Verifying ANSYS and Evaluating COMPARE Differences in Chapter 2 of the ANSYS Verification Testing Package User's Guide for more information on evaluating COMPARE differences. The following is an example of acceptable COMPARE differences for test case c0231:

```
COMPARE DIFFERENCE FOUND AT G=  NODAL RESULTS ARE FOR CYCLIC SECTOR T= NODAL RESULTS ARE FOR CYCLIC SECTOR
COMPARE DIFFERENCE FOUND AT G= NODAL RESULTS ARE FOR CYCLIC SECTOR T= NODAL RESULTS ARE FOR CYCLIC SECTOR
```

```
Notes for Test Case vm212

Test case vm212 may produce an expected compare difference due to an inconsequential warning message that appears in the ANSYS, Inc. supplied output file that may not appear in the output file generated by your system for this test case. This compare difference should be considered acceptable. The following is an example of this compare difference.

\[ \text{COMPARE DIFFERENCE FOUND AT} \quad \text{NG= 445 NT= 436} \]
\[ G= \text{NUMBER OF WARNING MESSAGES ENCOUNTERED}= 1 \]
\[ T= \text{NUMBER OF WARNING MESSAGES ENCOUNTERED}= 0. \]

Notes for Test Cases cyc-177s, cyc-178s, ev-173-53s, ev-175-20s, inrt-16s, and inrt-9s

Test cases cyc-177s, cyc-178s, ev-173-53s, ev-175-20s, inrt-16s, and inrt-9s may produce expected compare differences due to the use of a macro named qaend. The method that is used in the verification procedure (runqa) to handle this macro may cause one or more comparison differences. Any such compare differences are inconsequential and should be considered acceptable. The following is an example of such a compare difference.

\[ \text{EXTRA DATA SKIPPED ON TEST FILE} \quad \text{NG= 1033 NT= 1030} \]
\[ T= \text{USE COMMAND MACRO qaend} \]
\[ T= \text{ARGS}= 137 00 \]
\[ \text{END OF SKIPPED DATA} \quad \text{NG= 1033 NT= 1033} \]

Notes for test Cases dds-13s, dds-17s, and ev175-21s

The test cases dds-13s, dds-17s, and ev175-21s will run to completion only if the "Parallel Performance for ANSYS" product (DDS and AMG solvers) is included in your ANSYS installation.
<table>
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<th>File Name</th>
<th>MD5 Hash</th>
<th>Size</th>
<th>Percentage</th>
<th>Date</th>
<th>Time</th>
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<td>QA70-1</td>
<td>7020021010</td>
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<td>0</td>
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<td>81%</td>
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<td>510</td>
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<td>59%</td>
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<td>23:20</td>
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<td>23:20</td>
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<td>23:20</td>
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<td>02/12/2005</td>
<td>23:20</td>
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evl75-38s  7020021010  70SP20030909  0  0  808  808  85%  02/12/2005  23:21 INTEL_NT
INTEL NT  QA70-1  COMPAR REL  3.8 UP20020121 WINDOWS

7020021010  70SP20030909  0  0  600  600  85%  02/12/2005  23:21 INTEL_NT
INTEL NT  QA70-1  COMPAR REL  3.8 UP20020121 WINDOWS

... (repeated entries for other files)

mvhy-bk501  7020021010  70SP20030909  0  0  536  536  78%  02/12/2005  23:22 INTEL_NT
INTEL NT  QA70-1  COMPAR REL  3.8 UP20020121 WINDOWS

mvhy-am202  7020021010  70SP20030909  0  0  780  780  84%  02/12/2005  23:23 INTEL_NT
INTEL NT  QA70-1  COMPAR REL  3.8 UP20020121 WINDOWS

mvve-cr003  7020021010  70SP20030909  0  0  328  328  65%  02/12/2005  23:24 INTEL_NT
INTEL NT  QA70-1  COMPAR REL  3.8 UP20020121 WINDOWS

mvve-cr804  7020021010  70SP20030909  0  0  329  329  65%  02/12/2005  23:24 INTEL_NT
INTEL NT  QA70-1  COMPAR REL  3.8 UP20020121 WINDOWS

se-1a  7020021010  70SP20030909  0  0  400  400  72%  02/12/2005  23:24 INTEL_NT
INTEL NT  QA70-1  COMPAR REL  3.8 UP20020121 WINDOWS

se-20s  7020021010  70SP20030909  0  0  879  879  85%  02/12/2005  23:24 INTEL_NT
INTEL NT  QA70-1  COMPAR REL  3.8 UP20020121 WINDOWS

sxl20-1s  7020021010  70SP20030909  0  0  351  351  64%  02/12/2005  23:24 INTEL_NT
INTEL NT  QA70-1  COMPAR REL  3.8 UP20020121 WINDOWS

NOT AVAILABLE  QA70-1  70SP20030909  0  0  248  146  30%  02/12/2005  23:24 INTEL_NT
INTEL NT  QA70-1  COMPAR REL  3.8 UP20020121 WINDOWS

... (entries for other files)


---

**RPP-RPT-32237, Rev. 1**

---

```
*** 00000000 VERSION=INTEL NT RELEASE= 7.0 UP20021010  

EXPECTED COMPARE DIFFERENCE FOUND AT NG= 113 NT= 113  
G= 00000000 VERSION=INTEL NT RELEASE= 7.0 UP20021010  
T= 00292062 VERSION=INTEL NT RELEASE= 7.0SP11 UP20030909  

EXPECTED COMPARE DIFFERENCE FOUND AT NG= 114 NT= 114  
G= CURRENT JOBNAME=c0231 10:37:04 OCT 15, 2002 CP= 0.219  
T= CURRENT JOBNAME=c0231 21:33:01 FEB 12, 2005 CP= 0.094  
0 /verify,c0231  
0 /title, c0231 (fsk) Unmatched nodes mapping  

COMPARE DIFFERENCE FOUND AT NG= 192 NT= 192  
G= NODAL RESULTS ARE FOR CYCLIC SECTOR 1 - PHASE ANGLE = 30.580  
T= NODAL RESULTS ARE FOR CYCLIC SECTOR 1 - PHASE ANGLE = 237.330  

COMPARE DIFFERENCE FOUND AT NG= 219 NT= 219  
G= NODAL RESULTS ARE FOR CYCLIC SECTOR 2 - PHASE ANGLE = 30.580  
T= NODAL RESULTS ARE FOR CYCLIC SECTOR 2 - PHASE ANGLE = 237.330  

COMPARE DIFFERENCE FOUND AT NG= 246 NT= 246  
G= NODAL RESULTS ARE FOR CYCLIC SECTOR 3 - PHASE ANGLE = 30.580  
T= NODAL RESULTS ARE FOR CYCLIC SECTOR 3 - PHASE ANGLE = 237.330  

BOTTOM OF GOOD FILE REACHED AT LINE 289  
G= | ANSYS RUN COMPLETED |  

```

---

**NOTE- NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED**

---

```
NUMBER OF LINES SKIPPED IN GOOD FILE(BLANK LINES EXCLUDED) = 0  
NUMBER OF LINES SKIPPED IN TEST FILE(BLANK LINES EXCLUDED) = 0  
NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT = 0  
NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT = 0  
```

---

**COMPARE ERRORS = 3**

---

```
**PROBLEM: c0231**  
**COMPARE OPTIONS**  
**COMPARE_REL 3.8 UP20020121**  
**WINDOWS**  

| ALMOST ZERO {GOOD} = 1.0000E-006 | KROUND (DROP LAST DIGIT)= 1  
| ALMOST ZERO {TEST} = 1.0000E-006 | KAESPR (O=SUMMARY I=ALL)= 1  
| ABSOLUTE VALUE TOL = 1.0000E-010 | KSKIP(SKIP=ERR 0=Y, I=N)= 0  
| FRACTIONAL DIFFERENCE= 1.0000E-004 | MAXERR (STOP WHEN ERRS )= 100  
| ABSOLUTE DIFFERENCE= 1.0000E-006 | MAXBUF (# LINES TO SCAN)= 6  
|                       | KNOWN (# OF KNOWN ERRS)= 0  
```

---

"B.61"
LINES ON GOOD FILE = 304
LINES ON TEST FILE = 304

****************************************************
**Comparison of ANSYS Analysis Definition (PREP7) and Results Interpretation (POST1) for STRAIGHT CANTILEVER BEAM**

**Expected Comparisons**: Found at NG=113, NT=113

**Current Jobname**: vm184 20:46:18 OCT 15, 2002 CP=0.250

**Reason for Acceptable Differences**: Near-zero values

**Absolute Value Differences**: Found at NG=926, NT=926

**Current Jobname**: vm184 21:48:44 FEB 12, 2005 CP=0.109

**Absolute Value Differences**: Found at NG=1639, NT=1639

**Now Comparing Lines from ANSYS Analysis Definition (PREP7)**

**Now Comparing Lines from ANSYS Results Interpretation (POST1)**

---

B.63
T= VALUE -0.53533E-02 0.30756E-05 0.42553 0.42556
ABSOLUTE VALUE DIFFERENCE FOUND AT NG= 1673 NT= 1673
G= VALUE -0.12392E-01-0.71193E-05 0.98502 0.98510
T= VALUE -0.12392E-01 0.71194E-05 0.98502 0.98510
NOW COMPARING LINES FROM ***** ANSYS ANALYSIS DEFINITION (PREP7) *****
NOW COMPARING LINES FROM ***** ANSYS RESULTS INTERPRETATION (POST1)
*****
NOW COMPARING LINES FROM ***** ANSYS ANALYSIS DEFINITION (PREP7) *****
NOW COMPARING LINES FROM ***** ANSYS RESULTS INTERPRETATION (POST1)
*****
BOTTOM OF GOOD FILE REACHED AT LINE 3147
G= | ANSYS RUN COMPLETED |

NOTE- NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED
NUMBER OF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) = 0
NUMBER OF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) = 0
NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT = 0
NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT = 0
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
COMPARE ERRORS = 1 *
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

WARNING - 5 ABSOLUTE VALUE DIFFERENCE(S) FOUND.
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
NOTE - 1 summary line(s) contained absolute value differences.
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

PROBLEM: vm184
COMPARE OPTIONS COMPARE REL 3.8 UP20020121 WINDOWS
ALMOST ZERO (GOOD) = 1.0000E-006 KROUND (DROP LAST DIGIT)= 1
ALMOST ZERO (TEST) = 1.0000E-006 KABSPR (O=SUMMARY 1=ALL)= 1
ABSOLUTE VALUE TOL = 1.0000E-010 KSkip (Skip=Err O=Y, I=N)= 0
FRACTIONAL DIFFERENCE- 1.0000E-004 MAXERR (STOP WHEN ERRS )= 100
ABSOLUTE DIFFERENCE - 1.0000E-006 MAXBUF (# LINES TO SCAN)= 6
KNOW (# OF KNOWN ERRS)= 0

B.64
GREAD, TREAD = 1, 1

LINES ON GOOD FILE = 3162
LINES ON TEST FILE = 3162

*--------------------------------------------------------------------------*
**VERSI0N=INTEL NT**
**RELEASE= 7.0 UP20021010**

EXPECTED COMPARE DIFFERENCE FOUND AT NG= 113 NT= 113
G= 00000000 VERSION=INTEL NT RELEASE= 7.0 UP20021010
T= 00292062 VERSION=INTEL NT RELEASE= 7.0 SP11 UP20030909

**EXPECTED COMPARE DIFFERENCE FOUND AT NG= 114 NT= 114**
G= CURRENT JOBNANE=vml98 20:50:49 OCT 15, 2002 CP= 0.266
T= CURRENT JOBNANE=vml98 21:49:55 FEB 12, 2005 CP= 0.094

0 /VERIFY, VM198
0 /TITLE, VM198, LARGE STRAIN IN-PLANE TORSION TEST [%EL%]

NOW COMPARING LINES FROM ***** ANSYS ANALYSIS DEFINITION (PREP7) *****

NOW COMPARING LINES FROM ***** ANSYS RESULTS INTERPRETATION (POST1) *****

NOW COMPARING LINES FROM ***** TIME-HISTORY POSTPROCESSOR (POST26) *****

NOW COMPARING LINES FROM ***** ANSYS ANALYSIS DEFINITION (PREP7) *****

COMPARE DIFFERENCE FOUND AT NG= 618 NT= 618
G= RELEASE 0.0 UPDATE 0 CUSTOMER 00000000
T= RELEASE 0.0 UPDATE 0 CUSTOMER 00292062

NOW COMPARING LINES FROM ***** ANSYS RESULTS INTERPRETATION (POST1) *****

NOW COMPARING LINES FROM ***** TIME-HISTORY POSTPROCESSOR (POST26) *****

NOW COMPARING LINES FROM ***** ANSYS ANALYSIS DEFINITION (PREP7) *****

COMPARE DIFFERENCE FOUND AT NG= 907 NT= 907
G= RELEASE 0.0 UPDATE 0 CUSTOMER 00000000
T= RELEASE 0.0 UPDATE 0 CUSTOMER 00292062

NOW COMPARING LINES FROM ***** ANSYS RESULTS INTERPRETATION (POST1) *****

NOW COMPARING LINES FROM ***** TIME-HISTORY POSTPROCESSOR (POST26) *****

B.66
NOTE- NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED

NUMBER OF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) = 2
NUMBER OF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) = 2
NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT = 0
NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT = 0

******************************
COMPARE ERRORS = 2 *
******************************

---

PROBLEM: vm198

COMPARE OPTIONS

<table>
<thead>
<tr>
<th>ALMOST ZERO (GOOD)</th>
<th>ALMOST ZERO (TEST)</th>
<th>ABSOLUTE VALUE TOL</th>
<th>FRACTIONAL DIFFERENCE</th>
<th>ABSOLUTE DIFFERENCE</th>
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</thead>
<tbody>
<tr>
<td>$1.00000E-006$</td>
<td>$1.00000E-006$</td>
<td>$1.00000E-010$</td>
<td>$1.00000E-004$</td>
<td>$1.00000E-006$</td>
</tr>
</tbody>
</table>

KROUND (DROP LAST DIGIT) = 1
KABSPR (0=SUMMARY 1=ALL) = 1
KSKIP (SKIP=ERR 0=Y, 1=N) = 0
MAXERR (STOP WHEN ERRS ) = 100
MAXBUF (# LINES TO SCAN) = 6
KNOWN (# OF KNOWN ERRS) = 0
GREAD, TREAD = 1, 1

LINES ON GOOD FILE = 1208
LINES ON TEST FILE = 1208

******************************
**EXPECTED COMPARE DIFFERENCE FOUND AT NG= 113 NT= 113**

**EXPECTED COMPARE DIFFERENCE FOUND AT NG= 114 NT= 114**

0 /VERIFY, VMCS

0 /TITLE, VMCS, ALUMINUM BAR IMPACTING A RIGID BOUNDARY

0 /stitle, 1, Reason COMPARE differences are acceptable:

0 /stitle, 2, number of iterations, accuracy

**PLANE2**

0 /title, VMCS, ALUMINUM BAR IMPACTING A RIGID BOUNDARY -

**PLANE42**

0 /title, VMCS, ALUMINUM BAR IMPACTING A RIGID BOUNDARY -

**PLANE82**

0 /title, VMCS, ALUMINUM BAR IMPACTING A RIGID BOUNDARY -

**VISCO106**

0 /title, VMCS, ALUMINUM BAR IMPACTING A RIGID BOUNDARY -

**SOLID45**

0 /title, VMCS, ALUMINUM BAR IMPACTING A RIGID BOUNDARY -

**SOLID95**

0 /title, VMCS, ALUMINUM BAR IMPACTING A RIGID BOUNDARY -

**VISCO107**

0 /TITLE, VMCS, ALUMINUM BAR IMPACTING A RIGID BOUNDARY

NOW COMPARING LINES FROM ***** ANSYS ANALYSIS DEFINITION (PREP7) *****

NOW COMPARING LINES FROM ***** ANSYS RESULTS INTERPRETATION (POST1) *****
NOW COMPARING LINES FROM
***** TIME-HISTORY POSTPROCESSOR (POST26)

NOW COMPARING LINES FROM
***** ANSYS ANALYSIS DEFINITION (PREP7) *****

NOW COMPARING LINES FROM
***** ANSYS RESULTS INTERPRETATION (POST1)

NOW COMPARING LINES FROM
***** TIME-HISTORY POSTPROCESSOR (POST26)

NOW COMPARING LINES FROM
***** ANSYS ANALYSIS DEFINITION (PREP7) *****

NOW COMPARING LINES FROM
***** ANSYS RESULTS INTERPRETATION (POST1)

NOW COMPARING LINES FROM
***** TIME-HISTORY POSTPROCESSOR (POST26)

NOW COMPARING LINES FROM
***** ANSYS ANALYSIS DEFINITION (PREP7) *****

NOW COMPARING LINES FROM
***** ANSYS RESULTS INTERPRETATION (POST1)

NOW COMPARING LINES FROM
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***** ANSYS ANALYSIS DEFINITION (PREP7) *****

NOW COMPARING LINES FROM
***** ANSYS RESULTS INTERPRETATION (POST1)

NOW COMPARING LINES FROM
***** TIME-HISTORY POSTPROCESSOR (POST26)

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***** ANSYS ANALYSIS DEFINITION (PREP7) *****

NOW COMPARING LINES FROM
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NOW COMPARING LINES FROM
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***** ANSYS ANALYSIS DEFINITION (PREP7) *****

NOW COMPARING LINES FROM
***** ANSYS RESULTS INTERPRETATION (POST1)

NOW COMPARING LINES FROM
***** TIME-HISTORY POSTPROCESSOR (POST26)

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***** ANSYS ANALYSIS DEFINITION (PREP7) *****

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***** TIME-HISTORY POSTPROCESSOR (POST26)

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***** ANSYS ANALYSIS DEFINITION (PREP7) *****

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***** TIME-HISTORY POSTPROCESSOR (POST26)

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***** ANSYS ANALYSIS DEFINITION (PREP7) *****

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***** ANSYS RESULTS INTERPRETATION (POST1)

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***** TIME-HISTORY POSTPROCESSOR (POST26)

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***** ANSYS ANALYSIS DEFINITION (PREP7) *****

NOW COMPARING LINES FROM
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***** TIME-HISTORY POSTPROCESSOR (POST26)

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***** ANSYS ANALYSIS DEFINITION (PREP7) *****

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***** ANSYS RESULTS INTERPRETATION (POST1)

NOW COMPARING LINES FROM
***** TIME-HISTORY POSTPROCESSOR (POST26)

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***** ANSYS ANALYSIS DEFINITION (PREP7) *****

NOW COMPARING LINES FROM
***** ANSYS RESULTS INTERPRETATION (POST1)

NOW COMPARING LINES FROM
***** TIME-HISTORY POSTPROCESSOR (POST26)

NOW COMPARING LINES FROM
***** ANSYS ANALYSIS DEFINITION (PREP7) *****

NOW COMPARING LINES FROM
***** ANSYS RESULTS INTERPRETATION (POST1)

NOW COMPARING LINES FROM
***** TIME-HISTORY POSTPROCESSOR (POST26)

NOW COMPARING LINES FROM
***** ANSYS ANALYSIS DEFINITION (PREP7) *****

NOW COMPARING LINES FROM
***** ANSYS RESULTS INTERPRETATION (POST1)

NOW COMPARING LINES FROM
***** TIME-HISTORY POSTPROCESSOR (POST26)

NOW COMPARING LINES FROM
***** ANSYS ANALYSIS DEFINITION (PREP7) *****

NOW COMPARING LINES FROM
***** ANSYS RESULTS INTERPRETATION (POST1)

NOW COMPARING LINES FROM
***** TIME-HISTORY POSTPROCESSOR (POST26)

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NOW COMPARING LINES FROM
***** TIME-HISTORY POSTPROCESSOR (POST26)

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***** ANSYS ANALYSIS DEFINITION (PREP7) *****

NOW COMPARING LINES FROM
***** ANSYS RESULTS INTERPRETATION (POST1)

NOW COMPARING LINES FROM
***** TIME-HISTORY POSTPROCESSOR (POST26)

NOW COMPARING LINES FROM
***** ANSYS ANALYSIS DEFINITION (PREP7) *****

NOW COMPARING LINES FROM
***** ANSYS RESULTS INTERPRETATION (POST1)

NOW COMPARING LINES FROM
***** TIME-HISTORY POSTPROCESSOR (POST26)

NOW COMPARING LINES FROM
***** ANSYS ANALYSIS DEFINITION (PREP7) *****

NOW COMPARING LINES FROM
***** ANSYS RESULTS INTERPRETATION (POST1)
NOW COMPARING LINES FROM  

TIME-HISTORY POSTPROCESSOR (POST26)  

BOTTOM OF GOOD FILE REACHED AT LINE 1879  
G= | ANSYS RUN COMPLETED |  

NOTE- NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED  
NUMBER OF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) = 0  
NUMBER OF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) = 0  
NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT = 0  
NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT = 0  

COMPARE ERRORS = 2  

---------------------------------------------------------------------  
PROBLEM: vmc8  
COMPARE OPTIONS  
COMPAR REL 3.8 UP20020121  
WINODWS  

ALMOST ZERO (GOOD) = 1.0000E-006  
ALMOST ZERO (TEST) = 1.0000E-006  
ABSOLUTE VALUE TOL = 1.0000E-010  
FRACTIONAL DIFFERENCE = 1.0000E-004  
ABSOLUTE DIFFERENCE = 1.0000E-006  

KROUND (DROP LAST DIGIT) = 1  
KABSPR (0-SUMMARY 1-ALL) = 1  
KSKIP (SKIP=ERR 0=Y, 1=N) = 0  
MAXERR (STOP WHEN ERRORS) = 100  
MAXBUF (# LINES TO SCAN) = 6  
KNOWN (# OF KNOWN ERRORS) = 0  
GREAD, TREAD = 1, 1  

LINES ON GOOD FILE = 1894  
LINES ON TEST FILE = 1894  
---------------------------------------------------------------------
**EXPECTED COMPARE DIFFERENCE FOUND AT**

G= 00000000 VERSION=INTEL NT
T= 002 920 62 VERSION=INTEL NT

**RELEASE= 7.0**

**EXPECTED COMPARE DIFFERENCE FOUND AT**

G= CURRENT JOBNAME=cyc-177s 11:45:34 OCT 15, 2002 CP= 0.219
T= CURRENT JOBNAME=cyc-177s 23:11:09 FEB 12, 2005 CP= 0.109

0 /verify,cyc-177s
0 /TITLE, ceb,cyc-177s, Test cyc symm Buckling element 42
0 /title,1,Full Results to Sector Results!
0 /stitle,Reason Compare differences are acceptable:

**EXTRA DATA SKIPPED ON TEST FILE**

T= USE COMMAND MACRO QAEND
T= ARGS= 28 9.00
END OF SKIPPED DATA

**BOTTOM OF GOOD FILE REACHED AT LINE 1204**

G= | ANSYS RUN COMPLETED |

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

**NOTE- NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED**

**NUMBER OF LINES SKIPPED IN GOOD FILE(ELANK LINES EXCLUDED) - 2**
**NUMBER OF LINES SKIPPED IN TEST FILE(ELANK LINES EXCLUDED) - 2**
**NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT - 0**
**NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT - 0**

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

**COMPARE ERRORS = 1 * ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~**

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

**PROBLEM: cyc-177s**

**COMPARE OPTIONS**

**COMPARE_REL 3.8 UP20020121 WINDOWS**

**ALMOST ZERO (GOOD) = 1.0000E-006**
**ALMOST ZERO (TEST) = 1.0000E-006**
**ABSOLUTE VALUE TOL = 1.0000E-010**
**FRACTIONAL DIFFERENCE = 1.0000E-004**
**ABSOLUTE DIFFERENCE = 1.0000E-006**

**KROUND (DROP LAST DIGIT)= 1**
**KABSPR (0=SUMMARY 1=ALL)= 1**
**KSKIP(SKIP=ERR 0=Y, 1=N)= 0**
**MAXERR (STOP WHEN ERRS )= 100**
**MAXBUF (# LINES TO SCAN)= 6**
**KNOWN (# OF KNOWN ERRS)= 0**
**GREAD, TREAD = 1, 1**

B.71
LINES ON GOOD FILE = 1219
LINES ON TEST FILE = 1222
******************************************************************************************
**00000000**  VERSION=INTEL NT    RELEASE= 7.0    UP20021010

EXPECTED COMPARE DIFFERENCE FOUND AT  NG=  113  NT=  113
G=  00000000  VERSION=INTEL NT    RELEASE= 7.0    UP20021010
T=  00292062  VERSION=INTEL NT    RELEASE= 7.0.SP11    UP20030909

EXPECTED COMPARE DIFFERENCE FOUND AT  NG=  114  NT=  114
G=  CURRENT JOBNAME=cyc-178s  11:48:41  OCT 15, 2002  CP=  0.250
T=  CURRENT JOBNAME=cyc-178s  23:13:04  FEB 12, 2005  CP=  0.125

0  /verify,cyc-178s
0  /TITLE, ceb,cyc-178s, Test cyc sym Buckling element 182
0  /title,1,Full Results to Sector Results!
0  /stitle,Reason Compare differences are acceptable:

EXTRA DATA SKIPPED ON TEST FILE  NG=  1202  NT=  1194
T=  USE COMMAND MACRO QAEND
T=  ARGS=  289,00
END OF SKIPPED DATA  NG=  1202  NT=  1199

BOTTOM OF GOOD FILE REACHED AT LINE  1204
G=  |  ANSYS RUN COMPLETED

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
NOTE- NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED
NUMBER OF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) =  2
NUMBER OF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) =  2
NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED CUT =  0
NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED CUT =  0
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

COMPARE ERRORS =  1  *
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

PROBLEM: cyc-178s  COMPARE OPTIONS  COMPARE REL 3.8  UP20020121  WINDOWS

ALMOST ZERO (GOOD) =  1.0000E-006  KROUND (DROP LAST DIGIT)=  1
ALMOST ZERO (TEST)  =  1.0000E-006  KABSFR (0=SUMMARY 1=ALL)=  1
ABSOLUTE VALUE TOL  =  1.0000E-010  KSkip(Skip=Err 0=Y, 1=N)=  0
FRACTIONAL DIFFERENCE=  1.0000E-004  MAXERR (STOP WHEN ERRS )= 100
ABSOLUTE DIFFERENCE  =  1.0000E-006  MAXBUF (# LINES TO SCAN)=  6
                       KNOWN (# OF KNOWN ERRS)=  0
                       GREAD, TREAD =  1, 1

B.73
LINES ON GOOD FILE = 1219
LINES ON TEST FILE = 1222

*****************************************************************************
*** ERROR -- (VERSION=) was not found anywhere in the "TEST" file. ***
*** Comparison was supposed to start at this string, specified in CMPOPT. ***

NOTE- NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED

NUMBER OF LINES SKIPPED IN GOOD FILE (ELANK LINES EXCLUDED) = 0
NUMBER OF LINES SKIPPED IN TEST FILE (ELANK LINES EXCLUDED) = 0
NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT = 0
NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT = 0

COMPARE ERRORS = -68

---

PROBLEM: dds-13s

<table>
<thead>
<tr>
<th>COMPARE OPTIONS</th>
<th>COMPARE REL 3.8</th>
<th>UP20020121</th>
<th>WINDOWS</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALMOST ZERO (GOOD) = 1.0000E-006</td>
<td>KROUND (DROP LAST DIGIT)= 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ALMOST ZERO (TEST) = 1.0000E-006</td>
<td>KABSPR (0=SUMMARY 1=ALL)= 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABSOLUTE VALUE TOL = 1.0000E-010</td>
<td>KSKIP (SKIP=ERR 0=Y, 1=N)= 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRACTIONAL DIFFERENCE= 1.0000E-004</td>
<td>MAXERR (STOP WHEN ERRS )= 100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABSOLUTE DIFFERENCE = 1.0000E-006</td>
<td>MAXBUF (# LINES TO SCAN)= 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>KNOWN (# OF KNOWN ERRS)= 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>GREAD, TREAD = 1, 1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

LINES ON GOOD FILE = 402
LINES ON TEST FILE = 146
**WARNING — (VERSION=) was not found anywhere in the "TEST" file. **
**Comparison was supposed to start at this string, specified in CMPOPT. **

---

**NOTE— NONSTANDARD COMPARE — DIFOPT NAME QA70-1 HAS BEEN USED**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of lines skipped in good file (blank lines excluded)</td>
<td>0</td>
</tr>
<tr>
<td>Number of lines skipped in test file (blank lines excluded)</td>
<td>0</td>
</tr>
<tr>
<td>Number of lines on good file with strings condensed out</td>
<td>0</td>
</tr>
<tr>
<td>Number of lines on test file with strings condensed out</td>
<td>0</td>
</tr>
</tbody>
</table>

---

**COMPARE ERRORS =  -88**

---

**PROBLEM: dds-17s**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALMOST ZERO (GOOD)</td>
<td>1.0000E-006</td>
</tr>
<tr>
<td>ALMOST ZERO (TEST)</td>
<td>1.0000E-006</td>
</tr>
<tr>
<td>Absolute value tol</td>
<td>1.0000E-10</td>
</tr>
<tr>
<td>Fractional difference</td>
<td>1.0000E-004</td>
</tr>
<tr>
<td>Absolute difference</td>
<td>1.0000E-008</td>
</tr>
</tbody>
</table>

**COMPARE OPTIONS**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>KROUND (DROP LAST DIGIT)</td>
<td>1</td>
</tr>
<tr>
<td>KABSPR (0=SUMMARY 1=ALL)</td>
<td>1</td>
</tr>
<tr>
<td>KSKIP (SKIP=ERR 0=Y, 1=N)</td>
<td>0</td>
</tr>
<tr>
<td>MAXERR (STOP WHEN ERRS )</td>
<td>100</td>
</tr>
<tr>
<td>MAXBUF (# LINES TO SCAN)</td>
<td>6</td>
</tr>
<tr>
<td>KNOWN (# OF KNOWN ERRS)</td>
<td>0</td>
</tr>
<tr>
<td>GREAD, TREAD = 1, 1</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lines on good file</td>
<td>746</td>
</tr>
<tr>
<td>Lines on test file</td>
<td>146</td>
</tr>
</tbody>
</table>

---

B.76
**EXTRA DATA SKIPPED ON TEST FILE**

**USE COMMAND MACRO QAEND**

**END OF SKIPPED DATA**

**BOTTOM OF GOOD FILE REACHED AT LINE 1411**

**ANSYS RUN COMPLETED**

---

**NOTE- NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED**

**NUMBER OF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) = 2**

**NUMBER OF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) = 2**

**NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT = 0**

**NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT = 0**

---

**COMPARE ERRORS = 1**

---

**PROBLEM: evl73-53s**

**COMPARE OPTIONS**

**COMPARE_REL 3.8 UP20020121 WINDOWS**

**LINES ON GOOD FILE = 1426**

**LINES ON TEST FILE = 1429**

---
**ANSYS ANALYSIS DEFINITION (PREP7)**

EXTRA DATA SKIPPED ON TEST FILE

T= USE COMMAND MACRO QAEND

END OF SKIPPED DATA

BOTTOM OF GOOD FILE REACHED AT LINE 523

G=  | ANSYS RUN COMPLETED  |

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

NOTE - NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED
NUMBER OF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) = 2
NUMBER OF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) = 2
NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT = 0
NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT = 0

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

COMPARE ERRORS = 1 *

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

**PROBLEM: evl75-20s**

**COMPARE OPTIONS**

<table>
<thead>
<tr>
<th>ALMOST ZERO (GOOD)</th>
<th>ALMOST ZERO (TEST)</th>
<th>ABSOLUTE VALUE TOL</th>
<th>FRACTIONAL DIFFERENCE</th>
<th>ABSOLUTE DIFFERENCE</th>
<th>KROUND (DROP LAST DIGIT)</th>
<th>KABSPR (0=SUMMARY 1=ALL)</th>
<th>KSKIP (SKIP=ERR 0=Y, 1=N)</th>
<th>MAXERR (STOP WHEN ERRS )</th>
<th>MAXBUF (# LINES TO SCAN)</th>
<th>KNOWN (# OF KNOWN ERRS)</th>
<th>GREAD, TREAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0000E-006</td>
<td>1.0000E-006</td>
<td>1.0000E-010</td>
<td>1.0000E-004</td>
<td>1.0000E-006</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>100</td>
<td>6</td>
<td>0</td>
<td>1, 1</td>
</tr>
</tbody>
</table>

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
LINES ON GOOD FILE = 538
LINES ON TEST FILE = 541
*** ERROR -- (VERSION=) was not found anywhere in the "TEST" file. ***
*** Comparison was supposed to start at this string, specified in CMPOPT. ***

NOTE- NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED

NUMBER OF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) = 0
NUMBER OF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) = 0
NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT = 0
NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT = 0

*****************************************************************************

COMPARE ERRORS = -8
*****************************************************************************

PROBLEM: evl75-21s
COMPARE OPTIONS COMPARE_REL 3.8 UP20020121 WINDOWS

ALMOST ZERO (GOOD) = 1.0000E-006
ALMOST ZERO (TEST) = 1.0000E-006
ABSOLUTE VALUE TOL = 1.0000E-010
FRACTIONAL DIFFERENCE= 1.0000E-004
ABSOLUTE DIFFERENCE = 1.0000E-008
KROUND (DROP LAST DIGIT)= 1
KABSPR (0=SUMMARY 1=ALL) = 1
KSKIP (SKIP.ERR 0-Y, 1-N) = 0
MAXERR (STOP WHEN ERRS ) = 100
MAXBUF (# LINES TO SCAN) = 6
KNOWN (# OF KNOWN ERRS) = 0
GREAD, TREAD = 1, 1

LINES ON GOOD FILE = 566
LINES ON TEST FILE = 146

*****************************************************************************
\texttt{\textbackslash VERIFY, INRT-16S}

\texttt{\textbackslash TITLE, INRT-16S, ceh, component omega loading and layer elements}

\texttt{\textbackslash TITLE, INRT-16S, BENDING OF A COMPOSITE BEAM}

\texttt{EXTRA DATA SKIPPED ON TEST FILE NG= 462 NT= 459}

\texttt{T= USE COMMAND MACRO QAEND END OF SKIPPED DATA NG= 462 NT= 463}

\texttt{BOTTOM OF GOOD FILE REACHED AT LINE 469}

\texttt{G= | ANSYS RUN COMPLETED |}

\texttt{NOTE- NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED}

\texttt{NUMBER OF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) - 1}

\texttt{NUMBER OF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) - 1}

\texttt{NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT - 0}

\texttt{NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT - 0}

\texttt{COMPARE ERRORS = 1 *}

\texttt{*******************************************************************************}

\texttt{G0000000 VERSION=INTEL NT RELEASE= 7.0 UP20021010}

\texttt{EXPECTED COMPARE DIFFERENCE FOUND AT NG= 113 NT= 113}

\texttt{G= 00000000 VERSION=INTEL NT RELEASE= 7.0 UP20021010}

\texttt{T= 00292062 VERSION=INTEL NT RELEASE= 7.0SP11 UP20030909}

\texttt{EXPECTED COMPARE DIFFERENCE FOUND AT NG= 114 NT= 114}

\texttt{G= CURRENT JOBNAME=inrt-16s 16:14:59 OCT 15, 2002 CP= 0.219}

\texttt{T= CURRENT JOBNAME=inrt-16s 23:22:50 FEB 12, 2005 CP= 0.109}

\texttt{B.81}
*** ERROR -- (VERSION=) was not found anywhere in the "TEST" file. ***
*** Comparison was supposed to start at this string, specified in CMPOPT. ***

NOTE- NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED
NUMBER OF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) = 0
NUMBER OF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) = 0
NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT = 0
NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT = 0

COMPARE ERRORS = -88

---

PROBLEM: sxl20-ls

COMPARE OPTIONS

ALMOST ZERO (GOOD) = 1.0000E-006
ALMOST ZERO (TEST) = 1.0000E-006
ABSOLUTE VALUE TOL = 1.0000E-010
FRACTIONAL DIFFERENCE = 1.0000E-004
ABSOLUTE DIFFERENCE = 1.0000E-006

KROUND (DROP LAST DIGIT) = 1
KABSPR (0=SUMMARY 1=ALL) = 1
KSKIP (SKIP ERR 0=Y, 1=N) = 0
MAXERR (STOP WHEN ERRS ) = 100
MAXBUF (# LINES TO SCAN) = 6
KNOWN (# OF KNOWN ERRS) = 0
GREAD, TREAD = 1, 1

LINES ON GOOD FILE = 248
LINES ON TEST FILE = 146
Software Acceptance

1) Project Title and Number: DST Thermal and Seismic Analyses 48971
2) Software Name and Version: ANSYS 7.0 (Rev. 11)
3) Computer and Property Number: Generic PC WD44903
5) Scope of Testing: Hardware replacement and Software reinstallation (XP SP2)
6) Tests: Execute ANSYS Verification Testing Package
7) Discrepancies:
   aa) c0231. These differences are acceptable per the ANSYS Verification Package User’s Guide—ANSYS Release 7.0 (AVPUG).
   bb) vm33. These differences are acceptable due to the unused degree of freedom (see AVPUG).
   cc) vm176. These differences are acceptable due to the unused degree of freedom (see AVPUG).
   dd) vm184. These differences occur at the 5th significant figure.
   ee) vm198. This difference is the reporting of the customer number for this installation.
   ff) vmc8. These differences are acceptable as noted in the output because of the difference in number of iterations and accuracy.
   gg) cyc-177s. This difference is acceptable due to the handling of the QAEND macro (see AVPUG).
   hh) cyc-178s. This difference is acceptable due to the handling of the QAEND macro (see AVPUG).
   ii) dds-13s. This test case requires the “Parallel Performance Module” which is not part of this software installation and is not required for the DST analyses.
   jj) dds-17s. This test case requires the “Parallel Performance Module” which is not part of this software installation and is not required for the DST analyses.
   kk) ev173-53s. This difference is acceptable due to the handling of the QAEND macro (see AVPUG).
   ll) ev175-20s. This difference is acceptable due to the handling of the QAEND macro (see AVPUG).
   mm) ev175-21s. This test case requires the “Parallel Performance Module” which is not part of this software installation and is not required for the DST analyses.
nn) inrt-16s. This difference is acceptable due to the handling of the QAEND macro (see AVFUG).

8) Finding: This installation of ANSYS is acceptable.

Certified by:

JE Deibler
Code Custodian

Reviewed by:

SP Pilli
Staff Engineer
Notes for test case c0231

Test case c0231 may show considerable differences for the Phase Angle value that is part of the Postl Nodal Degree of Freedom Listing (PRNS command) output. Any such differences do not indicate a problem with this test case's results and should be considered acceptable. The output items of significance for this test case are the UZ values in the Postl Nodal Degree of Freedom Listing. Machine precision differences in the form of small numerical differences that are trivial with respect to the test's output items of significance may also show for this test case in the compare output for this test. Please see Verifying ANSYS and Evaluating COMPARE Differences in Chapter 2 of the ANSYS Verification Testing Package User's Guide for more information on evaluating COMPARE differences. The following is an example of acceptable COMPARE differences for test case c0231:


COMPARE DIFFERENCE FOUND AT G= NODAL RESULTS ARE FOR CYCLIC SECTOR T= NODAL RESULTS ARE FOR CYCLIC SECTOR


COMPARE DIFFERENCE FOUND AT G= NODAL RESULTS ARE FOR CYCLIC SECTOR T= NODAL RESULTS ARE FOR CYCLIC SECTOR


COMPARE DIFFERENCE FOUND AT NG= 259 NT= 259 G= VALUE -4.5501 0.39425 56 T= VALUE -4.5503 0.39419 56

COMPARE DIFFERENCE FOUND AT NG= 260 NT= 260 G= VALUE -4.5505 0.39416 56 T= VALUE -4.5503 0.39419 56

COMPARE DIFFERENCE FOUND AT NG= 261 NT= 261 G= VALUE -4.5507 0.39416 56 T= VALUE -4.5507 0.39416 56

COMPARE DIFFERENCE FOUND AT NG= 262 NT= 262 G= VALUE -4.5507 0.39416 56 T= VALUE -4.5507 0.39416 56

COMPARE DIFFERENCE FOUND AT NG= 263 NT= 263 G= VALUE -4.5507 0.39416 56 T= VALUE -4.5507 0.39416 56

COMPARE DIFFERENCE FOUND AT NG= 264 NT= 264 G= VALUE -4.5507 0.39416 56 T= VALUE -4.5507 0.39416 56

COMPARE DIFFERENCE FOUND AT NG= 265 NT= 265 G= VALUE -4.5507 0.39416 56 T= VALUE -4.5507 0.39416 56

COMPARE DIFFERENCE FOUND AT NG= 266 NT= 266 G= VALUE -4.5507 0.39416 56 T= VALUE -4.5507 0.39416 56


COMPARE DIFFERENCE FOUND AT NG= 269 NT= 269 G= VALUE -9.6034 -3.9649 56 T= VALUE -9.6036 -3.9643 56


Notes for Test Case vm33 and vm176

Test case vm33 and vm176 will produce a number of expected compare differences due to product restrictions in the PLANE13 element's functionality. The expected compare differences are the result of the MAG degree of freedom being absent in the test case's output when it is run with the ANSYS/ Mechanical product. Since the MAG degree of freedom is unused in these test cases, these compare differences should be considered acceptable.

Notes for Test Case vm212

Test case vm212 may produce an expected compare difference due to an inconsequential warning message that appears in the ANSYS, Inc. supplied output file that may not appear in the output file generated by your system for this test case. This compare difference should be considered acceptable. The following is an example of this compare difference.

```
COMPARE DIFFERENCE FOUND AT  NG= 445 NT= 436
G= NUMBER OF WARNING MESSAGES ENCOUNTERED= 1
T= NUMBER OF WARNING MESSAGES ENCOUNTERED= 0
```

Notes for Test Cases cyc-177s, cyc-178s, ev-173-53s, ev-175-20s, inrt-16s, and inrt-9s

Test cases cyc-177s, cyc-178s, ev-173-53s, ev-175-20s, inrt-16s, and inrt-9s may produce expected compare differences due to the use of a macro named qaend. The method that is used in the verification procedure (runqa) to handle this macro may cause one or more comparison differences. Any such compare differences are inconsequential and should be considered acceptable. The following is an example of such a compare difference.

```
EXTRA DATA SKIPPED ON TEST FILE  NG= 1033 NT= 1030
T= USE COMMAND MACRO qaend
T=ARGS= 137.00
END OF SKIPPED DATA  NG= 1033 NT= 1033
```

Notes for test Cases dds-13s, dds-17s, and ev175-21s

The test cases dds-13s, dds-17s, and ev175-21s will run to completion only if the "Parallel Performance for ANSYS" product (DDS and AMG solvers) is included in your ANSYS installation.
<p>| c0232 | QA70-1 | 70SP20030909 | 0 | 0 | 517 | 517 | 79% | 11/10/2005 | 17:29 | INTEL_NT |
| c0233 | QA70-1 | 70SP20030909 | 0 | 0 | 542 | 542 | 75% | 11/10/2005 | 17:29 | INTEL_NT |
| c0234 | QA70-1 | 70SP20030909 | 0 | 0 | 420 | 420 | 68% | 11/10/2005 | 17:29 | INTEL_NT |
| vm1   | QA70-1 | 70SP20030909 | 0 | 0 | 474 | 474 | 72% | 11/10/2005 | 17:29 | INTEL_NT |
| vm2   | QA70-1 | 70SP20030909 | 0 | 0 | 667 | 667 | 81% | 11/10/2005 | 17:29 | INTEL_NT |
| vm3   | QA70-1 | 70SP20030909 | 0 | 0 | 499 | 499 | 73% | 11/10/2005 | 17:29 | INTEL_NT |
| vm4   | QA70-1 | 70SP20030909 | 0 | 0 | 434 | 434 | 69% | 11/10/2005 | 17:29 | INTEL_NT |
| vm5   | QA70-1 | 70SP20030909 | 0 | 0 | 884 | 884 | 83% | 11/10/2005 | 17:29 | INTEL_NT |
| vm6   | QA70-1 | 70SP20030909 | 0 | 0 | 854 | 854 | 83% | 11/10/2005 | 17:29 | INTEL_NT |
| vm7   | QA70-1 | 70SP20030909 | 0 | 0 | 2176 | 2176 | 53% | 11/10/2005 | 17:29 | INTEL_NT |
| vm8   | QA70-1 | 70SP20030909 | 0 | 0 | 345 | 345 | 61% | 11/10/2005 | 17:29 | INTEL_NT |
| vm9   | QA70-1 | 70SP20030909 | 0 | 0 | 851 | 851 | 85% | 11/10/2005 | 17:29 | INTEL_NT |
| vm10  | QA70-1 | 70SP20030909 | 0 | 0 | 437 | 437 | 69% | 11/10/2005 | 17:29 | INTEL_NT |
| vm11  | QA70-1 | 70SP20030909 | 0 | 0 | 885 | 885 | 85% | 11/10/2005 | 17:29 | INTEL_NT |
| vm12  | QA70-1 | 70SP20030909 | 0 | 0 | 444 | 444 | 70% | 11/10/2005 | 17:29 | INTEL_NT |
| vm13  | QA70-1 | 70SP20030909 | 0 | 0 | 464 | 464 | 71% | 11/10/2005 | 17:29 | INTEL_NT |
| vm14  | QA70-1 | 70SP20030909 | 0 | 0 | 537 | 537 | 76% | 11/10/2005 | 17:29 | INTEL_NT |
| vm15  | QA70-1 | 70SP20030909 | 0 | 0 | 1356 | 1356 | 91% | 11/10/2005 | 17:30 | INTEL_NT |
| vm16  | QA70-1 | 70SP20030909 | 0 | 0 | 740 | 740 | 82% | 11/10/2005 | 17:30 | INTEL_NT |
| vm17  | QA70-1 | 70SP20030909 | 0 | 0 | 546 | 546 | 76% | 11/10/2005 | 17:30 | INTEL_NT |
| vm18  | QA70-1 | 70SP20030909 | 0 | 0 | 450 | 450 | 71% | 11/10/2005 | 17:30 | INTEL_NT |</p>
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<tr>
<td>---------</td>
<td>-------</td>
<td>------</td>
<td>--------</td>
<td>-----</td>
</tr>
<tr>
<td>vm179</td>
<td>7020021010</td>
<td>QA70-1</td>
<td>COMPARE_REL 3.8</td>
<td>UP20020121 WINDOWS</td>
</tr>
<tr>
<td>INTEL NT</td>
<td>70SP20030909</td>
<td>0 0 768 768 82%</td>
<td>11/10/2005</td>
<td>INTEL NT</td>
</tr>
<tr>
<td>INTEL NT</td>
<td>70SP20030909</td>
<td>0 0 651 651 79%</td>
<td>11/10/2005</td>
<td>INTEL NT</td>
</tr>
<tr>
<td>INTEL NT</td>
<td>70SP20030909</td>
<td>0 0 484 484 71%</td>
<td>11/10/2005</td>
<td>INTEL NT</td>
</tr>
<tr>
<td>INTEL NT</td>
<td>70SP20030909</td>
<td>0 0 973 973 87%</td>
<td>11/10/2005</td>
<td>INTEL NT</td>
</tr>
<tr>
<td>INTEL NT</td>
<td>70SP20030909</td>
<td>0 0 722 722 81%</td>
<td>11/10/2005</td>
<td>INTEL NT</td>
</tr>
<tr>
<td>INTEL NT</td>
<td>70SP20030909</td>
<td>0 0 3162 3162 95%</td>
<td>11/10/2005</td>
<td>INTEL NT</td>
</tr>
<tr>
<td>INTEL NT</td>
<td>70SP20030909</td>
<td>0 0 1489 1489 90%</td>
<td>11/10/2005</td>
<td>INTEL NT</td>
</tr>
<tr>
<td>INTEL NT</td>
<td>70SP20030909</td>
<td>0 0 3075 3075 95%</td>
<td>11/10/2005</td>
<td>INTEL NT</td>
</tr>
<tr>
<td>INTEL NT</td>
<td>70SP20030909</td>
<td>0 0 645 645 80%</td>
<td>11/10/2005</td>
<td>INTEL NT</td>
</tr>
<tr>
<td>INTEL NT</td>
<td>70SP20030909</td>
<td>0 0 411 411 68%</td>
<td>11/10/2005</td>
<td>INTEL NT</td>
</tr>
<tr>
<td>INTEL NT</td>
<td>70SP20030909</td>
<td>0 0 821 821 83%</td>
<td>11/10/2005</td>
<td>INTEL NT</td>
</tr>
<tr>
<td>INTEL NT</td>
<td>70SP20030909</td>
<td>0 0 824 824 84%</td>
<td>11/10/2005</td>
<td>INTEL NT</td>
</tr>
<tr>
<td>INTEL NT</td>
<td>70SP20030909</td>
<td>0 0 505 505 73%</td>
<td>11/10/2005</td>
<td>INTEL NT</td>
</tr>
<tr>
<td>INTEL NT</td>
<td>70SP20030909</td>
<td>0 0 509 509 74%</td>
<td>11/10/2005</td>
<td>INTEL NT</td>
</tr>
<tr>
<td>INTEL NT</td>
<td>70SP20030909</td>
<td>0 0 1268 1268 88%</td>
<td>11/10/2005</td>
<td>INTEL NT</td>
</tr>
<tr>
<td>INTEL NT</td>
<td>70SP20030909</td>
<td>0 0 835 835 84%</td>
<td>11/10/2005</td>
<td>INTEL NT</td>
</tr>
<tr>
<td>INTEL NT</td>
<td>70SP20030909</td>
<td>0 0 1258 1258 89%</td>
<td>11/10/2005</td>
<td>INTEL NT</td>
</tr>
<tr>
<td>INTEL NT</td>
<td>70SP20030909</td>
<td>0 0 3072 3072 95%</td>
<td>11/10/2005</td>
<td>INTEL NT</td>
</tr>
<tr>
<td>INTEL NT</td>
<td>70SP20030909</td>
<td>0 0 604 604 77%</td>
<td>11/10/2005</td>
<td>INTEL NT</td>
</tr>
<tr>
<td>INTEL NT</td>
<td>70SP20030909</td>
<td>0 0 1020 1020 87%</td>
<td>11/10/2005</td>
<td>INTEL NT</td>
</tr>
<tr>
<td>INTEL NT</td>
<td>70SP20030909</td>
<td>0 0 621 621 79%</td>
<td>11/10/2005</td>
<td>INTEL NT</td>
</tr>
</tbody>
</table>
vmc5 7020021010 70SP20030909 0 0 513 513 78% 11/10/2005 17:59 INTEL_NT
vmc6 7020021010 70SP20030909 0 0 433 433 74% 11/10/2005 17:59 INTEL_NT
vmc7 7020021010 70SP20030909 0 0 337 337 67% 11/10/2005 17:59 INTEL_NT
vmc8 7020021010 70SP20030909 2 0 1894 1894 92% 11/10/2005 18:28 INTEL_NT
vmd1 7020021010 70SP20030909 0 0 516 516 86% 11/10/2005 18:28 INTEL_NT
vmd2 7020021010 70SP20030909 0 0 337 337 67% 11/10/2005 18:28 INTEL_NT
vmd3 7020021010 70SP20030909 0 0 608 608 82% 11/10/2005 18:28 INTEL_NT
cyc-177s 7020021010 70SP20030909 1 0 1219 1222 91% 11/10/2005 18:29 INTEL_NT
cyc-178s 7020021010 70SP20030909 1 0 1219 1222 91% 11/10/2005 18:30 INTEL_NT
dds-13s 7020021010 NO_UPDATE -88 0 746 146 67% 11/10/2005 18:30 INTEL_NT
dds-17s 7020021010 NO_UPDATE -88 0 116 116 67% 11/10/2005 18:30 INTEL_NT
esp-112a 7020021010 70SP20030909 0 0 279 279 58% 11/10/2005 18:30 INTEL_NT
esp-124a 7020021010 70SP20030909 0 0 392 392 66% 11/10/2005 18:30 INTEL_NT
esp-127a 7020021010 70SP20030909 0 0 527 527 75% 11/10/2005 18:30 INTEL_NT
ess-97s 7020021010 70SP20030909 0 0 1378 1378 90% 11/10/2005 18:30 INTEL_NT
ev154-23s 7020021010 70SP20030909 0 0 1259 1259 89% 11/10/2005 18:30 INTEL_NT
ev154-25s 7020021010 70SP20030909 0 0 587 587 76% 11/10/2005 18:31 INTEL_NT
ev171-57s 7020021010 70SP20030909 0 0 542 542 79% 11/10/2005 18:31 INTEL_NT
ev173-53s 7020021010 70SP20030909 1 0 1426 1429 92% 11/10/2005 18:31 INTEL_NT
ev175-20s 7020021010 70SP20030909 1 0 538 541 79% 11/10/2005 18:31 INTEL_NT
INTEL_NT QA70-1 COMPARE_REL 3.8 UP20020121 WINDOWS

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B98
ev175-21s  7020021010  NO_UPDATE  -88  0  566  146  64%  11/10/2005  18:31  INTEL_NT
NOT_AVAILABLE  QA70-1

ev175-38s  7020021010  COMPARE_REL  3.8  UP20020121 WINDOWS
70SP20030909  0  0  808  808  85%  11/10/2005  18:31  INTEL_NT

ev182-zbpg11s  7020021010  COMPARE_REL  3.8  UP20020121 WINDOWS
70SP20030909  0  0  660  660  83%  11/10/2005  18:31  INTEL_NT

evl83-zdpl20s  7020021010  COMPARE_REL  3.8  UP20020121 WINDOWS
70SP20030909  0  0  577  577  80%  11/10/2005  18:31  INTEL_NT

INTEL NT

evl84-02s  7020021010  COMPARE_REL  3.8  UP20020121 WINDOWS
70SP20030909  0  0  267  267  56%  11/10/2005  18:31  INTEL_NT

evl84-07s  7020021010  COMPARE_REL  3.8  UP20020121 WINDOWS
70SP20030909  0  0  661  661  80%  11/10/2005  18:31  INTEL_NT

INTEL NT

ev35-23s  7020021010  COMPARE_REL  3.8  UP20020121 WINDOWS
70SP20030909  0  0  293  293  61%  11/10/2005  18:31  INTEL_NT

ev95-45s  7020021010  COMPARE_REL  3.8  UP20020121 WINDOWS
70SP20030909  0  0  892  892  85%  11/10/2005  18:31  INTEL_NT

INTEL NT

inrt-16s  7020021010  COMPARE_REL  3.8  UP20020121 WINDOWS
70SP20030909  1  0  484  486  77%  11/10/2005  18:31  INTEL_NT

INTEL NT

inrt-9s  7020021010  COMPARE_REL  3.8  UP20020121 WINDOWS
70SP20030909  0  0  421  421  73%  11/10/2005  18:31  INTEL_NT

INTEL NT

mvhy-bk501  7020021010  COMPARE_REL  3.8  UP20020121 WINDOWS
70SP20030909  0  0  536  536  78%  11/10/2005  18:31  INTEL_NT

INTEL NT

mvhy-gt202  7020021010  COMPARE_REL  3.8  UP20020121 WINDOWS
70SP20030909  0  0  780  780  84%  11/10/2005  18:31  INTEL_NT

INTEL NT

mvve-cr003  7020021010  COMPARE_REL  3.8  UP20020121 WINDOWS
70SP20030909  0  0  328  328  65%  11/10/2005  18:33  INTEL_NT

INTEL NT

mvve-cr804  7020021010  COMPARE_REL  3.8  UP20020121 WINDOWS
70SP20030909  0  0  329  329  65%  11/10/2005  18:33  INTEL_NT

INTEL NT

se-1s  7020021010  COMPARE_REL  3.8  UP20020121 WINDOWS
70SP20030909  0  0  400  400  72%  11/10/2005  18:33  INTEL_NT

INTEL NT

se-20s  7020021010  COMPARE_REL  3.8  UP20020121 WINDOWS
70SP20030909  0  0  879  879  85%  11/10/2005  18:33  INTEL_NT

INTEL NT

QA70-1

QA70-1

QA70-1

QA70-1

QA70-1

QA70-1
**Expected Compare Difference Found At**

**G= 00000000**
**VERSION=INTEL NT**
**RELEASE= 7.0**
**UP20021010**

**EXPECTED COMPARE DIFFERENCE FOUND AT NG= 113 NT= 113**

**T= 00292062**
**VERSION=INTEL NT**
**RELEASE= 7.0SP11**
**UP20030909**

**EXPECTED COMPARE DIFFERENCE FOUND AT NG= 114 NT= 114**

**G= CURRENT JOBNAME=c0231 10:37:04 OCT 15, 2002 CP= 0.219**

**T= CURRENT JOBNAME=c0231 17:28:23 NOV 10, 2005 CP= 0.375**

0 /verify,c0231

0 /title, c0231 (f3k) Unmatched nodes mapping

**Compare Difference Found At**

**G= NODAL RESULTS ARE FOR CYCLIC SECTOR 1 - PHASE ANGLE = 30.580**

**T= NODAL RESULTS ARE FOR CYCLIC SECTOR 1 - PHASE ANGLE = 237.330**

**Compare Difference Found At**

**G= NODAL RESULTS ARE FOR CYCLIC SECTOR 2 - PHASE ANGLE = 30.580**

**T= NODAL RESULTS ARE FOR CYCLIC SECTOR 2 - PHASE ANGLE = 237.330**

**Compare Difference Found At**

**G= NODAL RESULTS ARE FOR CYCLIC SECTOR 3 - PHASE ANGLE = 30.580**

**T= NODAL RESULTS ARE FOR CYCLIC SECTOR 3 - PHASE ANGLE = 237.330**

**Bottom Of Good File Reached At Line 289**

G= |

**ANSYS Run Completed**

---

**Note:** Nonstandard Compare - DIFOPT NAME QA70-1 has been used

**Number Of Lines Skipped In Good File (Blank Lines Excluded)**

**Number Of Lines Skipped In Test File (Blank Lines Excluded)**

**Number Of Lines On Good File With Strings Condensed Out**

**Number Of Lines On Test File With Strings Condensed Out**

---

**Compare Errors = 3**

PROBLEM: c0231

**Compare Options**

**Compare REL 3.8 UP20020121 WINDOWS**

**Almost Zero (Good)**

1.0000E-006

**Almost Zero (Test)**

1.0000E-006

**Absolute Value Tol**

1.0000E-010

**Fractional Difference**

1.0000E-004

**Absolute Difference**

1.0000E-006

**Known (# of Known Errors)**

0

**Known (# of Known Errors)**

1

**Known (# of Known Errors)**

0

**Known (# of Known Errors)**

0

---

**Known (# of Known Errors)**

0

**Known (# of Known Errors)**

0

---

**Known (# of Known Errors)**

0

**Known (# of Known Errors)**

0
GREAD, TREAD = 1, 1

LINES ON GOOD FILE = 304
LINES ON TEST FILE = 304

*****************************************
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00000000 VERSION=INTEL NT RELEASE= 7.0 UP20021010

EXPECTED COMPARE DIFFERENCE FOUND AT NG= 113 NT= 113
G= 00000000 VERSION=INTEL NT RELEASE= 7.0 UP20021010
T= 00292062 VERSION=INTEL NT RELEASE= 7.0SP11 UP20030909

EXPECTED COMPARE DIFFERENCE FOUND AT NG= 114 NT= 114
G= CURRENT JOBNAME=vm33 20:03:05 OCT 15, 2002 CF= 0.219
T= CURRENT JOBNAME=vm33 17:31:47 NOV 10, 2005 CF= 0.375

0 /VERIFY,VM33

0 /TITLE, VM33, TRANSIENT THERMAL STRESS IN A CYLINDER

NOW COMPARING LINES FROM ***** ANSYS ANALYSIS DEFINITION (PREP7) *****

COMPARE DIFFERENCE FOUND AT NG= 236 NT= 236
G= CURRENT NODAL DOF SET IS UX UY UZ TEMP VOLT MAG
T= CURRENT NODAL DOF SET IS UX UY UZ TEMP VOLT

COMPARE DIFFERENCE FOUND AT NG= 419 NT= 419
G= DEGREES OF FREEDOM: .......... UX UY UZ TEMP VOLT MAG
T= DEGREES OF FREEDOM: .......... UX UY UZ TEMP VOLT

EXTRA DATA SKIPPED ON GOOD FILE NG= 422 NT= 425
G= ELECTRO-MAGNETIC UNITS: ................. MKS
G= MUZERO: .................. 0.12566E-05
END OF SKIPPED DATA NG= 424 NT= 425

EXTRA DATA SKIPPED ON GOOD FILE NG= 427 NT= 428
G= Element 1 references undefined MURX or BH table for material 1.
G= *** WARNING *** CF= 0.000 TIME= 00:00:00
END OF SKIPPED DATA NG= 430 NT= 428

EXTRA DATA SKIPPED ON GOOD FILE NG= 453 NT= 449
G= MAGNETIC DOFS: ................. ON
END OF SKIPPED DATA NG= 454 NT= 449

NOW COMPARING LINES FROM ***** ANSYS RESULTS INTERPRETATION (POST1) *****

NOW COMPARING LINES FROM ***** TIME-HISTORY POSTPROCESSOR (POST26) *****

COMPARE DIFFERENCE FOUND AT NG= 881 NT= 875
G= NUMBER OF WARNING MESSAGES ENCOUNTERED= 4
T= NUMBER OF WARNING MESSAGES ENCOUNTERED= 3

BOTTOM OF GOOD FILE REACHED AT LINE 887
G= | ANSYS RUN COMPLETED |
NOTE: NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED

| NUMBER OF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) | 0 |
| NUMBER OF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) | 0 |
| NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT | 0 |
| NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT | 0 |

COMPARE ERRORS = 6

<table>
<thead>
<tr>
<th>PROBLEM: vm33</th>
<th>COMPARE OPTIONS</th>
<th>COMPARE_REL 3.8 UF20020121</th>
<th>WINDOWS</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALMOST ZERO (GOOD)</td>
<td>1.0000E-006</td>
<td>KROUND (DROP LAST DIGIT)</td>
<td>1</td>
</tr>
<tr>
<td>ALMOST ZERO (TEST)</td>
<td>1.0000E-006</td>
<td>KABSPR (0=SUMMARY 1=ALL)</td>
<td>1</td>
</tr>
<tr>
<td>ABSOLUTE VALUE TOL</td>
<td>1.0000E-010</td>
<td>KSkip (SKIP=ERR 0=Y, 1=N)</td>
<td>0</td>
</tr>
<tr>
<td>FRACTIONAL DIFFERENCE</td>
<td>1.0000E-004</td>
<td>MAXERR (STOP WHEN ERRs)</td>
<td>100</td>
</tr>
<tr>
<td>ABSOLUTE DIFFERENCE</td>
<td>1.0000E-006</td>
<td>MAXBUF (# LINES TO SCAN)</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>KNOWN (# OF KNOWN ERRs)</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GREAD, TREAD</td>
<td>1, 1</td>
</tr>
</tbody>
</table>

LINES ON GOOD FILE = 902
LINES ON TEST FILE = 896

**********************************************************************************
EXPECTED COMPARE DIFFERENCE FOUND AT  NG= 113 NT= 113
G= 00000000  VERSION=INTEL NT  RELEASE= 7.0  UP20021010
T= 00292062  VERSION=INTEL NT  RELEASE= 7.0SP11  UP20030909

EXPECTED COMPARE DIFFERENCE FOUND AT  NG= 114 NT= 114
G= CURRENT JOBNAME=vm176  20:43:52 OCT 15, 2002  CP= 0.234
T= CURRENT JOBNAME=vm176 17:43:39 NOV 10, 2005 CP= 0.375

0 /VERIFY,VM176

0 /TITLE, VM176, FREQUENCY RESPONSE OF ELECTRICAL INPUT

ADMITTANCE FOR A

NOW COMPARING LINES FROM ***** ANSYS ANALYSIS DEFINITION (PREP7) *****

COMPARE DIFFERENCE FOUND AT  NG= 276 NT= 276
G= CURRENT NODAL DOF SET IS UX UY UZ TEMP VOLT MAG
T= CURRENT NODAL DOF SET IS UX UY UZ TEMP VOLT

COMPARE DIFFERENCE FOUND AT  NG= 617 NT= 617
G= DEGREES OF FREEDOM: UX UY UZ TEMP VOLT MAG
T= DEGREES OF FREEDOM: UX UY UZ TEMP VOLT

EXTRA DATA SKIPPED ON GOOD FILE  NG= 623 NT= 627
G= ELECTRO-MAGNETIC UNITS.
G= MUZERO 0.12566E-05
END OF SKIPPED DATA  NG= 626 NT= 627

COMPARE DIFFERENCE FOUND AT  NG= 627 NT= 625
G= Element 1 references undefined MURX or BH table for material 3.
T= Element 1 references undefined KXX for material 3.

EXTRA DATA SKIPPED ON GOOD FILE  NG= 630 NT= 630
G= Element 1 references undefined KXX for material 3.

*** WARNING *** CP= 0.000 TIME= 00:00:00
END OF SKIPPED DATA  NG= 633 NT= 630

COMPARE DIFFERENCE FOUND AT  NG= 638 NT= 633
G= Element 11 references undefined MURX or BH table for material 4.
T= Element 11 references undefined KXX for material 4.

COMPARE DIFFERENCE FOUND AT  NG= 641 NT= 636
G= Element 11 references undefined RSVX or PERX for material 4.
T= Element 16 references undefined RSVX or PERX for material 4.

COMPARE DIFFERENCE FOUND AT  NG= 644 NT= 639
G= Element 11 references undefined RSVX or PERX for material 4.
T= Element 16 references undefined KXX for material 2.

EXTRA DATA SKIPPED ON GOOD FILE  NG= 647 NT= 648
G= Element 16 references undefined MURX or BH table for material 2.
G= *** WARNING ***
CP= 0.000 TIME= 00:00:00
G= Element 16 references undefined KXX for material 2.
G= *** WARNING ***
CP= 0.000 TIME= 00:00:00
END OF SKIPPED DATA
NG= 653 NT= 648

COMPARE DIFFERENCE FOUND AT
NG= 731 NT= 720
G= Element 1 references undefined MURX or BH table for material 3.
T= Element 1 references undefined KXX for material 3.
EXTRA DATA SKIPPED ON GOOD FILE
NG= 734 NT= 725
G= Element 1 references undefined KXX for material 3.
G= *** WARNING ***
CP= 0.000 TIME= 00:00:00
END OF SKIPPED DATA
NG= 737 NT= 725

COMPARE DIFFERENCE FOUND AT
NG= 742 NT= 728
G= Element 11 references undefined MURX or BH table for material 4.
T= Element 11 references undefined KXX for material 4.
COMPARE DIFFERENCE FOUND AT
NG= 745 NT= 731
G= Element 11 references undefined KXX for material 4.
T= Element 11 references undefined RSVX or PERX for material 4.
COMPARE DIFFERENCE FOUND AT
NG= 748 NT= 734
G= Element 11 references undefined RSVX or PERX for material 4.
T= Element 16 references undefined KXX for material 2.
EXTRA DATA SKIPPED ON GOOD FILE
NG= 751 NT= 742
G= Element 16 references undefined MURX or BH table for material 2.
G= *** WARNING ***
CP= 0.000 TIME= 00:00:00
G= Element 16 references undefined KXX for material 2.
G= *** WARNING ***
CP= 0.000 TIME= 00:00:00
END OF SKIPPED DATA
NG= 757 NT= 742

COMPARE DIFFERENCE FOUND AT
NG= 784 NT= 764
G= Element 1 references undefined MURX or BH table for material 3.
T= Element 1 references undefined KXX for material 3.
EXTRA DATA SKIPPED ON GOOD FILE
NG= 787 NT= 769
G= Element 1 references undefined KXX for material 3.
G= *** WARNING ***
CP= 0.000 TIME= 00:00:00
END OF SKIPPED DATA
NG= 790 NT= 769

COMPARE DIFFERENCE FOUND AT
NG= 795 NT= 772
G= Element 11 references undefined MURX or BH table for material 4.
T= Element 11 references undefined KXX for material 4.
COMPARE DIFFERENCE FOUND AT
NG= 798 NT= 775
G= Element 11 references undefined KXX for material 4.
T= Element 11 references undefined RSVX or PERX for material 4.
COMPARE DIFFERENCE FOUND AT
NG= 801 NT= 778
G= Element 11 references undefined RSVX or PERX for material 4.
T= Element 16 references undefined KXX for material 2.
EXTRA DATA SKIPPED ON GOOD FILE
NG= 804 NT= 786
G= Element 16 references undefined MURX or BH table for material 2.
G= *** WARNING ***
G= Element 16 references undefined KXX for material 2.
G= *** WARNING ***

END OF SKIPPED DATA
NG= 810 NT= 786

NOW COMPARING LINES FROM
****** TIME-HISTORY POSTPROCESSOR (POST26)

COMPARE DIFFERENCE FOUND AT
NG= 978 NT= 949
G= NUMBER OF WARNING MESSAGES ENCOUNTERED= 32
T= NUMBER OF WARNING MESSAGES ENCOUNTERED= 23

BOTTOM OF GOOD FILE REACHED AT LINE 964
G= | ANSYS RUN COMPLETED |

NOTE- NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED
NUMBER OF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) = 0
NUMBER OF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) = 0
NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT = 0
NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT = 0

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COMPARE ERRORS = 22 *

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PROBLEM: vml76

COMPARE OPTIONS COMPARE_REL 3.8 UC20020121 WINDOWS

ALMOST ZERO (GOOD) = 1.0000E-006 KKCOUND (DROP LAST DIGIT) = 1
ALMOST ZERO (TEST) = 1.0000E-006 KARSFPR (O=SUMMARY 1=ALL) = 1
ABSOLUTE VALUE TOL = 1.0000E-010 KNKIP (SKIP-ERR 0=Y, 1=N) = 0
FRACTIONAL DIFFERENCE= 1.0000E-004 MAXERR (STO WHEN ERRS ) = 100
ABSOLUTE DIFFERENCE = 1.0000E-006 MAXBUF (# LINES TO SCAN ) = 6
                    KNOWN (# OF KNOWN ERRS) = 0
                  GREAD, TREAD = 1, 1

LINES ON GOOD FILE = 999
LINES ON TEST FILE = 970

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

B.106
VERSION=INTEL NT RELEASE= 7.0 UP20021010

EXPECTED COMPARE DIFFERENCE FOUND AT NG= 113 NT= 113
G= 00000000 VERSION=INTEL NT RELEASE= 7.0 UP20021010
T= 00292062 VERSION=INTEL NT RELEASE= 7.0SP11 UP20030909

EXPECTED COMPARE DIFFERENCE FOUND AT NG= 114 NT= 114
G= CURRENT JOBNAME=vm184 20:46:18 OCT 15, 2002 CP= 0.250
T= CURRENT JOBNAME=vm184 17:44:26 NOV 10, 2005 CP= 0.375

/VERIFY,VM184

/TITLE, VM184, STRAIGHT CANTILEVER BEAM

/stitle,1,Reason COMPARE differences are acceptable:
/stitle,2, mesh accuracy - element number on warning near-zero values

/TITLE, VM184, STRAIGHT CANTILEVER BEAM

NOW COMPARING LINES FROM ***** ANSYS ANALYSIS DEFINITION (PREP7) *****

NOW COMPARING LINES FROM ***** ANSYS RESULTS INTERPRETATION (POST1) *****

ABSOLUTE VALUE DIFFERENCE FOUND AT NG= 926 NT= 926
G= VALUE -0.24849E-01 0.98917 -0.43496E-05 0.98948
T= VALUE -0.24849E-01 0.98917 0.43497E-05 0.98948

ABSOLUTE VALUE DIFFERENCE FOUND AT NG= 902 NT= 902
G= VALUE -0.53544E-02 0.26671E-05 0.42554 0.42557
T= VALUE -0.53544E-02 0.26671E-05 0.42554 0.42557

ABSOLUTE VALUE DIFFERENCE FOUND AT NG= 1011 NT= 1011
G= VALUE -0.12394E-01 0.61739E-05 0.98504 0.98511
T= VALUE -0.12394E-01 0.61739E-05 0.98504 0.98511

NOW COMPARING LINES FROM ***** ANSYS ANALYSIS DEFINITION (PREP7) *****

NOW COMPARING LINES FROM ***** ANSYS RESULTS INTERPRETATION (POST1) *****

COMPARE DIFFERENCE FOUND AT NG= 1580 NT= 1580
G= VALUE 0.24811E-01 0.98813 -0.43696E-05 0.98844
T= VALUE 0.24811E-01 0.98813 0.43701E-05 0.98844

ABSOLUTE VALUE DIFFERENCE FOUND AT NG= 1639 NT= 1639
G= VALUE -0.53533E-02 0.30755E-05 0.42553 0.42556
T= VALUE -0.53533E-02 0.30756E-05 0.42553 0.42556

ABSOLUTE VALUE DIFFERENCE FOUND AT NG= 1673 NT= 1673
G= VALUE -0.12392E-01-0.71193E-05 0.98502 0.98510
T= VALUE -0.12392E-01 0.71194E-05 0.98502 0.98510

NOW COMPARING LINES FROM  ***** ANSYS ANALYSIS DEFINITION (PREP7) *****

NOW COMPARING LINES FROM  ***** ANSYS RESULTS INTERPRETATION (POST1)*****

NOW COMPARING LINES FROM  ***** ANSYS ANALYSIS DEFINITION (PREP7) *****

NOW COMPARING LINES FROM  ***** ANSYS RESULTS INTERPRETATION (POST1)*****

BOTTOM OF GOOD FILE REACHED AT LINE 3147
G= | ANSYS RUN COMPLETED |

NOTE- NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED

NUMBER OF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) = 0
NUMBER OF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) = 0
NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT = 0
NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT = 0

COMPARE ERRORS = 1 *

WARNING - 5 ABSOLUTE VALUE DIFFERENCE(S) FOUND.

NOTE - 1 summary line(s) contained absolute value differences.

---------------------------------------------------------------------
PROBLEM: vm184  COMPARE OPTIONS COMPARE_REL 3.8 UF20020121 WINDOWS
ALMOST ZERO (GOOD) = 1.0000E-006  KROUND (DROP LAST DIGIT)= 1
ALMOST ZERO (TEST) = 1.0000E-006  KAEBPR (O=SUMMARY 1=ALL)= 1
ABSOLUTE VALUE TOL = 1.0000E-010  KSkip(SKIP=ERR 0=Y, 1=N)= 0
FRACTIONAL DIFFERENCE= 1.0000E-004  MAXERR (STOP WHEN ERRS )= 100
ABSOLUTE DIFFERENCE = 1.0000E-006  MAXBUF (# LINES TO SCAN)= 6
---------------------------------------------------------------------
GREAD, TREAD = 1, 1

LINES ON GOOD FILE = 3162
LINES ON TEST FILE = 3162

*****************************************************************************
0 /VERIFY, VM198
0 /TITLE, VM198, LARGE STRAIN IN-PLANE TORSION TEST [%EL%]

NOW COMPARING LINES FROM ****** ANSYS ANALYSIS DEFINITION (PREP7) ******

NOW COMPARING LINES FROM ****** ANSYS RESULTS INTERPRETATION (POST1) ******

NOW COMPARING LINES FROM ****** TIME-HISTORY POSTPROCESSOR (POST26) ******

NOW COMPARING LINES FROM ****** ANSYS ANALYSIS DEFINITION (PREP7) ******

COMPARE DIFFERENCE FOUND AT  G= RELEASE 0.0 UPDATE 0 CUSTOMER 00000000
T= RELEASE 0.0 UPDATE 0 CUSTOMER 00292062

NOW COMPARING LINES FROM ****** ANSYS RESULTS INTERPRETATION (POST1) ******

NOW COMPARING LINES FROM ****** TIME-HISTORY POSTPROCESSOR (POST26) ******

NOW COMPARING LINES FROM ****** ANSYS ANALYSIS DEFINITION (PREP7) ******

COMPARE DIFFERENCE FOUND AT  G= RELEASE 0.0 UPDATE 0 CUSTOMER 00000000
T= RELEASE 0.0 UPDATE 0 CUSTOMER 00292062

NOW COMPARING LINES FROM ****** ANSYS RESULTS INTERPRETATION (POST1) ******

NOW COMPARING LINES FROM ****** TIME-HISTORY POSTPROCESSOR (POST26) ******

NOW COMPARING LINES FROM ****** ANSYS ANALYSIS DEFINITION (PREP7) ******

COMPARE DIFFERENCE FOUND AT  G= RELEASE 0.0 UPDATE 0 CUSTOMER 00000000
T= RELEASE 0.0 UPDATE 0 CUSTOMER 00292062

NOW COMPARING LINES FROM ****** ANSYS RESULTS INTERPRETATION (POST1) ******

NOW COMPARING LINES FROM ****** TIME-HISTORY POSTPROCESSOR (POST26) ******
G= | ANSYS RUN COMPLETED |

NOTE- NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED

NUMBER OF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) = 2
NUMBER OF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) = 2
NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT = 0
NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT = 0

COMPARE ERRORS = 2 *

PROBLEM: vml98
COMPARE OPTIONS COMPARE_REL 3.8 UP20020121 WINDOWS

ALMOST ZERO (GOOD) = 1.0000E-006
ALMOST ZERO (TEST) = 1.0000E-006
ABSOLUTE VALUE TOL = 1.0000E-010
FRACTIONAL DIFFERENCE = 1.0000E-004
ABSOLUTE DIFFERENCE = 1.0000E-006

KROUND (DROP LAST DIGIT) = 1
KABSPR (0=SUMMARY 1=ALL) = 1
KSKIP (SKIP=ERR 0=Y, 1=N) = 0
MAXERR (STOP WHEN ERRS ) = 100
MAXBUF (# LINES TO SCAN) = 6
KNOWN (# OF KNOWN ERRS) = 0
GREAD, TREAD = 1, 1

LINES ON GOOD FILE = 1208
LINES ON TEST FILE = 1208
EXPECTED COMPARE DIFFERENCE FOUND AT  NG=  113  NT=  113
G= D0000000  VERSION=INTEL NT  RELEASE= 7.0  UP20021010
T= D0292062  VERSION=INTEL NT  RELEASE= 7.0SP11 UP20030909

EXPECTED COMPARE DIFFERENCE FOUND AT  NG=  114  NT=  114
G= CURRENT JOBNAME=vmc8  21:52:06  OCT 15, 2002  CP=  0.219
T= CURRENT JOBNAME=vmc8  17:59:57  NOV 10, 2005  CP=  0.375

0 /VERIFY,VMC8
0 /TITLE, VMC8, ALUMINUM BAR IMPACTING A RIGID BOUNDARY
0 /stitle,1,Reason COMPARE differences are acceptable:
0 /stitle,2, number of iterations, accuracy

PLANE2
0 /title, VMC8, ALUMINUM BAR IMPACTING A RIGID BOUNDARY -

PLANE42
0 /title, VMC8, ALUMINUM BAR IMPACTING A RIGID BOUNDARY -

PLANE82
0 /title, VMC8, ALUMINUM BAR IMPACTING A RIGID BOUNDARY -

VISCO106
0 /title, VMC8, ALUMINUM BAR IMPACTING A RIGID BOUNDARY -

SOLID45
0 /title, VMC8, ALUMINUM BAR IMPACTING A RIGID BOUNDARY -

SOLID95
0 /title, VMC8, ALUMINUM BAR IMPACTING A RIGID BOUNDARY -

VISCO107
0 /TITLE, VMC8, ALUMINUM BAR IMPACTING A RIGID BOUNDARY

NOW COMPARING LINES FROM ***** ANSYS ANALYSIS DEFINITION (PREP7) *****

NOW COMPARING LINES FROM ***** ANSYS RESULTS INTERPRETATION (POST1) *****

COMPARE DIFFERENCE FOUND AT  NG=  880  NT=  880
G= SET COMMAND GOT LOAD STEP=  2  SUBSTEP= 320  CUMULATIVE ITERATION= 3255
T= SET COMMAND GOT LOAD STEP=  2  SUBSTEP= 320  CUMULATIVE ITERATION= 3240
NOW COMPARING LINES FROM
****** TIME-HISTORY POSTPROCESSOR (POST26)

NOW COMPARING LINES FROM
****** ANSYS ANALYSIS DEFINITION (PREP7) ******

NOW COMPARING LINES FROM
****** ANSYS RESULTS INTERPRETATION (POST1) ******

NOW COMPARING LINES FROM
****** TIME-HISTORY POSTPROCESSOR (POST26)

NOW COMPARING LINES FROM
****** ANSYS ANALYSIS DEFINITION (PREP7) ******

NOW COMPARING LINES FROM
****** ANSYS RESULTS INTERPRETATION (POST1)

NOW COMPARING LINES FROM
****** TIME-HISTORY POSTPROCESSOR (POST26)

NOW COMPARING LINES FROM
****** ANSYS ANALYSIS DEFINITION (PREP7) ******

NOW COMPARING LINES FROM
****** ANSYS RESULTS INTERPRETATION (POST1)

NOW COMPARING LINES FROM
****** TIME-HISTORY POSTPROCESSOR (POST26)

NOW COMPARING LINES FROM
****** ANSYS ANALYSIS DEFINITION (PREP7) ******

NOW COMPARING LINES FROM
****** ANSYS RESULTS INTERPRETATION (POST1)

NOW COMPARING LINES FROM
****** TIME-HISTORY POSTPROCESSOR (POST26)

NOW COMPARING LINES FROM
****** ANSYS ANALYSIS DEFINITION (PREP7) ******

NOW COMPARING LINES FROM
****** ANSYS RESULTS INTERPRETATION (POST1)

NOW COMPARING LINES FROM
****** TIME-HISTORY POSTPROCESSOR (POST26)

NOW COMPARING LINES FROM
****** ANSYS RESULTS INTERPRETATION (POST1)
NOW COMPARING LINES FROM

***** TIME-HISTORY POSTPROCESSOR [POST26]

BOTTOM OF GOOD FILE REACHED AT LINE 1879
G= | ANSYS RUN COMPLETED |

__________________________________________________________________________
NOTE- NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED
NUMBER OF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) = 0
NUMBER OF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) = 0
NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT = 0
NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT = 0
__________________________________________________________________________

COMPARE ERRORS = 2 *

PROBLEM: vmc8

ALMOST ZERO (GOOD) = 1.0000E-006
ALMOST ZERO (TEST) = 1.0000E-006
ABSOLUTE VALUE TOL = 1.0000E-010
FRACTIONAL DIFFERENCE = 1.0000E-004
ABSOLUTE DIFFERENCE = 1.0000E-006

KROUND (DROP LAST DIGIT)=
KABSPR (0=SUMMARY 1=ALL)=
KSKIP (SKIP=ERR 0=Y, 1=N)=
MAXERR (STOP WHEN ERRS )=
MAXBUF (# LINES TO SCAN)=
KNOWN (# OF KNOWN ERRS)=

GREAD, TREAD = 1, 1

LINES ON GOOD FILE = 1894
LINES ON TEST FILE = 1894

*****************************************************************************

B.114
00000000 VERSION=INTEL NT RELEASE= 7.0  UP200221010

EXPECTED COMPARE DIFFERENCE FOUND AT NG= 113 NT= 113
G= 00000000 VERSION=INTEL NT RELEASE= 7.0  UP200221010
T= 00292062 VERSION=INTEL NT RELEASE= 7.0  SP11 UP20030909

EXPECTED COMPARE DIFFERENCE FOUND AT NG= 114 NT= 114
G= CURRENT JOBNAME=cyc-177s 11:45:34 OCT 15, 2002 CP= 0.219
T= CURRENT JOBNAME=cyc-177s 18:28:58 NOV 10, 2005 CP= 0.359

0 /verify,cyc-177s
0 /TITLE, ceb,cyc-177s, Test cyc symm Buckling element 42
0 /title,1,Full Results to Sector Results!
0 /stitle,Reason Compare differences are acceptable:

EXTRA DATA SKIPPED ON TEST FILE NG= 1202 NT= 1194
T= USE COMMAND MACRO QAEND
T= ARGS= 289.00
END OF SKIPPED DATA NG= 1202 NT= 1199

BOTTOM OF GOOD FILE REACHED AT LINE 1204
G= | ANSYS RUN COMPLETED

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

NOTE—NONSTANDARD COMPARE = DIOPT NAME QA70-1 HAS BEEN USED
NUMBER OF LINES SKIPPED IN GOOD FILE(BLANK LINES EXCLUDED) = 2
NUMBER OF LINES SKIPPED IN TEST FILE(BLANK LINES EXCLUDED) = 2
NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT = 0
NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT = 0

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COMPARE ERRORS = 1 *

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PROBLEM: cyc-177s  COMPARE OPTIONS  COMPARE REL 3.8 UP20020121  WINDOWS

ALMOST ZERO (GOOD) = 1.0000E-006  KROUND (DROP LAST DIGIT) = 1
ALMOST ZERO (TEST) = 1.0000E-006  KABSPR (0=SUMMARY 1=ALL) = 1
ABSOLUTE VALUE TOL = 1.0000E-010  KSKIP(SKIP=ERR 0=Y, 1=N) = 0
FRACTIONAL DIFFERENCE = 1.0000E-004  MAXERR (STOP WHEN ERRS ) = 100
ABSOLUTE DIFFERENCE = 1.0000E-006  MAXBUF (# LINES TO SCAN) = 6
                       KNOWN (# OF KNOWN ERRS) = 0
                       GREAD, TREAD = 1, 1

B.115
LINES ON GOOD FILE = 1219
LINES ON TEST FILE = 1222

*****************************************************************************
**RPP-RPT-32237, Rev. 1**

```
00000000 VERSION=INTEL NT
RELEASE= 7.0 UP20021010

EXPECTED COMPARE DIFFERENCE FOUND AT
G= 00000000 VERSION=INTEL NT
T= 002 920 62 VERSION=INTEL NT
RELEASE= 7.0
NG= 113 NT= 113
UP20021010

EXPECTED COMPARE DIFFERENCE FOUND AT
G= CURRENT JOBNAME=cyc-178s 11:48:41 OCT 15, 2002 CP= 0.25
T= CURRENT JOBNAME=cyc-178s 18:29:39 NOV 10, 2005 CP= 0.359

0 /verify,cyc-178s
0 /TITLE, ceb,cyc-178s, Test cyc symm Buckling element 182
0 /title,1,Full Results to Sector Results!
0 /stitle,Reason Compare differences are acceptable:

EXTRA DATA SKIPPED ON TEST FILE
T= USE COMMAND MACRO QAEND
T= ARGS= 28 9.00
END OF SKIPPED DATA

BOTTOM OF GOOD FILE REACHED AT LINE 1204
G= | ANSYS RUN COMPLETED

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
NOTE- NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED
NUMBER OF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) - 2
NUMBER OF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) - 2
NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED CUT - 0
NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED CUT - 0
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

COMPARE ERRORS = 1 *

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
**PROBLEM: cyc-178s**

<table>
<thead>
<tr>
<th>COMPARE OPTIONS</th>
<th>COMPARE_REL 3.8 UP20020121</th>
<th>WINDOWS</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALMOST ZERO (GOOD)</td>
<td>1.0000E-006</td>
<td>KROUND (DROP LAST DIGIT)= 1</td>
</tr>
<tr>
<td>ALMOST ZERO (TEST)</td>
<td>1.0000E-006</td>
<td>KABSPR (0=SUMMARY 1=ALL)= 1</td>
</tr>
<tr>
<td>ABSOLUTE VALUE TOL</td>
<td>1.0000E-010</td>
<td>KSkip(SKIP=ERR 0=Y, 1=N)= 0</td>
</tr>
<tr>
<td>FRACTIONAL DIFFERENCE</td>
<td>1.0000E-004</td>
<td>MAXERR (STOP WHEN ERRS )= 100</td>
</tr>
<tr>
<td>ABSOLUTE DIFFERENCE</td>
<td>1.0000E-006</td>
<td>MAXBUF (# LINES TO SCAN)= 6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>KNOWN (# OF KNOWN ERRS)= 0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GREAD, TREAD = 1, 1</td>
</tr>
</tbody>
</table>
```

B.117
LINES ON GOOD FILE = 1219
LINES ON TEST FILE = 1222
*****************************************************************************

B.118
*** ERROR -- (VERSION=) was not found anywhere in the "TEST" file. ***
*** Comparison was supposed to start at this string, specified in CMPOPT. ***

NOTE- NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED

NUMBER OF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) = 0
NUMBER OF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) = 0
NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT = 0
NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT = 0

COMPARE ERRORS = -88

<table>
<thead>
<tr>
<th>PROBLEM: dds-13s</th>
<th>COMPARE OPTIONS</th>
<th>COMPARE_REL 3.8 UP20020121</th>
<th>WINDOWS</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALMOST ZERO (GOOD) = 1.0000E-006</td>
<td>KROUND (DROP LAST DIGIT) = 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ALMOST ZERO (TEST) = 1.0000E-006</td>
<td>KABSPR (0=SUMMARY 1=ALL) = 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABSOLUTE VALUE TOL = 1.0000E-010</td>
<td>KSkip (SKIP=ERR 0=Y, 1=N) = 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRACTIONAL DIFFERENCE= 1.0000E-004</td>
<td>MAXERR (STOP WHEN ERRS ) = 100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABSOLUTE DIFFERENCE = 1.0000E-006</td>
<td>MAXBUF (# LINES TO SCAN) = 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>KNOWN (# OF KNOWN ERRS) = 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>GREAD, TREAD = 1, 1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

LINES ON GOOD FILE = 402
LINES ON TEST FILE = 146
*** ERROR -- (VERSION=) was not found anywhere in the "TEST" file. ***
*** Comparison was supposed to start at this string, specified in CMPOPT. ***

---

NOTE - NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED

NUMBER OF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) = 0
NUMBER OF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) = 0
NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT = 0
NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT = 0

---

COMPARE ERRORS = -88

---

PROBLEM: dds-17s

COMPARE OPTIONS

COMPARE_REL 3.8 UP20020121 WINDOWS

ALMOST ZERO (GOOD) = 1.0000E-006
ALMOST ZERO (TEST) = 1.0000E-006
ABSOLUTE VALUE TOL = 1.0000E-010
FRACTIONAL DIFFERENCE = 1.0000E-004
ABSOLUTE DIFFERENCE = 1.0000E-006

KROUND (DROP LAST DIGIT) = 1
KABSPR (0=SUMMARY 1=ALL) = 1
KSKIP (SKIP=ERR 0=Y, 1=N) = 0
MAXERR (STOP WHEN ERRS ) = 100
MAXBUF (# LINES TO SCAN) = 8
KNOWN (# OF KNOWN ERRS) = 0
GREAD, TREAD = 1, 1

---

LINES ON GOOD FILE = 746
LINES ON TEST FILE = 146
**Expected Compare Difference Found At**

\( \text{G}= 00000000 \quad \text{VERSION}= \text{INTEL NT} \quad \text{RELEASE}= 7.0 \quad \text{UP20021010} \)

\( \text{T}= 002092062 \quad \text{VERSION}= \text{INTEL NT} \quad \text{RELEASE}= 7.0 \quad \text{SP}11 \quad \text{UP20030909} \)

**Expected Compare Difference Found At**

\( \text{G}= \text{CURRENT JOBNAM}= \text{evl73-53s} \quad 14:02:31 \quad \text{OCT} \quad 15, \quad 2002 \quad \text{CP=} \quad 0.234 \)

\( \text{T}= \text{CURRENT JOBNAM}= \text{evl73-53s} \quad 18:31:16 \quad \text{NOV} \quad 10, \quad 2005 \quad \text{CP=} \quad 0.406 \)

0 /verify,evl73-53s

0 /title,evl73-53s,mfquresh,Test to verify PSOVL,E LFORM for 171-175 (3D) with PENE

**Extra Data Skipped on Test File**

\( \text{NG}= 114 \quad \text{NT}= 114 \)

**Use Command Macro QAEND**

**Args=** 20.000

**End of Skipped Data**

\( \text{NG}= 1409 \quad \text{NT}= 1401 \)

**Bottom of Good File Reached at Line** 1411

**Ansys Run Completed**

---

**Note—Nonstandard Compare—Dipopt Name QA70=1 Has Been Used**

- Number of Lines Skipped in Good File (Blank Lines Excluded) = 2
- Number of Lines Skipped in Test File (Blank Lines Excluded) = 2
- Number of Lines on Good File with Strings Condensed Out = 0
- Number of Lines on Test File with Strings Condensed Out = 0

---

**Compare Errors** = 1 *

---

**Problem:** evl73-53s

**Compare Options**

- Almost Zero (Good) = 1.0000E-006
- Almost Zero (Test) = 1.0000E-006
- Absolute Value TOL = 1.0000E-010
- Fractional Difference = 1.0000E-004
- Absolute Difference = 1.0000E-006

**Windows**

- KROUND (Drop Last Digit) = 1
- KABSPR (0=SUMMARY 1=ALL) = 1
- KSKIP (SKIP=ERR 0=Y, 1=N) = 0
- MAXERR (STOP WHEN ERRS ) = 100
- MAXBUF (# LINES TO SCAN) = 6
- KNOWN (# OF KNOWN ERRS) = 0
- GREAD, TREAD = 1, 1

---

Lines on Good File = 1426

Lines on Test File = 1429

---

B.121
**VERSION=INTEL NT RELEASE= 7.0 UP20021010**

EXPECTED COMPARE DIFFERENCE FOUND AT  NG= 113 NT= 113
G= 00000000  VERSION=INTEL NT RELEASE= 7.0 UP20021010
T= 00292062  VERSION=INTEL NT RELEASE= 7.0 SP11 UP20030909

**EXPECTED COMPARE DIFFERENCE FOUND AT  NG= 114 NT= 114**
G= CURRENT JOBNAME=evl75-20s 14:22:03 OCT 15, 2002 CP= 0.250
T= CURRENT JOBNAME=evl75-20s 18:31:34 NOV 10, 2005 CP= 0.328

0 /verify,evl75-20s
0 /title,evl75-20s, mfq, Check real constant FKN and FTOLN and
KEYOPT(2)=0, 1

NOW COMPARING LINES FROM ***** ANSYS ANALYSIS DEFINITION (PREP7) *****

EXTRA DATA SKIPPED ON TEST FILE
T= USE COMMAND MACRO QAEND
T= ARGs= 3.0000
END OF SKIPPED DATA
NG= 521 NT= 513

BOTTOM OF GOOD FILE REACHED AT LINE 523
G= ANSYS RUN COMPLETED

NOTE- NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED
NUMBER OF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) = 2
NUMBER OF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) = 2
NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT = 0
NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT = 0

**COMPARE ERRORS = 1 * **

PROBLEM: evl75-20s  COMPARISON OPTIONS COMPARISON_REL 3.8 UP20020121  WINDOWS

ALMOST ZERO (GOOD) = 1.0000E-006  KROUND (DROP LAST DIGIT)= 1
ALMOST ZERO (TEST) = 1.0000E-006  KABSPR (0=SUMMARY 1=ALL)= 1
ABSOLUTE VALUE TOL = 1.0000E-010  KSkip (SKIP=ERR 0=Y, 1=N)= 0
FRACTIONAL DIFFERENCE= 1.0000E-004  MAXERR (STOP WHEN ERRS )= 100
ABSOLUTE DIFFERENCE = 1.0000E-006  MAXBUF (# LINES TO SCAN)= 6
Known (# OF KNOWN ERRS) = 0
Gread, Tread = 1, 1

B.122
LINES ON GOOD FILE = 538
LINES ON TEST FILE = 541
****************************************************************************
*** ERROR -- (VERSION=) was not found anywhere in the "TEST" file. ***
*** Comparison was supposed to start at this string, specified in CMPOPT. ***

NOTE- NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED
NUMBER OF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) = 0
NUMBER OF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) = 0
NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT = 0
NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT = 0

COMPARE ERRORS = -88

PROBLEM: evl75-21s
COMPARE OPTIONS COMPARE_REL 3.8 UP20020121 WINDOWS

ALMOST ZERO (GOOD) = 1.0000E-006
ALMOST ZERO (TEST) = 1.0000E-006
ABSOLUTE VALUE TOL = 1.0000E-010
FRACTIONAL DIFFERENCE = 1.0000E-004
ABSOLUTE DIFFERENCE = 1.0000E-006
KROUND (DROP LAST DIGIT) = 1
KABSPR (0=SUMMARY 1=ALL) = 1
KSKIP (SKIP=ERR 0=Y, 1=N) = 0
MAXERR (STOP WHEN ERRS = 100
MAXBUF (# LINES TO SCAN) = 8
KNOWN (# OF KNOWN ERRS) = 6
GREAD, TREAD = 1, 1

LINES ON GOOD FILE = 566
LINES ON TEST FILE = 146
**EXPECTED COMPARE DIFFERENCE FOUND AT**

G= 00000000 VERSION=INTEL NT
T= 002 920 62 VERSION=INTEL NT

RELEASE= 7.0
NG= 113 NT= 113
UP20021010

**EXPECTED COMPARE DIFFERENCE FOUND AT**

G= CURRENT JOBNAME=inrt-16s 16:14:59 OCT 15, 2002 CP= 0.219
T= CURRENT JOBNAME=inrt-16s 18:32:29 NOV 10, 2005 CP= 0.391

0 /VERIFY,INRT-16S
0 /TITLE, INRT-16S, ceh, component omega loading and layer elements

0 /TITLE, INRT-16S, BENDING OF A COMPOSITE BEAM

EXTRA DATA SKIPPED ON TEST FILE
T= USE COMMAND MACRO QAEND
END OF SKIPPED DATA

BOTTOM OF GOOD FILE REACHED AT LINE 469
G= | ANSYS RUN COMPLETED |

---

NOTE- NONSTANDARD COMPARE - DIFOPT NAME QA70-1 HAS BEEN USED

NUMBER OF LINES SKIPPED IN GOOD FILE (BLANK LINES EXCLUDED) = 1
NUMBER OF LINES SKIPPED IN TEST FILE (BLANK LINES EXCLUDED) = 1
NUMBER OF LINES ON GOOD FILE WITH STRINGS CONDENSED OUT = 0
NUMBER OF LINES ON TEST FILE WITH STRINGS CONDENSED OUT = 0

---

COMPARE ERRORS = 1 *

---

PROBLEM: inrt-16s

<table>
<thead>
<tr>
<th>COMPARE OPTIONS</th>
<th>COMPARE_REL 3.8 UP20020121</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>ALMOST ZERO (GOOD)</th>
<th>ALMOST ZERO (TEST)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0000E-006</td>
<td>1.0000E-006</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ABSOLUTE VALUE TOL.</th>
<th>KROUND (DROP LAST DIGIT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0000E-010</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FRACTIONAL DIFFERENCE</th>
<th>KABSFR (0-SUMMARY 1=ALL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0000E-004</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ABSOLUTE DIFFERENCE</th>
<th>MAXERR (STOP WHEN ERRS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0000E-006</td>
<td>100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MAXBUF (# LINES TO SCAN)</th>
<th>KNOWN (# OF KNOWN ERRS)</th>
<th>GREAD, TREAD =</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>0</td>
<td>1, 1</td>
</tr>
</tbody>
</table>

---

LINES ON GOOD FILE = 484
LINES ON TEST FILE = 486

---
Appendix C

ANSYS Model Files
Appendix C

ANSYS Model Files

C.1 Introduction

This appendix contains the ANSYS model input files for the thermal and operating load analyses. The input files for the seismic analyses are available in the seismic report (Rinker et al. 2007). To conserve space and avoid duplication of the same data multiple times, some of the files listed will be used multiple times, but they are only included one time in this document.

There are twenty-six files needed to actually build the model and run the initial mechanical loads. The key file for this phase of the analysis is the “set_slicea.mac” macro file. The set_slicea.mac file calls all of the other necessary files for the actual ANSYS run. At the end of this initial phase, the ANSYS database file is copied into a new subdirectory along with the eighteen temperature distribution macro files that apply the temperatures via body forces to each node point in the model and a short input macro file to re-start the ANSYS run. The actual nodal temperature values are not included in this appendix, as it would take over three thousand pages to do so. The actual nodal temperatures are included separately on electronic media. The ACI load factors are applied at the end of the 60 years of thermal cycling in a separate restart analysis. Section D.2 contains all the input files needed for the Best Estimate Soil - Best Estimate Concrete (BES-BEC) analysis. Sections D.3 and D.4 contain only the files that are different to run the Lower Bound Soil - Best Estimate Concrete and Upper Bound Soil - Best Estimate Concrete analyses.

Section D.5 contains the input files for the BES-BEC analysis with the anchor bolts modeled as springs. In addition to the secant stiffness spring model described in “set_slicea.mac”, this analysis required fewer load steps for the thermal transient because of the lower (135°F) steady state waste temperature. These input files are also listed in this section.

The post-processing files required to extract the results from the TOLA model in preparation for combination with the seismic results are shown in Section D.6.

The input file for the detailed AP anchor bolt study described in Appendix B is listed in Section D.7.
C.2 Best Estimate Soil Model Input Files

C.2.1 Model Files

Input file: set_slicea.mac

* *** AP 210F, Waste Height=422 SpG =1.83 for 20 years
10/11/2006
* *** AP 210F, Waste Height=460 SpG =1.83 for 40 years
10/11/2006

* *** AP modifications 8/9/04
* *** Liquid level 460" SpG 1.83 8/11/04
* *** Liquid level 460", SpG 2.0 7/26/04
* *** Liquid level 460", SpG 1.7 7/19/04
* *** 2nd liner extension 0.25 thick 7/21/04
* *** 2nd liner extension contact <> concrete 7/21/04
* *** Augmented stiffness 5% Econc (350) 7/19/04
* *** 5% pivot, bcs, mmd 6/25/04
* *** Use msub 6/24/04
* *** cvtit, f(m), 0.005, 0 6/16/04
* *** Augmented stiffness 2% Econc (350) 6/14/04
* *** Augmented stiffness 30000 6/11/04
* *** 6/10/04 changes
* *** Do not merge insulating concrete <> 2nd liner @ OD of concrete
* *** Add 1st radius element to contact of 1st liner <> ins conc
* *** Add contact 2nd liner <> slab concrete
* *** Correct node select for type,61 real,70 6/9/04
* *** Recorint Beam188 on z=0 face
* *** Fix Liner-Dome common nodes 5/6/04
* *** Delete "j-bolts" in wall 5/6/04
* *** Move j-bolt real definition to pnnla6.mac 3/30/04

* *** Changed Liner Coupling per J. Deibler 3/29/04
* *** Augmented stiffness 15000 3/24/04
* *** Default convergence criteria 3/22/04
* *** Best estimate soil properties 3/19/04
* *** Soil-Concrete - 5 regions 2/23/04
* *** Correct Drucker-Prager - soil
* *** Correct mat,1 temperature dependent modulus
* *** Replace shell64 with shell181
* *** Primary tank pressure -12" H2O (was -6)
* *** 125 pcf overburden, 110 pcf undisturbed soil
* *** 10/30/03
* *** Define additional soils for load factor restart
* *** No cracking insulating concrete
* *** fix mch (esel,r,mat,,2)
* *** 1 yr + 15 day creep 5/14/03
* *** Load step 5 creep for 330 days
* *** New load step 6 => mch +5 days
* *** "sets" degraded concrete properties
* ***
* *** Turn off concrete crushing 5/5/03
* ***
* *** Run 2, Load Step 1, 2 & thermal
* *** (8.3 soil, 125 lb/ft3)
* *** (0.05" primary tank corrosion wall, floor)
* *** 4/16/03
* ***
* *** JED mods 3/29/03
* ***

* if i_rebuild.eq.1, then
  pnnla
/*else
resume,pnnla9,db
*/endif

prep7

allsel
epdele,all,all

!get misc area components for applying loads, etc.
/input,set_areas_slice,mac

!add steel plate below wall (on slab)
real,45,1/4
csys,22
vsel,s,mat,,2
aslv
asel,r,loc,z,-8.125
asel,r,loc,x,480,498
aatt,1,4,5,22
mat,1
real,45
amesh,all

!define contact elements (all have default friction of 0.3)

et,60,170
net,61,173
mp,mu,61,.3 !Soil-concrete dome
mu,62,.4
mu,63,.4
mu,64,.4
mu,65,.3
mu,66,.2
mu,67,.05 !soil-concrete wall
mu,68,.3 !soil-concrete footing/top
mu,69,.05 !soil-concrete footing/side
mu,70,.6 !soil-concrete foundation
mu,71,.4 !2nd liner-insulating concrete
6/10/04

! Soil-concrete contact - dome
r,61,.1,.1
real,61
type,61
mat,61
cmsel,s,aconc_soil
nsla,,1
nsel,r,loc,z,452,600
esln
esurf
type,60
cmsel,s,asoil
nsla,,1
nsel,r,loc,z,452,600
esln
esurf

! Soil-concrete contact - wall
Isol concreate contact - Footing - top
real, 67
mat, 67
cmsel, s, aconcs oil
nsla, 1
nsel, r, loc, z, -3,-453
esln
csurf
type, 61

Isol concreate contact - Footing - side
real, 69
mat, 69
cmsel, s, aconcs oil
nsla, 1
nsel, r, loc, x, 531
esln
csurf
type, 60

Isol concreate contact - Foundation
real, 70
mat, 70
cmsel, s, aconcs oil
nsla, 1
nsel, r, loc, z, -31,-30
r, loc, x, 440,531
cm, foundconc, node
nsla, 1
nsel, r, loc, x, 440
r, loc, z, -33,-8

*** was -32 6/9/04
cm, foundconc
esln
esurf
type,60
cmsel,s,asoil
nsla,1
nsel,r,loc,z,-31,-30
r,loc,x,440,531
cm,foundsoil,node
nsla,1
nsel,r,loc,x,440
r,loc,z,-33,-8
cmsc,a,foundsoil
esln
esurf

!secondary liner contact
r,62,,1,,1
real,62
type,60
mat,62
cmsel,s,aconc_shell
csys,0
asel,u,loc,y,459,99999
nsla,1
esln
esel,r,mat,,2
esurf
type,61
cmsel,s,area_secon
csys,0
asel,u,loc,y,-99999,3.87
nsla,1
esln

!primary liner contact with dome
r,63,,1,,1
real,63
type,60
mat,63
cmsel,s,aconc_shell
asel,r,loc,y,459,99999
nsla,1
esln
esel,r,mat,,2
esurf
type,61
cmsel,s,area_prim
asel,r,loc,y,459,99999
nsla,1
esln

!primary liner contact with insulating concrete
r,64,,1,,1
real,64
type,60
mat,64
cmsel,s,area_insul_top
nsla,1
esln
esel,r,mat,,4
esurf
type,61
cmsel,s,area_prim
csys,0
secondary liner contact with foundation concrete 6/10/04
real,71
type,60
mat,71
cmse,slab_top
aseln,1
esln
esurf
type,61
cmse,area_secon
aseln,1
esln
esurf
merge insulating concrete bottom nodes and secondary liner nodes
cmesl,s,area_insul_bot
cmsel,a,area_secon
csys,0
cpintf,uz,.1

slab top/insulating concrete
real,65
type,60
mat,65
cmse,s,slab_top
nsln,1
esln
esurf
type,61
cmse,s,area_insul_bot
nsln,1
esln
esurf

wall/slab contact
real,66
type,60
mat,66
aseln,986,992
cmsl,slab_top_wall,area
nsln,1
esln
esel,t,mat,.2
esurf
type,61
aseln,214
,a,,706
,a,,913,918,5
,a,,934
cmsl,wall_bot,area
I define the local coordinate systems and rebar orientations
/input/set_esys_3d,mac

I apply loads
/input/apply_loads_slice,mac

I apply axisymmetric boundary conditions
/csys,22
/nset,s,loc,y,180
/nset,a,loc,y,180+swp_th-.001,183
csys,0
/nset,a,loc,x,0
d,all,uy,0
d,all,rotx,0
d,all,rotz,0

I merge liner/concrete nodes at dome centerline
/kset,s,,2
/kset,a,,329
/knlk
nummrg,node
allsel

!copy jbolts, etc for slice model
/csys,22
/esel,s,type,,20,21
cm,e_bolt0,elem
egen,2.500000,all,,0,0,0,0,0,0,swp_th
/esel,s,mat,,1
esel,u,real,,45
/nset
/esel,a,,22789,22790 !*** 5/6/04
/esel,u,,20260,20261 !*** 6/10/04
nummrg,node

!divide jbolt/bottom anchors properties by 2 for slice model
r,30,19635/2,3068e-2/2,3068e-2/2,5,5
/esel,s,type,,20,21
cmsel,u,e_bolt0
/nset
/esel,a,,500000,999999
/cm,ntemp,node
vsels,mat,2
vsels,mat,6
csys,0
vsels,loc,y,-9999,-8.12
cm,vtemp,volu
*get, nv, volu, count
*do, i, nv
*get, iv, volu, num, min
eslv
nsle
cmsel, a, ntemp
nummrg, node
cm, ntemp, node
cmsel, s, vtemp
cmsel, s, vtemp
vsels, u, iv
cm, vtemp, volu
*enddo

***
*** Delete primary-secondary tank coupling at tangent
***  JED 3/31/03
***

r, 3/16
insulating concrete confining ring
thickness

/prep7

esels, mat, 5
nsle, 1
csys, 0
*get, top elev, node, mxloc, y
cm, soil elem, elem

*do, i, 1, 16
set_layer, soil_z0(i), soil_z1(i), soil_emod(i), soil_pr(i)
*enddo

max_mat=100
!set backfill/overburden material
*do, i, 1, 8
set_backfill, bf_z0(i), bf_z1(i), bf_emod(i), bf_pr
*enddo

!Don't do this!! 5/6/04
!make sure anchors/jbolts/studs etc are merged with concrete
!esel., type., 12, 13
!a, type., 20, 21
!a, type., 24, 25
!nsle
!insel., 22789, 22790
*** 3/26/04
!numm, node

***
*** Augmented Stiffness 2/27/04
***
et, 32.45
*get, ec350, ex, 2, temp, 350
mp, ex, 12, ec350*0.05 17/19/04
priv, 12., 15
esel., type., 12, 15
egen, 2, 0, all., 10
esel., mat., 12
emod, all., type., 32
I***
I***Redefine j-bolts 4/1/04
I***

alls
csys
nod0k=node(-550,575,0)
nod1k=node(-550,575,27)
et,30,188  !New j-bolts
type,30
mat,1
real,20
seen,2
sect,2,beam,csolid
secd,.25/(2**.5),1,1  !Use 1/2 area for symmetry
esel,,type,,20
nsle
ase1,c,loc,z
esln,1
*get,jb0,elem,,count
*do,i,1,jb0
*get,jn1,elem,,num,,min
*get,jn2,elem,jb1,node,1
c,jn1,jn2,nod0k
csel,u,,jb1
*enddo

esel,,type,,20
nsle

nset,,u,loc,z
esln,1
*get,jb2,elem,,count
*do,i,1,jb2
*get,jb3,elem,,num,,min
*get,jn3,elem,jb3,node,1
*get,jn4,elem,jb3,node,2
c,jn3,jn4,nod1k
csel,u,,jb3
*enddo

alls
e1	2nd liner extension issues 7/21/04
asel,,928,,1
egen,2,100000,all,,4,,0,0,0
modm,nocheck
alls
emod,15784,-1,114183,104465
,15955,-3,104465,114183
,28878,-3,104465,114183
acle,928
real,62
type,62
mat,62
asel,,928,,1
esln
esel,,type,,12
esurf
type,61
esel,,type,,23
x,real,,45
nsle
esurf
dsym,symm,y,5
alls

!*** AP modifications 8/9/04
!*** Thickness from set_parms.mac
!* r50=1.06  !shell thickness (in) (R1 of Figure 11 in RPP-13990)
!* r51=3/8.06  !shell thickness (in) (R2, R6, R7, R9 of Figure 11 in RPP-13990)
!* r52=7/8.06  !shell thickness (in) (R3 of Figure 11 in RPP-13990)
!* r53=3/4.06  !shell thickness (in) (R4 of Figure 11 in RPP-13990)
!* r54=1/2.06  !shell thickness (in) (R5, R8 of Figure 11 in RPP-13990)
!* r55=1/4  !shell thickness (in) (R10 of Figure 11 in RPP-13990)
!* r56=3/8  !shell thickness (in) of secondary liner above 357.5 in

!*** Additional liner thickness
r,57.9/16,.06
,58,15/16,.06
!*** Redefine secondary liner thickness
r,55,3/8
,56,1/2
,59,9/16

!*** Primary liner
csys
esel,,real,,51
nsle

nsel,r,loc,y,380,468.5
esln,,1
esel,r,real,,51
esmod,all,real,54
esel,,real,,54
nsle
nsel,r,loc,y,142,238
esln,,1
esel,r,real,,54
esmod,all,real,57
esel,,real,,52
nsle
nsel,r,loc,y,,12
,r,loc,x,-450,-437
esln,,1
esel,r,real,,52
esmod,all,real,58
esel,,real,,51
nsle
nsel,r,loc,y,-1,1
esln,,1
esel,r,real,,51
esmod,all,real,54

!*** Secondary liner
esel,,real,,55,56
nsle
nsel,r,loc,y,24,460
esln,,1
esel,r,real,,55,56
esmod,all,real,55
esel,,real,,55
nsle
nsel,r,loc,y,3,875,24

RPP-RPT-32377, Rev. 1
esln,,1
esel,,real,,55
emod,all,real,56
esel,,real,,55
nsle
nsel,loc,x,-9,3.375
r,loc,x,-480,-467
esln,,1
esel,,real,,55
emod,all,real,59
esel,,real,,55
nsle
nsel,loc,x,-468,-420
esln,,1
cnvt,f,,005,0
m,,005,0
crpl,,05
nsub,10,100,5
!del,,1,,01,,2
tounes,all,all
!bure,on,250
eqsl,sparse,05,-1
hcso,mmd
!allsel
save
solve
time,2
***
**** Add waste and pressure loads
***
pres_surf=0 !ground surface uniform pressure psf
point_cent=0 !point load at center lb
pres_annulus=-20 !annulus pressure inches h2o
pres_int=-12 !annulus internal pressure inches h2o
h_waste=422 !total waste height
height_waste1=h_waste/3 !height of waste 1 inches
gamma_waste1=1.83 !specific gravity of waste 1
height_waste2=h_waste/3 !height of waste 2 inches
gamma_waste2=1.83 !specific gravity of waste 2
height_waste3=h_waste/3 !height of waste 3 inches
gamma_waste3=1.83 !specific gravity of waste 3

!inp,apply Loads_slice,mac
delt,,1,,01,,25
solv

time,3

!***
!*** Add surface loads
!***

pres_surf=40
uniform pressure psf

point_cent=200000
lb

pres_annulus=-20
inches h2o

pres_int=-12
pressure inches h2o

hwaste=422
height_waste1=hwaste/3
inches

gamma_waste1=1.83
specific gravity of
waste 1

height_waste2=hwaste/3
inches

gamma_waste2=1.83
specific gravity of
waste 2

height_waste3=hwaste/3
inches

gamma_waste3=1.83
specific gravity of
waste 3

/inp,apply_loads_slice.mac

save

solv

Input file: apply_loads_slice.mac

!*** Eliminate in-plane pressure 2nd liner
!*** Add pressure 1st liner @ connection
!*** 12/4/03

!***

alls el
sfdele,all,all
sfdele,all,all,all
sfgrad,pres
fdele,all,all
esel,s,type,,59
edele,all

!40 psf pressure on ground surface

!***

!*** No pressure - Phase II, Load Case S5
csys,0

*get,ymx,kp,,mxloc,y
asel,s,loc,y,ymx

lsla
nsla,,1
esel,all
sf,all,pres,pres_surf/144

!200K point load at center

!***

!*** No concentrated load - Phase II, Load Case S5
csys,22

nsel,r,loc,x,0,clr
*get,nnode,node,,count
f,all,fz,-point_cent/nnode*swp_th/360
liner pressure loads
p_annulus=pres_annulus/12*62.4/144
p_internal=pres_int/12*62.4/144

! waste depth and unit weight
hw1=height_waste1
gammaw1=gamma_waste1
hw2=height_waste2
gammaw2=gamma_waste2
hw3=height_waste3
gammaw3=gamma_waste3

*if,abs(gammaw1),lt,le-3,then
  gammaw1=1e-6
*else
  gammaw1=gammaw1*62.4/1728
*endif
*if,abs(gammaw2),lt,le-3,then
  gammaw2=1e-6
*else
  gammaw2=gammaw2*62.4/1728
*endif
*if,abs(gammaw3),lt,le-3,then
  gammaw3=1e-6
*else
  gammaw3=gammaw3*62.4/1728
*endif

zz4=0
zz3=hwl
zz2=zz3+hw2
zz1=zz2+hw3

zz0=460
pp0=p_internal
pp1=p_internal-p_annulus
pp2=pp1+hw3*gammaw3
pp3=pp2+hw2*gammaw2
pp4=pp3+hw1*gammaw1

allsel
! primary liner
csel,s,real,,50,54
nsle
ctm,tliner,node

! top reaches of dome
allsel
csys,0
cmsel,s,aliner
nsel,r,loc,y,zz0-.03,9999
sfgrad,pres
sf,all,pres,pp0

! space between top of fluid and prim/second liner intersection
cmsel,s,aliner
nsel,r,loc,y,zz1,zz0
sf,all,pres,pp1

! waste region 3
cmsel,s,aliner
nsel,r,loc,y,zz2,zz1
eslin
csel,r,type,,1
nsle,,1
sfgrad,pres,0,y,zz1,(pp1-pp2)/hw3
sf,all,pres,pp1

!waste region 2
cmsel,s,nliner
nsel,r,loc,y,zz3,zz2
csln
esel,r,type,,1
nsle,,1
sfgrad,pres,0,y,zz2,(pp2-pp3)/hw2
sf,all,pres,pp2

!waste region 1
cmsel,s,nliner
nsel,r,loc,y,zz4,zz3
csln
esel,r,type,,1
nsle,,1
sfgrad,pres,0,y,zz3,(pp3-pp4)/hw1
sf,all,pres,pp3

!annulus
esel,s,type,,1
nsle,,1
cmsel,u,nliner
nsel,u,loc,y,-9999,-8.124
csln
esel,r,type,,1
nsle,,1
cm,nsecon,mode
csln
esel,r,real,,55,56
sfgrad,pres

sf,all,pres,p_annulus

Input file: mesh_size.mac

esize=3.2
rebar [in]
soil_size=14
swp_th=24/(2*pi*480)*360 [deg]
num_div=6

Input file: PNNLA.mac

set_parms
/prep7
! 3/28/03
! DST - AV

*afun,deg

k,1,0,h6
k,2,0,h5
k,3,0,0
k,4,-ir2,0
k,5,ir2,h3+36+6+13/16
k,6,-r1*sin(th1),h6-r1+r1*cos(th1) !Intersection of exterior dome radii
larc,6,1,3,r1 !Exterior dome radius - center
rectng,-ir2,0,h2,h1
rectng,-or,-ir,h2,h3 !Wall to tangent point
k,42,kx(41),ky(41)-l intersection
k,43,kx(1),ky(1)-covext centerline outer
k,44,kx(1),ky(43)-l inner
larc,39,41,3,r2-covext outer radius
larc,41,43,3,r1-covext center radius
larc,40,42,3,r2-covext-l outer radius
larc,42,44,3,r1-covext-l center radius
a,37,38,40,42,44,43,41,39 Dome outer rebar

!Dome & wall rebar
!Inner rebar
k,45,kx(12)-covint1,ky(12)
,46,kx(45)-1,ky(45)
,47,kx(13)-covint1,ky(13)
,48,kx(47)-1,ky(47)
,53,0,ky(2)+covint2
,56,0,ky(55)+1
loca,12,1,,h3,,(30*12+1.5)/(80*12+1.5)
k,49,ir+1.72,164
,53,ir+2.21,144
1,53.55
loca,13,1,,h3,,(30*12+2.5)/(80*12+2.5)
k,50,ir+2.86,163.9
,54,ir+3.68,143.85
1,54,56
loca,14,1,,h3,,(30*12+4)/(80*12+4)

loca,15,1,,h3,,(30*12+5.5)/(80*12+5.5)
k,52,ir+6.4,154.65
csys,0
1,45,47
,46,48
csys,11
a,45,47,49,51,53,55,56,54,52,50,48,46
csys,0

!Foundation rebar
covtop=3.5
covbot=3
ssli=(ky(27)-ky(26))/(kx(27)-kx(26))
sslo=(ky(28)-ky(29))/(kx(28)-kx(29))
k,60,kx(30)+3,ky(30)+covbot
k,61,kx(60),ky(60)+1
k,62,kx(31)+3,ky(8)-covtop
k,63,kx(62),ky(62)+1
k,64,0,ky(8)-covtop
k,65,0,ky(64)-l
k,74,0,ky(25)+covbot+1
k,75,0,ky(25)+covbot
k,66,kx(26)-ssli*covbot,ky(26)+covbot
k,67,kx(66)-ssli,ky(66)+l
k,68,kx(27)-ssli*covbot,ky(27)+covbot
k,69,kx(68)-ssli,ky(68)+l
k,70,kx(28)-sslo*covbot,ky(28)+covbot
k,71,kx(70)-sslo,ky(70)+1
k,72,kx(29)-sslo*covbot,ky(29)+covbot
k,73,kx(72)-sslo,ky(72)+1
a,60,61,73,71,69,67,74,75,66,68,70,72
!Haunch mid section rebar
k,80,kx(14)+11+.5,ky(14)+36
k,81,kx(80),ky(40)
k,82,kx(80),.5*(ky(80)+ky(81))
k,83,kx(14)+72,ky(14)+98
k,84,kx(14)+103,ky(14)+113
k,85,kx(84),ky(84)+1
k,86,kx(83),ky(83)+1
k,87,kx(82),ky(82)+1
k,88,kx(81)-1,ky(81)
k,89,kx(80)-1,ky(80)
a,80,82,87,81,88,89
a,82,83,84,85,86,87

ldiv,13,.34
csys,0
wpcs,-l
kwpa,57
wpro,-90
wpro,,60
asel,,7
asbw,all
wpcs,-l
wpro,,atan(ssli)
asbw,2
wpcs,-l
wpro,,atan(sslo)
asbw,1
wpcs,-l
wpro,,atan(sslo)
asbw,7

divide bottom slab rebar at radial locations
*dim,bsr,,4
dl5=27.4
bsr(1)=(7+7.5)*2+dl5,(14+15)/2*12+dl5,31*12+6-9,435
asel,,7
csys,0
wpcs,-1
wpro,,90
*do,i,1,4
wpoff,,bsr(i)
asbw,all
wpoff,,bsr(i)
*endo
csys,0
wpcs,-l
wpoff,kx(68),ky(68)
wpro,,90
wpro,,atan(ssli)
asbw,2
wpcs,-l
wpoff,kx(70),ky(70)
wpro,,90
wpro,,atan(sslo)
asbw,1
wpcs,-l
wpoff,kx(72),ky(72)
wpro,,90
wpro,,atan(sslo)
asbw,7

divide top slab rebar at radial locations
*dim,tsr,,7
tsr(1)=kx(69),kx(35),kx(98),kx(71),kx(100),kx(102),kx(73)
! divide wall rebar
*dim,wr,,4
wr(l)=10*12+19+h2,17*12,23*12+19+h2,h3-42
asel,s,,15,16
csys,0
wpaysys,-1
wprot,,90
*do,i,1,7
wpoff,tsr(i)
asbw,all
wpoff,-tsr(i)
*enddo

! divide dome rebar
*dim,dr,,7
dl6=32.9
dr(i)=7*12+3+dl6,12*12+6+dl6,22*12+6,124+26.75*2,12.2
6*12+2,29*12+6,28*12+6+dl6,
asel,s,,18,28,10
csys,0
wpaysys,-1
wprot,,90
kwpave,3
*do,i,1,7
wpoff,wr(i)
asbw,all
wpoff,-wr(i)
*enddo

! divide bent bar, top of haunch
wpaysys,-1
kwpave,17
wpoff,48*cos(30)
wprot,,90
asel,s,,29
asbw,all
allsel
1,40,39
asbl,28,127
allsel
nummrg,all
numcmp,all

! J-bolts
! 32-35 arc tank wall stiffeners
*dim,jx,,35
*dim,jy,,35
*dim,jdeg,,35
jx(1)=479,479,479,479,479,479,479,479,479,479
jx(11)=479,479,479,479,479,479,479,479,479,479
jx(21)=412,391,369,347,324,329,297,272,241,206,165
jx(31) = 107,479,479,479,479
jy(1) = 19,43,67,91,115,139,163,187,211,235
jy(11) = 259,283,307,331,355,379,402,424,442,460
jy(21) = 474,486,496,504,511,515,518,522,525,527
jy(31) = 529,89.5,89.5*2,89.5*3,89.5*4
jdeg(1) = 90,90,90,90,90,90,90,90,90,90
jdeg(11) = 90,90,90,90,90,90,75,55,45,40
jdeg(21) = 35,30,25,20,15,10,9,8,7,6,5
jdeg(31) = 1,90,90,90,90

csys
asel,,24,29,5
,a,,42,46,4
,a,,14,16,2
,a,,19,21,2
,a,,30,51,21
,a,,45,49,2
,a,,50,56,2
,a,,60,62,2

*do,i,1,35
wpavsys,-1
wpave,-jx(i),jy(i)
wprot,jdeg(i)
wprot,,90
ashw,all
*enddo

! bottom anchors
lanch=5+3/16
ldiv,228,.14
kgen,2,38,,0,lanch,0
a,12,268,269,38

!flange of wall stiffeners - 6"
lset,,175,246,71
,a,,266,303,37
*do,i,32,35
wpavsys,-1
wpave,-jx(i),jy(i)
wprot,jdeg(i)
wprot,,90
wpoff,,6
lsbw,all
*enddo
lset,all

! dome stiffener (detail 9)
lang,16,51,90,8
lset,,414
lsnum
lset,all
*get,stang,line,,ixv,x
wpavsys,-1
kwpa,51
wpro,,90
wpro,,acos(stang)
wpoff,,6
lsbw,all
asbl,106,414

! line for concentrated load
wpavsys,-1
kwpa,1
Identify areas

Inside layer of rebar
asel, loc, x, -485, -484
a, 33, 34
a, 21, 91, 70
a, 30, 100, 70
a, 104, 105
a, 102, 119, 8
a, 107, 111, 4
a, 19, 62, 43
a, 51, 60, 9
a, 112, 116, 2
a, 118, 120, 2
a, 50, 56, 2
a, 122, 127, 5
a, 47
cm, as1, area

Outside layer of rebar
asel, loc, x, -496, -495
a, 18, 64, 46
a, 57, 59
a, 61, 63, 2
a, 53, 55, 2
a, 28, 43, 15
cm, as2, area

Bottom layer of slab
asel, 1, 2

Top layer of slab
asel, loc, y, -13, -11
cm, as4, area

Haunch
asel, s, 32
cm, haunch, area

Concrete insulation
asel, s, 3
cm, cisul, area

Slab
asel, s, 31
cm, slab, area

Haunch vertical steel
asel, s, 9
cm, hvert, area

Haunch radial
asel, s, 10
cm, hrad, area

Concrete
asel
cm, sel, u, hrad
cm, sel, u, hvert
cmset, u, slab
cmset, u, cinsul
cmset, u, haunch
cmset, u, as4
cmset, u, as3
cmset, u, as2
cmset, u, as1
cm, conc, area
alset
save, pnnla, db

Input file: PNNLA2.mac
mat_lin,=1
mat_conc=2
mat_rebar=3
mat_insul=4
mat_soil=5
mat_haunch=6
type_lin,=1
!liner shells
type_tank=2
!tank concrete
type_haunch=3
!haunch concrete
type_slab=4
!slab concrete
type_rebar=5
!rebar
type_insul=6
!insulating concrete
type_soil=7
!soil
et,type_insul,181
et,type_soil,181
et,type_lin,=10,65
et,type_tank+10,65
et,type_haunch+10,65
et,type_slab+10,65
et,type_rebar+10,65
et,type_insul+10,65
et,type_soil+10,45

!define local element coordinate systems for rebar regions
ccmsel, as1
ccmsel, as2
ccmsel, as3
ccmsel, as4
ccmsel, hrad
ccmsel, hvert
*get, narea, area, count
cm, atemp, area

*afun, deg
ics=100
*do, i, 1, narea
*get, ia, area, num, min
asel, s, ia
lsla
kll
ccsys, 0
*get, minx, kp, mnloc, x
*get, maxx, kp, mxloc, x
*get, miny, kp, mnloc, y
*get, maxy, kp, mxloc, y
\[ \theta = 90 \]

*if, minx, ne, maxx, then

\[ \theta = \arctan\left(\frac{\text{maxy} - \text{miny}}{\text{maxx} - \text{minx}}\right) \]

*endif

\[ \text{wp} \text{c} \text{s} \text{y} \text{s}, -1 \]

\[ \text{kwpave}, \text{all} \]

\[ \text{wprot}, \theta \]

\[ \text{cswplan}, \text{ics}, 0 \]

\[ \text{aatt}, \text{mat} \text{rebar}, \text{type} \text{rebar}, \text{ics} \]

\[ \text{cm} \text{sel}, \text{s} \text{,atemp} \]

\[ \text{asel}, u, \text{,ia} \]

\[ \text{cm}, \text{atemp}, \text{area} \]

ics=ics+l

*enddo

!define spherical coordinate system for haunch, with center at global origin

\[ \text{csys}, 0 \]

\[ \text{wp} \text{c} \text{s} \text{y} \text{s}, -1 \]

local, ics, 2

\[ \text{asel}, s, \text{32} \]

\[ \text{aatt}, \text{mat} \text{conc}, 604, \text{type} \text{haunch}, \text{ics} \]

!set real constants for rebar

\[ \text{csys}, 0 \]

\[ \text{wp} \text{c} \text{s} \text{y} \text{s}, -1 \]

!wall external

\[ \text{set}_r \text{y}, -8, 131, 206, 'as1' \]

\[ \text{set}_r \text{y}, 131, 204, 207, 'as1' \]

\[ \text{set}_r \text{y}, 204, 287, 208, 'as1' \]

\[ \text{set}_r \text{y}, 287, 339, 209, 'as1' \]

\[ \text{set}_r \text{y}, 339, 382, 210, 'as1' \]

!wall internal

\[ \text{csys}, 0 \]

\[ \text{wp} \text{c} \text{s} \text{y} \text{s}, -1 \]

\[ \text{set}_r \text{y}, -8, 131, 206, 'as1' \]

\[ \text{set}_r \text{y}, 131, 204, 207, 'as1' \]

\[ \text{set}_r \text{y}, 204, 287, 208, 'as1' \]

\[ \text{set}_r \text{y}, 287, 339, 209, 'as1' \]

\[ \text{set}_r \text{y}, 339, 382, 210, 'as1' \]

!slab bottom

\[ \text{csys}, 0 \]

\[ \text{wp} \text{c} \text{s} \text{y} \text{s}, -1 \]

\[ \text{set}_r \text{y}, -75, 0, 101, 'as3' \]

\[ \text{set}_r \text{y}, -115, -75, 102, 'as3' \]

\[ \text{set}_r \text{y}, -202, -115, 103, 'as3' \]

\[ \text{set}_r \text{y}, -350, -202, 104, 'as3' \]

\[ \text{set}_r \text{y}, -369, -350, 105, 'as3' \]

\[ \text{set}_r \text{y}, -435, -369, 106, 'as3' \]

\[ \text{set}_r \text{y}, -442, -435, 107, 'as3' \]

\[ \text{set}_r \text{y}, -531, -442, 108, 'as3' \]

!slab top

\[ \text{csys}, 0 \]

\[ \text{wp} \text{c} \text{s} \text{y} \text{s}, -1 \]

\[ \text{set}_r \text{y}, -75, 0, 111, 'as4' \]

\[ \text{set}_r \text{y}, -115, -75, 112, 'as4' \]

\[ \text{set}_r \text{y}, -202, -115, 113, 'as4' \]

\[ \text{set}_r \text{y}, -350, -202, 114, 'as4' \]

\[ \text{set}_r \text{y}, -369, -350, 115, 'as4' \]

\[ \text{set}_r \text{y}, -435, -369, 116, 'as4' \]

\[ \text{set}_r \text{y}, -442, -435, 117, 'as4' \]

\[ \text{set}_r \text{y}, -531, -442, 118, 'as4' \]
!dome external
csys,0
wposys,-1
set_rx,-120,0,301,'as2'
set_rx,-183,-120,302,'as2'
set_rx,-270,-183,303,'as2'
set_rx,-305,-270,304,'as2'
set_rx,-314,-305,305,'as2'
set_rx,-354,-314,306,'as2'
set_rx,-369,-354,307,'as2'
set_rx,-400,-369,308,'as2'

!dome internal
csys,0
wposys,-1
set_rx,-120,0,301,'asl'
set_rx,-183,-120,302,'asl'
set_rx,-270,-183,303,'asl'
set_rx,-305,-270,304,'asl'
set_rx,-314,-305,305,'asl'
set_rx,-354,-314,306,'asl'
set_rx,-369,-354,307,'asl'
set_rx,-400,-369,308,'asl'

!launch external
csys,5
wposys,-1
cmse,s,as2
asel,r,loc,x,396,450
set_real,401
cmse,s,as2
asel,r,loc,x,450,504
r,loc,z,381,999

set_real,402
cmse,s,as2
asel,r,loc,z,408,450
set_real,403
cmse,s,as2
asel,r,loc,z,372,410
set_real,404

!launch internal
cmse,as1
set_ry,381,408,405,'as1'
set_ry,408,483,406,'as1'

! Split launch vertical at top of radial intersection
lsel,all
ksel,all
asel,s,,9
ldiv,82,.47
1,278,87
*get,ics(area,9,attr,esys
asbl,9,418
cm,hvert,area
aatt,mat_rebar,,type_rebar,ics

!launch middle (vertical)
asel,,,67
set_real,500
!Lower
asel,,,65
set_real,501
!Upper
!launch middle (radial)
asel,s,,,10
set_real,502
insulating concrete
asel,s,,3
aatt,mat Insul,600,type Insul,0

haunch concrete
asel,s,,32
aatt,mat Haunch,503,type Haunch,ics

alls el
asel,u,mat,mat Insul
asel,u,mat,mat rebar
asel,u,mat,mat Haunch
aatt,mat conc,700,type tank,0
cm,atemp,area
asel,r,loc,x,-999,-8.125
aatt,mat conc,700,type slab,0
cmsel,s,atemp
asel,u,type,type slab
aatt,mat conc,700,type tank,0

asel,,27 Outer cover haunch
l,39,18
asbl,27,419
aatt,mat conc,700,type tank,0

alls el
save, pnnla2, db

Input file: PNNLA3.mac

identify jbolt lines

*** Remove jbolts from wall 5/6/04
lsel,,315,322,7
,a,,318,327,9

lsel,,229,389,160
,a,,310,394,84
,a,,399,407,8
,a,,287,288
,a,,413

lsel,,,414,415

lsel,,3,9,6
,a,,14,19,5
,a,,330
,a,,58,59
,a,,339,341,2
,a,,348,373,5
,a,,380,381
,a,,385

lsel,,loc,x,-480
,loc,y,382
lsel,,1
lsel,a,,16,17
Input file: PNNLA4.mac

Input file: PNNLA4.mac

I copy areas for overlapping with soil

I copy areas for overlapping with soil

Input file: PNNLA4.mac

I copy areas for overlapping with soil

I copy areas for overlapping with soil

I copy areas for overlapping with soil

I copy areas for overlapping with soil

I copy areas for overlapping with soil

I copy areas for overlapping with soil

Input file: PNNLA4.mac

I copy areas for overlapping with soil

I copy areas for overlapping with soil

I copy areas for overlapping with soil

h top=12
radsoil=550
depthsoil=60
csys,0
wpcsys,-1
aselnone
rectng,-radsoil,0,ymn-depthsoil,ymx+htop
cm,as0,area
allsel
asba,as0,a_new
aseln,283
adele,alln,1
aseln,282
aseln,282
cm,soil,area
atts,mat_soil,1,type_soil

I*** Clean up mesh 4/1/03
I***
Input file: PNNL.A5.mac
vsel,s,mat,,1
cm,vtemp,volu
gen,2,all
cm,vvv,volu
cmsel,s,vtemp
clear,all
dele,all,,1
cmsel,s,vw
eslv
emodif,all,mat,mat_soil

!rotate all nodes to cylindrical coordinate system (22)
csys,0
wpsys,-1
wprot,-90
cswplan,22,1
alsel
nrotate,all

csys,0
!merge slab/rebar nodes/kps
vsel,s,type,,type_rebar+10
vsel,r,loc,y,-999,-11
vsel,a,type,,type_slab+10
vsel,u,mat,,1
eslv
nsle
asl
lsla
kssl
nummrg,node
nummrg,kp

!merge tank/rebar nodes/kps
vsel,s,type,,type_rebar+10
vsel,r,loc,y,-8,999
vsel,a,type,,type_tank+10
vsel,a,type,,type_haunch+10
vsel,u,mat,,1
asl
lsla
kssl
nsla,,1
nummrg,node
nummrg,kp

!couple soil to concrete exterior
esel,s,mat,,mat_soil
nsle
kssl
lsla,,1
asl,,1
cm,asoil,area
vsel,s,type,,type_tank+10
asl
asel,r,ext
cm,atank,area
vsel,s,type,,type_slab+10
asl
asel,r,ext
cm,aslab,area
vsel,s,type,,type_insul+10
asl
cm,ainsul,area

top of dome
csys,0
cm sel,s,atank
cm sel,a,as oil
asel,r,loc, y, 452, 999
lsla
ns la,,1
cpintf,uz,1

ls ide of tank
cm sel,s,atank
cm sel,a,as oil
asel,r,loc, y, 8.125, 452
ls la
ns la,,1
cpintf,ux,1

ls ide of slab
cm sel,s,as lab
cm sel,a,as oil
asel,r,loc, y, -31, -6.7
lsla
ns la,,1
cpintf,ux,1

ls ide of slab
cm sel,s,as lab
cm sel,a,as oil
asel,r,loc, y, -31, -6.7
asel,r,loc, x, -999, -529
lsla
ns la,,1
cpintf,ux,1

bottom of slab
cm sel,s,as lab
cm sel,a,as oil
asel,r,loc, x, -530, 0
asel,r,loc, y, -999, -18.5
lsla
ns la,,1
cpintf,uz,1

couple top of slab / bottom of wall
cm sel,s,as lab
cm sel,a,atank
lsla
ns la,,1
cpintf,uz,1

couple top of slab / bottom of insulating concrete
v sel,s,mat,,mat_insul
cm,vtemp,volu
g en,2,all
cm,volu_insul,volu
cm sel,s,vtemp
clear,all
vdelete,all,,1
v delete,all,,1
cm sel,s,volu_insul
asm
cm,ainsul,area
cm sel,s,as lab
cm sel,a,ainsul
lsla
ns la,,1
cpintf,uz,1
Input file: PNNLA6.mac

!*** mesh J-bolt @ liner w/separate node 5/6/04

!*** Use mesh200 for J-bolts 4/1/04
!*** redefine as beam188 in set_slicea.mac

resu,pnnla5,db

generate J-bolts

type_bolt=20
et,type_bolt,200,2
mat,mat_liner
type,type_bolt
csys,0
cmsel,s, line_bolt
csys,11
lsel,r,loc,x,480,483
qlgen,2,all,3000
ksll
ksel,r,loc,x,481,486
numm,kp
cmsel,s, line_bolt
lsel,u,loc,x,480,483
,423,435
lmesh,all
csys

generate studs

type_stud=21
et,type_stud,4
area_stud=pi*.5**2/4
iy=pi*.5**4/64
iz=iy
ty=.5
tz=.5
r,30,area_stud,iy,iz,ty,tz
cmsel,s, line_bolanch
real,30
mat,mat_liner
type,type_stud
lmesh,all

generate wall base plate
asel,s,214
,a,,706
,a,,913,918,5
,a,,934
cm,baseplate,area
type_baseplate=22
et,type_baseplate,63
r,40,375
mat,mat_liner
type,type_baseplate
real,40
amesh,all

generate confining ring below 12" secondary liner fillet
ksel,s,loc,x,-480-.01,-480+.01
ksel,r,loc,y,-8.2,6.9
lslk,1
asll
asel,u,loc,z,0
cm,confineplate,area
type_confine=23
et,type_confine,63
r,41,3/16
type,type_confine
real,41
mat,mat_liner
amesh,all

!generate confining ring for insulating concrete
csys,0
kisel,s,loc,x,-447
lslk,1
asll,1
cm,confining_area
type_confine=23
type,type_confine
real,41
mat,mat_liner
amesh,all

!generate construction stiffeners
cmsel,s,line_wstiff
asll
asel,u,loc,z,0
cm,stiff_area,area
type_stiff=24
et,type_stiff,63
type,type_stiff
r,42,.5
real,42
mat,mat_line
amesh,all

!generate detail #9
cmsel,s,line_hstiff
asll
asel,u,loc,z,0
cm,detail9,area
type_anchor=25
et,type_anchor,63
type,type_anchor
r,43,.375*1.1
real,43
mat,mat_liner
amesh,all

allsel
save,pnnla6,db

Input file: PNNLA7.mac
!primary liner
allsel
aslv
lsla
cmsel,s,line_prim
lsel,a,34
cm,ltemp,line

asll
asel,u,loc,z,0
ksll
nummrg,kp
cm,line_prim,line
cm,area_prim,area
! Reverse normals - dome
asel,r,loc,y,459,999
arev,all
asel,none
kisel,s,loc,x,0
ksel,r,loc,y,ymx
*get,iktop,kp,,num,min
ksel,s,loc,x,0
ksel,r,loc,y,ymn
*get,ikbot,kp,,num,min
ksel,all
cmsel,s,ltemp
cmsel,s,area_prim
lsla,u
arotat,all,,,,ikbot,iktop,swp_th,1
lsla
ksll
nummrg,kp
aatt,mat_liner,,type_liner
esize,4
smrt,off
kSEL,,9,436,427!radius part of primary liner
lesi,all,,8,,1
kSEL,,440,441
lesi,all,,1,,1
amesh,all

cm,atemp,area
agen,2,all
cm,area_liner_prim,area
cmsel,s,atemp
aclear,all
vset,all
aslv,u
adele,all,,1
r,50,r50
r,51,r51

r,52,r52
r,53,r53
r,54,r54
r,55,r55

!11" lid at tank bottom
cmsel,s,area_liner_prim
esla
cm,etemp,elem
nsla,,1
cm,ntemp,node
nsel,r,loc,x,-24,0
nsel,r,loc,y,-999,10
esln
cmsel,r,etemp
emodif,all,real,50

!3/8" bottom (on top of insulating concrete)
cmsel,s,ntemp
nsel,r,loc,x,-450+48,-24
nsel,r,loc,y,-999,10
esln
cmsel,r,etemp
emodif,all,real,51

!17/8" at fillet
cmsel,s,atemp
nsel,r,loc,x,-450,-450+48
nsel,r,loc,y,-999,36.89
esln
cmsel,r,etemp
emodif,all,real,52
I/3/4" vertical run  
cmse1,s,ntemp  
sel,r,loc,x,-450  
sel,r,loc,y,36.88,144.89  
esln  
cmse1,r,etemp  
emodif,all,real,53  

I/1/2" vertical run  
cmse1,s,ntemp  
sel,r,loc,x,-450  
sel,r,loc,y,144.88,381.5  
esln  
cmse1,r,etemp  
emodif,all,real,54  

I/3/8" upper reaches of liner  
cmse1,s,ntemp  
sel,r,loc,x,-450,-72.1  
sel,r,loc,y,381.6,999  
esln  
cmse1,r,etemp  
emodif,all,real,51  

I/1/2" at top/center  
cmse1,s,ntemp  
sel,r,loc,x,-72,0  
sel,r,loc,y,381.6,999  
esln  
cmse1,r,etemp  
emodif,all,real,54  

! couple vertical displacements at liner bottom  

(first rotate the shell nodes)  
csel,s,type,,type_liner  
nsle  
csys,22  
rotate,all  
csys,0  
ase1,s,loc,y,0  
nsle,,1  
cpintf,uz,1  
cm,liner_insul_cpl,y,node  

alsel  
save,pnnla7,db  

Input file: PNNLA8.mac  
! create shell elements for secondary liner  
cmse1,s,line_secon  
asse1  
ase1,u,loc,z,0  
cm,atemp,area  
! Reverse normals - upper section  
ase1,r,loc,y,381,999  
arev,all  
lsel,,21,22  
,25  
arev,all,,ikbot,iktop,swp_th,1  
cmse1,a,atemp  
ase1,a,,27  
cm,area_secon,area  
lsla  
ksll  
ummrg,kp
lessi,437,,1
,438,,1
,9,,6
,22,,6
aatt,mat_liner,55,type_liner
amesh,all

cm,atemp,area
agen,2,all
cm,area_second,area
cmsel,s,atemp
aclear,all
asl,v,u
adede,all,,1

ksel,s,loc,x,0
ksel,r,loc,y,ymx
*get,iktop,kp,,num,min
ksel,s,loc,x,0
ksel,r,loc,y,ymn
*get,ikbot,kp,,num,min
ksel,all

!couple vertical displacements at liner bottom
!(first rotate the shell nodes)
esel,s,type,,type_liner
nsle
csys,22
nrotate,all

csys,0

!couple shell horizontal displacements to sidewall

esel,s,type,,type_liner
nsle
cm,ntemp,node
esel,s,mat,,mat_conc
nsle
cmsel,a,atemp
cm,ntemp,node
nsel,r,loc,y,-2,460
cpintf,ux,,1
cm,liner_wall_cp_x,node

!couple shell vertical displacement to dome
cmsel,s,atemp
nsel,r,loc,y,460,999
cpintf,uz,,1
cm,liner_dome_cp_z,node

!merge secondary liner nodes with slab top nodes
asel,,loc,y,-8.125
asel,,loc,x,-465,1
lsia
nsll,,1
cpdefe,all,all
cpintf,uz,,1
albel
save,pnnla8,db

Input file: PNNLA9.mac
*** Do not common node intersection of
*** primary & secondary liner JED 3/19/04
alls el
mpdele,all,all
tbdele,all,all
set_materials
set_options
acel,0,1,0
alls el

!merge coincident nodes between liners and jbolts/studs/anchors
esel,s,type,,type_bolt
esel,a,type,,type_stiff
esel,a,type,,type_anchor
esel,a,type,,type_stud
esel,a,type,,type_liner
nsel,,1
nsel,u,,22789,22790
nummrg,node

set_soil
alls el
ddele,all,all

!constrain boundaries
csys,0
nsel,s,loc,x,0
d,all,ux,0
d,all,uy,0
alls el

*get,xmn,node,,mnloc,x
*get,ymn,node,,mnloc,y
*get,ymx,node,,mxloc,y

nsel,s,loc,y,ymn
d,all,ux,0,,uy,uz

kset,,1
kset,r,loc,z,0

asll
nsla,,1
d,all,ux,0
d,all,uy,0
nsla,,1
d,all,ux,0,,uy,uz

csys,22
nsel,s,loc,y,180-.01,180+.01
nsel,a,loc,y,180+swp_th-.01,180+swp_th+.01
d,all,uy,0
alls el

save,pnmla9.db

Input file: set_areas_slice.mac
acel,,,150,161
,,177,179,2
,,154,212,28
,,224,228,2
cm,area_prim,area
**Input file: setbackfill.mac**

```plaintext
asels,,1,199,,1
aselnve
cmse,,area_prim
cm,area_secon,area
cmse,,area_prim
nsla,,l
esln
sfdele,all,all
sfdele,all,all,all

asels,,239
nsla,,l
esln
arev,all

cmse,,invert
.a.,ahorz
cm,asoil,area

asels,,314,316
.a.,700
.a.,196
.a.,221,261,40
.a.,870,876,6
.a.,881,887,6
.a.,636,646,10
.a.,605,625,20
.a.,651,693,42
.a.,641,655,15
.a.,231,238,7
.a.,710
.a.,333
.a.,243,244
.a.,190,191
.a.,723,733,10
.a.,756,762,6
.a.,784,796,12
.a.,806,818,12
.a.,828,839,11
.a.,853,864,11
.a.,844
cm,acone_shell,area

asels,,106,143,37
cm,area_irsul_top,area

asels,,27
cm,area_irsul_bot,area

asels,,929
cm,slab_top,area

Input file: set_backfill.mac

****
****Dilation angle 8 6/4/04
****Add materials for load factor restart 8/2/03
```
!*** JED mod 4/1/03
!*** Define backfill/overburden
!***
max_mat=max_mat+1
cmse,soil_elem
nsle
hsub=top_elev-arg2-h2+24
rsub=-(68*12+hsub/1.5)
nsel,t,loc,y,top_elev-arg1,top_elev-arg2
x,loc,x,rsub,0
csln
esel,r,mat,max_mat
eemod,all,mat,max_mat+20
soil_ex=arg3
! elastic modulus [psi]
soil_prxy=arg4
! Poisson ratio
soil_alpx=0
coefficient [me/F]
soil_cohesion=1
(assume small number) [psi]
soil_friction=35
! internal friction angle [deg]
soil_dilat=8
! dilatancy angle [deg]
soil_alpx=soil_alpx*1e-6
\text{lb/in}^3
soil_dens=b_gam/1728
\text{lb/in}^3
mp,ex,max_mat+20,soil_ex
mp,dens,max_mat+20,soil_dens
mp,prxy,max_mat+20,soil_prxy
mp,alpx,max_mat+20,soil_alpx
tb,dp,max_mat+20
tbdata,1,soil_cohesion,soil_friction,soil_dilat

!*** materials max_mat+70 for load factor restart
mp,ex,max_mat+70,soil_ex
mp,dens,max_mat+70,soil_dens*1.7/1.4
mp,prxy,max_mat+70,soil_prxy
mp,alpx,max_mat+70,soil_alpx
tb,dp,max_mat+70
tbdata,1,soil_cohesion,soil_friction,soil_dilat

Input file: set_csyst.mac
*get,ia,area,,num,min
*get,iareal,area,ia,attr,real
*get,imat,area,ia,attr,mat
*get,iatype,area,ia,attr,type
aat,imat,iareal,iatype,arg1

Input file: set_esyst.mac
!*** Set wall & dome rebar to material 3 6/4/04
!***
/prep7
! define reinforced concrete real constants

!—Create local coordinate systems for esys
!—spherical 1
wpcsysts,-1,0
kwpave,1
wpoff,-1260
cswpla,200,2
wpcsysts,-1,0
kwpave,1
wpoft,-892
cswplt,201,2

csys,0
wpcsys,-1
rat=40/15
k,10000,0,0,0
kwpave,10000
wprot,90
cswplan,202,2,rat,rat

esel,s,real,100,118 !slab
esel,r,type,15
eselif,all,esys,22

esel,s,real,200,210 !vertical wall
esel,r,type,15
eselif,all,esys,22

esel,s,real,300,308 !inner exterior dome
esel,r,type,15
nsle
esys,22
nsel,r,loc,x,0,170
esln
esel,r,type,15
eselif,all,esys,200

esel,s,real,300,308 !outer exterior dome
esel,r,type,15
nsle
esys,22
nsel,r,loc,x,170,9999

esel,s,real,401,402 !exterior haunch
esel,r,type,15
eselif,all,esys,201

esel,s,real,403,404 !vertical haunch
esel,r,type,15
eselif,all,esys,22

esel,s,real,405,406 !interior haunch
esel,r,type,15
eselif,all,esys,202

esel,s,real,500,501 !vertical mid haunch
esel,r,type,15
eselif,all,esys,22

esel,s,real,502 !spherical mid haunch
esel,r,type,15
eselif,all,esys,201

esel,s,real,503 !tie bar haunch
eselif,all,esys,ics

! Slab bottom
r,101,6,.0256,.0256,.0256 ! Center to 6'3"
rmor,90,90,90
r,102,6,.0258,.0256,.0256 ! 6'3" to 7'6"+ld
rmor,90,90,90
<table>
<thead>
<tr>
<th>Section</th>
<th>Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slab top</td>
<td>7'6&quot; + ld to 14'6&quot; + ld</td>
</tr>
<tr>
<td>108.6, 6, 0.0316, 6, 0.0256</td>
<td>90, 90, 90</td>
</tr>
<tr>
<td>104.6, 6, 0.0360, 6, 0.0256</td>
<td>90, 90, 90</td>
</tr>
<tr>
<td>105.6, 6, 0.0326, 6, 0.0256</td>
<td>90, 90, 90</td>
</tr>
<tr>
<td>106.6, 6, 0.0393, 6, 0.0256</td>
<td>90, 90, 90</td>
</tr>
<tr>
<td>107.6, 6, 0.0267, 6, 0.0552</td>
<td>90, 90, 90</td>
</tr>
<tr>
<td>108.6, 6, 0.1016, 6, 0.0552</td>
<td>90, 90, 90</td>
</tr>
<tr>
<td>Slab top</td>
<td>10'3&quot; to 17&quot;</td>
</tr>
<tr>
<td>202.6, 6, 0.0982</td>
<td>90, 90, 90, 90</td>
</tr>
<tr>
<td>203.6, 6, 0.0655</td>
<td>90, 90, 90, 90</td>
</tr>
<tr>
<td>204.6, 6, 0.0655</td>
<td>90, 90, 90, 90</td>
</tr>
<tr>
<td>205.6, 6, 0.0655</td>
<td>90, 90, 90, 90</td>
</tr>
<tr>
<td>Slab top</td>
<td>28'3-1/2&quot; to tangent height</td>
</tr>
<tr>
<td>206.6, 6, 0.0982</td>
<td>90, 90, 90, 90</td>
</tr>
<tr>
<td>207.6, 6, 0.0982</td>
<td>90, 90, 90, 90</td>
</tr>
<tr>
<td>208.6, 6, 0.0655</td>
<td>90, 90, 90, 90</td>
</tr>
<tr>
<td>209.6, 6, 0.0655</td>
<td>90, 90, 90, 90</td>
</tr>
<tr>
<td>210.6, 6, 0.0655</td>
<td>90, 90, 90, 90</td>
</tr>
<tr>
<td>Dome top &amp; bottom</td>
<td>25'4-1/2&quot; to 26'2&quot;</td>
</tr>
<tr>
<td>301.6, 6, 0.0453</td>
<td>90, 90, 90, 90</td>
</tr>
<tr>
<td>302.6, 6, 0.0490</td>
<td>90, 90, 90, 90</td>
</tr>
<tr>
<td>303.6, 6, 0.0661</td>
<td>90, 90, 90, 90</td>
</tr>
<tr>
<td>304.6, 6, 0.0496</td>
<td>90, 90, 90, 90</td>
</tr>
<tr>
<td>305.6, 6, 0.1399</td>
<td>90, 90, 90, 90</td>
</tr>
<tr>
<td>Wall internal</td>
<td>25'4-1/2&quot; to 26'2&quot;</td>
</tr>
<tr>
<td>206.6, 6, 0.0982</td>
<td>90, 90, 90, 90</td>
</tr>
<tr>
<td>207.6, 6, 0.0982</td>
<td>90, 90, 90, 90</td>
</tr>
<tr>
<td>208.6, 6, 0.0655</td>
<td>90, 90, 90, 90</td>
</tr>
<tr>
<td>209.6, 6, 0.0655</td>
<td>90, 90, 90, 90</td>
</tr>
<tr>
<td>210.6, 6, 0.0655</td>
<td>90, 90, 90, 90</td>
</tr>
<tr>
<td>Wall external</td>
<td>25'4-1/2&quot; to 26'2&quot;</td>
</tr>
<tr>
<td>201.6, 6, 0.0982</td>
<td>90, 90, 90, 90</td>
</tr>
<tr>
<td>202.6, 6, 0.0982</td>
<td>90, 90, 90, 90</td>
</tr>
<tr>
<td>203.6, 6, 0.0655</td>
<td>90, 90, 90, 90</td>
</tr>
<tr>
<td>204.6, 6, 0.0655</td>
<td>90, 90, 90, 90</td>
</tr>
<tr>
<td>205.6, 6, 0.0655</td>
<td>90, 90, 90, 90</td>
</tr>
</tbody>
</table>
r,306,,,3,1300   ! 25'2" to 29'9"
rmor,90,,,3,1657,90,90
r,307,,,3,1197   ! 28' to 29'6"
rmor,90,,,3,2485,90,90
r,308,,,3,1139   ! 29'6" to 32'6"
rmor,90,,,3,2485,90,90

! Haunch external
! Dome (esys,201)
r,401,,,3,2209   ! 33'3" to 37'6"
rmor,90,,,3,1534,90,90
r,402,,,3,2209   ! 37'6" to 41'4"
rmor,90,,,3,1375,90,90
!
Wall (esys,22)
r,403,,,3,2485   ! Height: 34' to corner
rmor,90,,,3,2045,90,90
r,404,,,3,1309   ! Height: tangent to 34'
rmor,90,,,3,2700,90,90

! Haunch internal
!
(esys,202)
r,405,,,3,1309   ! Height: tangent to 34'
rmor,90,,,3,1309,90,90
r,406,,,3,2209   ! 33'3" radius to 34' height
rmor,90,,,3,1489,90,90

! Haunch middle
!
(esys,202)
r,502,3,,0.007,,3,0.0261   ! 33'3" to vertical
rmor,90,3,0.0007,3,0.0261
!
(esys,22)
r,500,3,,0.007,,3,1.243   ! lower vertical
rmor,90,3,0.0236,90,90

r,501,3,,0.0007,,3,1.243   ! upper vertical
rmor,90,3,0.0109,90,90

! Haunch ties
r,503,3,,0.006
rmor,90,,90,90

! Secondary liner above 357.5"
! (esel,56)
esel,s,real,,55
nsle,,1
esys,0
nsel,t,loc,y,357.5,99999
esln,,1
esel,t,type,,1
emodif,all,real,56

Input file: set_mat.mac
*get,ia,area,,num,min
*get,ia,area,ia,attr,real
*get,ia,area,ia,attr,type
*get,ia,area,ia,attr,esys
ia,attr,ia,area,ia,attr,esys

Input file: set_materials.mac
***
*** 6/7/04 Add 205F & 215F degraded concrete
*** 6/4/04 MISO rebar (mats 3 & 6)
*** 10/9/03 Fill out temperature dependent steel modulus table
*** 7/23/03 Elastic insulating concrete (no cracking)
*** 6/17/03 Correct alpx,mat_liner
***
5/14/03
Add 6 concrete materials: mats 21 - 26
Constant (degraded) properties @
230,250,270,290,310,330
to be used after \( t = \) 3+15+330 days
Remove concrete crushing 5/5/03

Temperature dependent Materials
Best estimate - mean values
All steel elastic
Run 2 (nocreep) 4/16/03

Specify all material properties
/prep7

[1] steel (for liner, jbolts, studs, anchors, bearing plates)
\( \text{steel_alpx} = \text{steel_alpx} \times 10^{-6} \) in/in/F
\( \text{steel_dens} = \text{steel_dens} \times 10^{3} \) lb/in^3

mpde
mpde,1,50,70,100,125,150,175
mpde,7,200,225,250,275,300,325
mpde,13,350

mpda,ex,mat_liner,1,29.5e6,29.5e6,29.5e6,29.2e6,29.0e6,
28.9e6
mpda,ex,mat_liner,7,28.8e6,28.6e6,28.5e6,28.4e6,28.3e6,
28.1e6
mpda,ex,mat_liner,13,28.0e6

mp,ex,mat_liner,steel_dens
mp,proxy,mat_liner,steel_proxy

mpda,alpx,mat_liner,1,5.73e-6,5.73e-6,5.73e-6,5.82e-6,
5.91e-6,6.0e-6
mpda,alpx,mat_liner,7,6.09e-6,6.18e-6,6.27e-6,6.35e-6,
6.43e-6,6.51e-6
mpda,alpx,mat_liner,13,6.59e-6

tb,bsiso,mat_liner
tbdata,steel_yield,steel_tan*steel_ex

[2] structural concrete
\( \text{conc_alpx} = \text{conc_alpx} \times 10^{-6} \) in/in/F
\( \text{conc_dens} = \text{conc_dens} \times 10^{3} \) lb/in^3

mp,ex,mat_conc,7.434e6,-30.09e3,71.16,-0.709
mp,ex,mat_conc,1,5.083e6,5.083e6,5.083e6

mp,proxy,mat_conc,conc_proxy
mp,alpx,mat_conc,conc_alpx


tb,concr,mat_conc,5

tbda,1,,1.98,519,-1

tbda,1,200,2

tbda,1,1.98,519,-1

tbda,225,3

tbda,1,1.98,427,-1

tbda,250,4

tbda,1,1.98,335,-1

tbda,350,5

tbda,1,1.98,335,-1


tb,creep,mat_conc
tbda,1,2545e-6,1,0.838,320,1

[21] degraded structural concrete (205F)
I [22] degraded structural concrete (215F)
mp,ex,22,3.557e6
dens,22,conc_dens
prxy,22,conc_prxy
alpx,22,conc_alpx
tb,creep,22
tbda,1,1.98,465,-1
tb,creep,22
tbda,1,2545e-6,1,-838,320,,1

I [23] degraded structural concrete (225F)
mp,ex,23,3.467e6
dens,23,conc_dens
prxy,23,conc_prxy
alpx,23,conc_alpx
tb,creep,23
tbda,1,1.98,427,-1
tb,creep,23
tbda,1,2545e-6,1,-838,320,,1

I [24] degraded structural concrete (235F)
mp,ex,24,3.380e6
dens,24,conc_dens
prxy,24,conc_prxy
alpx,24,conc_alpx
tb,creep,24
tbda,1,1.98,390,-1
tb,creep,24
tbda,1,2545e-6,1,-838,320,,1

I [25] degraded structural concrete (245F)
mp,ex,25,3.297e6
dens,25,conc_dens
prxy,25,conc_prxy
alpx,25,conc_alpx
tb,creep,25
tbda,1,1.98,354,-1
tb,creep,25
tbda,1,2545e-6,1,-838,320,,1

I [26] degraded structural concrete (255F)
mp,ex,26,3.217e6
dens,26,conc_dens
prxy,26,conc_prxy
alpx,26,conc_alpx
tb,creep,26
tbda,1,1.98,335,-1
tb,creep,26
tbda,1,2545e-6,1,-838,320,,1

I [27] degraded structural concrete (265F)
mp,ex,27,3.141e6
dens,27,conc_dens
prxy,27,conc_prxy
alpx,27,conc_alpx
tb,creep,27
tbda,1,1.98,335,-1
![28] degraded structural concrete (275F)
mp, ex, 28, 3.067e6
, dens, 28, conc, dens
, proxy, 28, conc_proxy
, alp, 28, conc_alp
tb, concr, 28

tb, creep, 28

tbda, 1, 2545e-6, 1, -838, 320, 1

![29] degraded structural concrete (285F)
mp, ex, 29, 2.996e6
, dens, 29, conc, dens
, proxy, 29, conc_proxy
, alp, 29, conc_alp

tb, concr, 29

tbda, 1, 2545e-6, 1, -838, 320, 1

![30] degraded structural concrete (295F)
mp, ex, 30, 2.927e6
, dens, 30, conc, dens
, proxy, 30, conc_proxy
, alp, 30, conc_alp

tb, concr, 30

tbda, 1, 1.98, 335, -1

tb, creep, 30

tbda, 1, 2545e-6, 1, -838, 320, 1

![31] degraded structural concrete (305F)
mp, ex, 31, 2.860e6
, dens, 31, conc, dens
, proxy, 31, conc_proxy
, alp, 31, conc_alp

tb, concr, 31

tbda, 1, 1.98, 335, -1

tb, creep, 31

tbda, 1, 2545e-6, 1, -838, 320, 1

![32] degraded structural concrete (315F)
mp, ex, 32, 2.796e6
, dens, 32, conc, dens
, proxy, 32, conc_proxy
, alp, 32, conc_alp

tb, concr, 32

tbda, 1, 1.98, 335, -1

tb, creep, 32

tbda, 1, 2545e-6, 1, -838, 320, 1

![33] degraded structural concrete (325F)
mp, ex, 33, 2.734e6
, dens, 33, conc, dens
, proxy, 33, conc_proxy
, alp, 33, conc_alp

tb, concr, 33

tbda, 1, 1.98, 335, -1

tb, creep, 33

tbda, 1, 2545e-6, 1, -838, 320, 1

![34] degraded structural concrete (335F)
mp, ex, 34, 2.673e6
, dens, 34, conc, dens
![3][35] degraded structural concrete (345F)

mp,ex,35,2.615e6
,dens,35,conc_dens
,prxy,35,conc_prxy
,alpx,35,conc_alpx
!tb,creep,35
!tbda,1.,2545e-6,1.,-838,320.,1

![4][4] rebar

rebar_alpx=rebar_alpx*1e-6 !in/in/F
rebar_dens=rebar_gamma/1728 !lb/sec^2/in^4

mp,ex,mat_rebar,mat_rebar_ex
mp,dens,mat_rebar,mat_rebar_dens
mp,prxy,mat_rebar,mat_rebar_prxy
mp,alpx,mat_rebar,mat_rebar_alpx
!tb,mi50,mat_rebar,4,4
!tbte,100,1
!tbpt,2069e-6,60000
,"3770e-6,61720
,"9555e-6,66682
,"20129e-6,70582
!tbte,300,3
!tbpt,1896e-6,53304
,"3770e-6,659850
,"9555e-6,64831
,"20129e-6,68453
!tbte,400,4
!tbpt,1780e-6,51630
,"3770e-6,57979
,"9555e-6,62780
,"20129e-6,66325

![5][4] insulating concrete

insul_alpx=insul_alpx*1e-6 !in/in/F
insul_dens=insul_gamma/1728 !lb/in^3

mp,ex,mat_insul,mat_insul_ex
mp,dens,mat_insul,mat_insul_dens
mp,prxy,mat_insul,mat_insul_prxy
mp,alpx,mat_insul,mat_insul_alpx
!tb,concr,mat_insul
!tbda,1,insul_open,insul_closed,insul_crack,-1

![5][5] soil

! These soil properties for material 5 are overwritten later

!soil_ex=575000 !elastic modulus [psi]
!soil_prxy=0.1 !Poisson ratio
!soil_alpx=0 !thermal expansion coefficient [me/F]
!soil_gamma=125 !unit weight [lbf/ft^3]

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C.43
\texttt{! soil\_cohesion=0 ! drucker-prager constant (assume small number) [psi]}

\texttt{! soil\_friction=35.4 ! internal friction angle [deg]}

\texttt{! soil\_dilat=35.4 ! dilatancy angle [deg]}

\texttt{! soil\_alpx=soil\_alpx*1e-6 \textbackslash{} lin/lin/F}

\texttt{! soil\_dens=soil\_gamma/1728 \textbackslash{} lb/in^3}

\texttt{! mp\_ex,mat\_soil,soil\_ex}

\texttt{! mp\_dens,mat\_soil,soil\_dens}

\texttt{! mp\_prxy,mat\_soil,soil\_prxy}

\texttt{! mp\_alpx,mat\_soil,soil\_alpx}

\texttt{! tb\_mp,mat\_soil}

\texttt{! tb\_data,1,soil\_cohesion,soil\_friction,soil\_dilat}

\texttt{! set mat\_haunch\_materials equal to mat\_cone\_material}

\texttt{vsel,s,mat,mat\_haunch}

\texttt{eslv}

\texttt{emodif,all,mat,mat\_cone}

\texttt{mp\_dele,all,mat\_haunch}

\texttt{! set slab\_rebar\_material\_properties}

\texttt{vsel,s,mat,mat\_rebar}

\texttt{eslv}

\texttt{nsle}

\texttt{nsel,f,loc,y,-999,-8.125}

\texttt{esln,1}

\texttt{esel,r,mat,mat\_rebar}

\texttt{mat\_rebar=6}

\texttt{emodif,all,mat,mat\_rebar}

\texttt{! [6] slab\_rebar}

\texttt{rebar\_alpx=rebar\_alpx*1e-6 \textbackslash{} lin/lin/F}

\texttt{rebar\_dens=rebar\_gamma/1728 \textbackslash{} lb/in^3}

\texttt{mp\_ex,mat\_rebar,rebar\_ex}

\texttt{mp\_dens,mat\_rebar,rebar\_dens}

\texttt{mp\_prxy,mat\_rebar,rebar\_prxy}

\texttt{mp\_alpx,mat\_rebar,rebar\_alpx}

\texttt{tb\_miso,mat\_rebar,4,4}

\texttt{tb\_te,100,1}

\texttt{tb\_pt,1379e-6,40000}

\texttt{,,2513e-6,44887}

\texttt{,,6370e-6,48690}

\texttt{,,13419e-6,51311}

\texttt{tb\_te,200,2}

\texttt{tb\_pt,1264e-6,36652}

\texttt{,,2513e-6,41147}

\texttt{,,6370e-6,44588}

\texttt{,,13419e-6,47055}

\texttt{tb\_te,300,3}

\texttt{tb\_pt,1225e-6,35536}

\texttt{,,2513e-6,39900}

\texttt{,,6370e-6,43221}

\texttt{,,13419e-6,45636}

\texttt{tb\_te,400,4}

\texttt{tb\_pt,1187e-6,34420}

\texttt{,,2513e-6,38653}

\texttt{,,6370e-6,41853}

\texttt{,,13419e-6,44217}

\texttt{alls el}

\texttt{esel,s,mat,3}

\texttt{esel,a,mat,6}

\texttt{emodif,all,mat,2}
Input file: set_options.mac

*** Turn on creep, turn on steel plasticity 6/8/04

/prep

! remove structural concrete CONCR material model
!tbdele,concr,mat_conc

! remove concrete CREEP material model
!tbdele,creep,mat_conc

! remove insulating concrete CONCR material model
!tbdele,concr,mat_insul

! remove insulating concrete CREEP material model
!tbdele,creep,mat_insul

! remove liner BISO material model
!tbdele,BISO,mat_liner

! remove rebar BISO material model
!tbdele,BISO,mat_rebar

! remove soil DP material model
!tbdele,DP,mat_soil

Input file: set_parms.mac

*** Run 2, Load Case 1 - 4
*** (8.3' soil, 125 lb/ft3)
*** (0.06" primary tank corrosion)
*** 4/16/03
***
*** JED mods 3/20/03
*** add clr - concentrated load radius
*** add backfill properties 3/24
*** backfill properties f(depth) 4/1

finish
/clear
/fil,pnula
/prep7
/titLAP 422"(20yr)/460"(40yr), 210F, 1.83 SpG, BES
! DST - AY

pi=acos(-1)

cr=10*12 ! Concentrated load radius
or=12*41.5 ! Outside radius concrete wall
ir=12*40 ! Inside radius concrete wall
ir2=12*37.5 ! Radius primary tank
icr=37*12+3 ! Radius insulating concrete
h1=0
h2=-8,125
h3=381,5 ! Height dome tangent (31'9-1/2")
h4=h3+70.875 ! Height exterior corner (+ 5'10-7/8" = 37'8-3/8")
h5=h3+15*12 ! Height interior center dome
h6=h5+15 ! Height exterior center dome
covext=2   !Concrete cover - exterior dome
covint1=4   !Concrete cover - wall
covint2=1.5 !Concrete cover - interior dome

r1=105*12+.25 !Exterior dome radius - center
th1=7+45+14/60 !Angle at tangent of external radii
r2=74*12+4   !Exterior dome radius - outer
r3=3*12+8.375 !Radius primary tank to dome

! This file sets the values of all parameters that may be changed
! These were originally defined in define Soil layers.mac:
overburden=8.3*12 !overburden height above dome apex (ft)
subdepth=168*12 !subgrade soil depth (ft)
totalwidth=240*12 !total soil width (radius) from tank centerline to edge (ft)

! These were originally defined in dstay7.mac:
r50=1-.06   !shell thickness (in) (R1 of Figure 11 in RPP-13990)
r51=3/8-.06 !shell thickness (in) (R2,R6,R7,R9 of Figure 11 in RPP-13990)
r52=7/8-.06 !shell thickness (in) (R3 of Figure 11 in RPP-13990)
r53=3/4-.06 !shell thickness (in) (R4 of Figure 11 in RPP-13990)
r54=1/2-.06 !shell thickness (in) (R5,R8 of Figure 11 in RPP-13990)
r55=1/4   !shell thickness (in) (R10 of Figure 11 in RPP-13990)

! This was originally defined in set esys 3d.mac:
r56=3/8   !shell thickness (in) of secondary liner above 357.5 in

! These were originally defined in set materials.mac:

![1] steel (for liner, jbolts, studs, anchors, bearing plates)
steel_ex=27.766 !elastic modulus [psi]
steel_prxy=0.3 !Poisson ratio
steel_alpx=6.38 !thermal expansion coefficient [microstrain/degree F]

![2] structural concrete
conc_ex=3.866 !elastic modulus [psi]
conc_prxy=0.15 !Poisson ratio
conc_alpx=3.7 !thermal expansion coefficient [microstrain/degree F]

conc_gamma=145 !unit weight [lbf/ft^3]
conc_yield=36000 !yield strength [psi]
conc_open=0.1 !shear transfer coefficient for open crack
conc_closed=0.98 !shear transfer coefficient for closed crack
conc_crush=3000 !uniaxial crushing stress [psi]
conc_crack=0.1*conc_crush !tensile cracking stress [psi]
<table>
<thead>
<tr>
<th>Material</th>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rebar</td>
<td>Elastic modulus</td>
<td>29,006 psi</td>
</tr>
<tr>
<td></td>
<td>Poisson ratio</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>Thermal expansion coefficient</td>
<td>6.0 microstrain/degree F</td>
</tr>
<tr>
<td></td>
<td>Unit weight</td>
<td>490 psi</td>
</tr>
<tr>
<td></td>
<td>Yield strength</td>
<td>71,000 psi</td>
</tr>
<tr>
<td></td>
<td>Tangent modulus</td>
<td>5,900 psi</td>
</tr>
<tr>
<td>Insulating concrete</td>
<td>Elastic modulus</td>
<td>165,000 psi</td>
</tr>
<tr>
<td></td>
<td>Poisson ratio</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>Thermal expansion coefficient</td>
<td>3.7 me/deg F</td>
</tr>
<tr>
<td></td>
<td>Unit weight</td>
<td>50 lb/ft³</td>
</tr>
<tr>
<td></td>
<td>Shear transfer coefficient for open crack</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Shear transfer coefficient for closed crack</td>
<td>0.98</td>
</tr>
<tr>
<td></td>
<td>Uniaxial crushing stress</td>
<td>200 psi</td>
</tr>
<tr>
<td></td>
<td>Tensile cracking stress</td>
<td>20 psi</td>
</tr>
<tr>
<td>Slab rebar</td>
<td>Elastic modulus</td>
<td>29,006 psi</td>
</tr>
<tr>
<td></td>
<td>Poisson ratio</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>Thermal expansion coefficient</td>
<td>6.0 microstrain/degree F</td>
</tr>
<tr>
<td></td>
<td>Unit weight</td>
<td>490 lb/ft³</td>
</tr>
<tr>
<td></td>
<td>Yield strength</td>
<td>49,000 psi</td>
</tr>
<tr>
<td></td>
<td>Tangent modulus</td>
<td>49,000 psi</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Backfill</th>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Elastic modulus</td>
<td>34,500 psi</td>
</tr>
<tr>
<td></td>
<td>Poisson ratio</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>Thermal expansion coefficient</td>
<td>3.45 me/deg F</td>
</tr>
<tr>
<td></td>
<td>Unit weight</td>
<td>50 lb/ft³</td>
</tr>
<tr>
<td></td>
<td>Shear transfer coefficient for open crack</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Shear transfer coefficient for closed crack</td>
<td>0.98</td>
</tr>
<tr>
<td></td>
<td>Uniaxial crushing stress</td>
<td>200 psi</td>
</tr>
<tr>
<td></td>
<td>Tensile cracking stress</td>
<td>20 psi</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Soil</th>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Friction angle</td>
<td>34.5 deg</td>
</tr>
<tr>
<td></td>
<td>Dilatancy angle</td>
<td>34.5 deg</td>
</tr>
<tr>
<td></td>
<td>Thermal expansion coefficient</td>
<td>0 me/deg F</td>
</tr>
<tr>
<td></td>
<td>Unit weight</td>
<td>35.17*12 psi</td>
</tr>
<tr>
<td></td>
<td>Shear transfer coefficient for open crack</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Shear transfer coefficient for closed crack</td>
<td>0.98</td>
</tr>
<tr>
<td></td>
<td>Uniaxial crushing stress</td>
<td>20 psi</td>
</tr>
<tr>
<td></td>
<td>Tensile cracking stress</td>
<td>20 psi</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Load</th>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ground surface uniform pressure</td>
<td>0 psi</td>
</tr>
<tr>
<td></td>
<td>Point load at center lb</td>
<td>0 lb</td>
</tr>
<tr>
<td></td>
<td>Annulus internal pressure inches h2o</td>
<td>0 psi</td>
</tr>
<tr>
<td></td>
<td>Total waste height</td>
<td>35.17*12 psi</td>
</tr>
<tr>
<td></td>
<td>Height of waste 1 inches</td>
<td>11 psi</td>
</tr>
<tr>
<td></td>
<td>Specific gravity of waste 1</td>
<td>35.17</td>
</tr>
<tr>
<td></td>
<td>Height of waste 2 inches</td>
<td>11 psi</td>
</tr>
<tr>
<td></td>
<td>Specific gravity of waste 2</td>
<td>35.17</td>
</tr>
<tr>
<td></td>
<td>Height of waste 3 inches</td>
<td>11 psi</td>
</tr>
<tr>
<td></td>
<td>Specific gravity of waste 3</td>
<td>35.17</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Soil layers</th>
<th>Property</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>*dim,soil_emod,16</td>
</tr>
<tr>
<td></td>
<td>*dim,soil_pr,16</td>
</tr>
<tr>
<td></td>
<td>*dim,soil_z0,16</td>
</tr>
<tr>
<td></td>
<td>*dim,soil_z1,16</td>
</tr>
<tr>
<td></td>
<td>*dim,soil_pr,8</td>
</tr>
<tr>
<td></td>
<td>*dim,soil_z0,8</td>
</tr>
<tr>
<td></td>
<td>*dim,soil_z1,8</td>
</tr>
</tbody>
</table>
bfinc=(h6+overburden+18.5)/8
sdinc=(subdepth+60)/8

*do,i,1,8
soil_z0(i)=i*bfinc !vertical distance from surface
soil_z1(i)=(i-1)*bfinc
soil_z0(i+8)=i*sdinc+bfinc*8
soil_z1(i+8)=(i-1)*sdinc+bfinc*8
bf_z0(i)=i*bfinc
bf_z1(i)=(i-1)*bfinc
*enddo

!Elastic modulus
soil_emod(1)=58000,62000,64618,67236,69563,72180,74798,77125,82117,9000
soil_emod(11)=109697,129650,151456,172835,191000,200000
bf_emod(1)=12000,15000,19500,24000,28000,32500,37000,40000

!Poisson's ratio
soil_pr(1)=.24,.24,.24,.24,.24,.24,.24,.24,.24,.24
soil_pr(11)=.24,.24,.24,.24,.24,.24,.24,.24,.24,.24
bf_pr=27

!*** Soil 110 pcf - undisturbed
!*** Soil 125 pcf - backfill/overburden
s_gam=110 !lb/ft^3 density of soil layers (excluding backfill)
b_gam=125 !lb/ft^3 density of soil layers (excluding backfill)

Input file: set_real.mac
*get,ia,area,num_min
*get,iamat,area,ia,attr,mat
*get,iatype,area,ia,attr,type
*get,iacsys,area,ia,attr,esys
aatt,iamat,arg1,iatype,iacsys

Input file: set_rx.mac
cmsel,s,arg4
csys,0
asel,r,loc,x,arg1,arg2
set_real,arg3

Input file: set_ry.mac
cmsel,s,arg4
csys,0
asel,r,loc,y,arg1,arg2
set_real,arg3

Input file: set_slayer.mac
!***
!*** dilation angle 8 6/4/04
!*** Add materials for load factor restart 8/2/03
!*** JED mod 3/24/03
!*** Define soil
!*** (redefine backfill/overburden in set_backfill)
!***
max_mat=max_mat+1

/prep7

cmsel,s,soil_elem
csys,0
hsb=top_elev-arg2-h2+24
nsel,r,loc,y,top_elev-arg1,top_elev-arg2
esln,
esel,r,mat,.5
emodif,all,mat,max_mat
emodif,all,real,7
soil_ex=arg3
soil_prxy=arg4
soil_alpx=0
soil_cohesion=1
soil_friction=35
soil_dilat=8
soil_alpx=soil_alpx*1e-6
soil_dens=s_gam/1728
mp,ex,max_mat,soil_ex
mp,dens,max_mat,soil_dens
mp,prxy,max_mat,soil_prxy
mp,alpx,max_mat,soil_alpx
mp,dp,max_mat+50
mp,alpx,max_mat+50,soil_alpx
mp,dens,max_mat+50,soil_dens*1.7/1.4
mp,prxy,max_mat+50,soil_prxy

Input file: set_soil.mac
****
*** JED mod 3/24/03
*** define subdepth (depth of soil below foundation
***
/prep7

mp,ex,max_mat+50,soil_ex
mp,dens,max_mat+50,soil_dens
mp,prxy,max_mat+50,soil_prxy
mp,alpx,max_mat+50,soil_alpx
mp,dp,max_mat+50
mp,alpx,max_mat+50,soil_alpx
mp,dens,max_mat+50,soil_dens*1.7/1.4
mp,prxy,max_mat+50,soil_prxy

mp,ex,max_mat+50,soil_ex
mp,dens,max_mat+50,soil_dens*1.7/1.4
mp,prxy,max_mat+50,soil_prxy

soil cohesion=l
soil friction=35
soil dilat=8

soil ex=arg3
soil prxy=arg4
soil alpx=0

elastic modulus [psi]
Poisson ratio
thermal expansion coefficient
[me/F]
drucker-prager constant [psi]
tinternal friction angle [deg]
dilatancy angle [deg]

soil alpx=soil alpx*1e-6
soil dens=s_gam/1728

lin/in/F
lb/in^3

mp,ex,max_mat,soil_ex
mp,dens,max_mat,soil_dens
mp,prxy,max_mat,soil_prxy
mp,alpx,max_mat,soil_alpx
mp,dp,max_mat
mp,alpx,max_mat+50,soil_alpx
mp,dens,max_mat+50,soil_dens*1.7/1.4
mp,prxy,max_mat+50,soil_prxy

/* materials max_mat+50 for load factor restart

mp,ex,max_mat+50,soil_ex
mp,dens,max_mat+50,soil_dens*1.7/1.4
mp,prxy,max_mat+50,soil_prxy

adrag,1986,1989
aovlap,all
C.2.2 Thermal Cycling Files

There are six input files required to run the full 60 years of thermal cycling and creep. These are listed sequentially below.

Input file: set_type.mac

```plaintext
*get,ia,area,num,min
*get,iareal,area,ia,attr,real
*get,iamat,area,ia,attr,mat
*get,iacsys,area,ia,attr,esys
att,iamat,iareal,argl,iacsys
```

Input file: set_slice_0

```plaintext
/resu
/sol
/nty,res:
*** Thermal load - Initial ramp
```
![**]
frt=7.5/24
time,3+frt

** Fast heat to 125F
**
/nopr
/inp,frh,temp
/inp,bkh,temp
/gopr
nsub,3,10,2
solv

time,2.125+3+frt

** One of Two steps to 210F
**
/nopr
/inp,frh1,temp
/inp,bkh1,temp
/gopr
nsub,3,10,2
solv

time,4.25+3+frt

** Two of Two steps to 210F

/nopr
/inp,frh2,temp
/inp,bkh2,temp
/gopr
nsub,3,10,2
solv

time,26

** 150F

/nopr
/inp,frss,temp
/inp,bkss,temp
/gopr
nsub,150,1000,10
solv

time,41

** Steady state @ 210F

/nopr
/inp,frss1,temp
/inp,bkss1,temp
/gopr
nsub,150,1000,15
solv

time,353

** Hold for 1 Year

/nopr
nsub,300,10000,10
save
solv

time,353+1

** mpchg and 1.0 days
*do,i,1,14
csel,typr,,12,15
nsle
nsel,r,bf,temp,190+i*10,200+i*10
celu
csel,r,mat,,2
mpch,20+i,all
*enddo
esel,type,12,15
nsle
nsel,r,bf,temp,330,345
esln
esel,r,mat,,2
mpch,35,all
esel,all
nsub,10,100,2
solv
time,354+2.125 !LS 13
!*** Cool to ambient
!***
!*** First of Two steps to 125F
!***
/nopr
/inp,frc1,temp
/inp,bkc1,temp
/gopr
nsub,15,200,5
solv
time,354+4.25 !LS 14
!***
!*** Second of two steps to 125F
!***
/nopr
/inp,frc2,temp
/inp,bkc2,temp
/gopr
nsub,15,200,5
solv
time,354+4.25+fhrt !LS 17
!***
!*** Fast cool down to 50F
!***
/nopr
/inp,frc3,temp
/inp,bkc3,temp
/gopr
nsub,7,100,3
solv
time,354+4.25+fhrt+1 !LS 18
!***
!*** Tank cool down transient to 50F
!***
/nopr
/inp,frc4,temp
/inp,bkc4,temp
/gopr
nsub,5,100,2
solv
time,368 !LS 19
!***
!*** Uniform 50F
/nsub,47,150,20
bf,all,temp,50
solv

!*** Cycle 4 More Years
*do,i,1,4
time, 3 + fhrt + 365*i 

Flute 20

*** Thermal load - Initial ramp

/nope
/inp, frh, temp
/inp, bkh, temp
/gopr
/nsub, 3, 10, 2
/solv

-time, 3 + 2.125 + fhrt * 365*i 

Flute 21

*** First of two steps to 210F

/nope
/inp, frh, temp
/inp, bkh, temp
/gopr
/nsub, 20, 100, 6
/solv

-time, 3 + 4.25 + fhrt * 365*i 

Flute 22

*** Second of two steps to 210F

/nope
/inp, frh, temp
/inp, bkh, temp
/gopr
/nsub, 20, 100, 6
/solv

-time, 3 + 23 + 365*i 

Flute 25

*** 350F

/nope
/inp, frh, temp
/inp, bkh, temp
/gopr
/nsub, 150, 1000, 10
/solv

-time, 3 + 38 + 365*i 

Flute 26

*** Steady state @ 210F

/nope
/inp, frh, temp
/inp, bkh, temp
/gopr
/nsub, 150, 1000, 30
/solv

-time, 3 + 351 + 365*i 

Flute 27

*** Creep for 1 Year

/nope
/nsub, 300, 10000, 6
/solv

*** Cool to ambient

-time, 3 + 351 + 2.125 + 365*i 

Flute 28

***
!*** First of two steps to 125F
!

/nopr
/inp,frc1,temp
/inp,bkc1,temp
/gopr
nsub,15,200,5
solv
time,3+351+4.25+365*i !LS 29

!*** Second of two steps to 125F
!

/nopr
/inp,frc2,temp
/inp,bkc2,temp
/gopr
nsub,15,200,5
solv
time,3+351+4.25+365*i !LS 32

!*** Fast cool down to 50F
!

/nopr
/inp,frc3,temp
/inp,bkc3,temp
/gopr
nsub,7,100,3
solv
time,3+351+4.25+fltr+365*i !LS 33

!*** Tank cool down transient to 50F
!

/nopr
/inp,frc4,temp
/inp,bkc4,temp
/gopr
nsub,5,100,2
solv
time,3+365+365*i !LS 34

!*** Uniform 50F
!

/nsup,47,150,20
/bf,all,temp,50
/save
/solv

*enddo
! End of 5 Year Thermal Cycles

Input file: Extended13yr.inp
/fil,set_slice_0
/resu
/sol
/any,.rest
/**** Thermal load - Initial ramp
/****
/fltr=7.5/24
time,3+fltr+365*i
/****
/**** Fast heat to 125F
/****
/nopr
/inp,frh,temp
/inp,bkh,temp
/gopr
nsub,3,10,2
solv

time,2.125+3+flrt+365*5
!!!
!*** One of Two steps to 210F
!!!
/nopr
/inp,frh1,temp
/inp,bkh1,temp
/gopr
nsub,3,10,2
solv

time,4.25+3+flrt+365*5
!!!
!*** Two of Two steps to 210F
/nopr
/inp,frh2,temp
/inp,bkh2,temp
/gopr
nsub,3,10,2
solv

time,26+365*5
!!!
!*** Steady State @ 210
/nopr
/inp,frss,temp
/inp,bkss,temp
/gopr
nsub,150,1000,10
solv

time,41+365*5
!!!
!*** Steady state @ 210F
/nopr
/inp,frss1,temp
/inp,bkss1,temp
/gopr
nsub,150,1000,15
solv

time,354+365*17
!!!
!*** Hold for 13 Years
nsub,300,10000,10
save
solv

time,354+2.125+365*17
!!!
!*** Cool to ambient
!!!
(!*** First of Two steps to 125F
!!!
/nopr
/inp,frc1,temp
/inp,bkc1,temp
/gopr
nsub,15,200,5
solv

time,354+4.25+365*17
!!!
!*** Second of two steps to 125F
nopr
/inp,frc2,temp
/inp,bkc2,temp
/gopr
nsub,15,200,5
solv

time,354+4.25+fltr+365*17
***
!*** Fast cool down to 50F
nopr
/inp,frc3,temp
/inp,bkc3,temp
/gopr
nsub,7,100,3
solv

time,354+4.25+fltr+1+365*17
***
!*** Tank cool down transient to 50F
nopr
/inp,frc4,temp
/inp,bkc4,temp
/gopr
nsub,5,100,2
solv

time,368+365*17
**** Uniform 50F

Input file: TwoYrCycle.inp
/fil,set_slice_0
resu
/solu

****** Thermal load - Initial ramp
fltr=7.5/24

****** Cycle
*do,i,18,19

time,3+fltr+365*i
****** Thermal load - Initial ramp
nopr
/inp,frh,temp
/inp,bkh,temp
/gopr
nsub,3,10,2
solv

time,3+2.125+fltr*365*i
****** First of two steps to 210F
nopr
/inp,frh1,temp
/inp,bkh1,temp
/gopr
nsub,20,100,6
solv

** time,3+4.25+fhrt+365*i
***
** Second of two steps to 210F
***
/nopr
/inp,fth2,temp
/inp,bkh2,temp
/gopr
nsub,20,100,6
solv

** time,3+23+365*i
***
** 350F
***
/nopr
/inp,frh2,temp
/inp,bkh2,temp
/gopr
nsub,20,100,6
solv

** time,3+38+365*i
***
** Steady state @ 210F
***
/nopr
/inp,frss1,temp
/gopr
nsub,150,1000,30
solv

** time,3+351+365*i
***
** Creep for 1 Year
***
nsub,300,10000,6
solv

** time,3+351+2.125+365*i
***
** First of two steps to 125F
***
/nopr
/inp,frc1,temp
/inp,bkc1,temp
/gopr
nsub,15,200,5
solv

** time,3+351+4.25+365*i
***
** Second of two steps to 125F
***
/nopr
/inp,frc2,temp
/inp,bkc2,temp
/gopr
nsub,15,200,5
*enddo

! End of 20 Year Thermal Cycles

Input file: TwoYrCycleWith460wh.inp
/sfil, set_slice_0
/resu
/sol
/any,,rest

time,365*20+3+1

*** Add waste, pressure and surface loads

pres_surf=40 !ground surface uniform pressure
point_cent=200000 !point load at center lb
pres_annulus=-20 !annulus pressure inches h2o
pres_int=-12 !annulus internal pressure inches h2o
h_waste=460 !total waste height
height_waste1=h_waste/3 !height of waste 1 inches
gamma_waste1=1.83 !specific gravity of waste 1
height_waste2=h_waste/3 !height of waste 2 inches
gamma_waste2=1.83 !specific gravity of waste 2
height_waste3=h_waste/3 !height of waste 3 inches
gamma_waste3=1.83 !specific gravity of waste 3

/inp, apply_loads_slice, mac
/solv

*** Thermal load - Initial ramp

fhrt=7.5/24
**Cycle**

*do,i,20,21

time,3+1+fhrt+365*i

**Thermal load - Initial ramp**

/nopr
'inp,fth,temp
'inp,bkh,temp
/gopr
nsup,3,10,2
solv

time,3+1+2.125+fhrt*365*i

**First of two steps to 210F**

/nopr
'inp,fth1,temp
'inp,bkh1,temp
/gopr
nsup,20,100,6
solv

time,3+1+4.25+fhrt+365*i

**Second of two steps to 210F**

/nopr
'inp,fth2,temp
'inp,bkh2,temp

**350F**

/nopr
'inp,frh1,temp
'inp,bkh1,temp
/gopr
nsup,150,1000,10
solv

time,3+1+38+365*i

**Steady state @ 210F**

/nopr
'inp,frh11,temp
'inp,bkh11,temp
/gopr
nsup,150,1000,30
solv

time,3+1+351+365*i

**Creep for 1 Year**

/nsup,300,10000,6
solv

/**/ Cool to ambient
**First of two steps to 125F**

```plaintext
/nopr
/inp,fr1,temp
/inp,bk1,temp
/gopr
nsub,15,200,5
solv
```

**Second of two steps to 125F**

```plaintext
/nopr
/inp,fr2,temp
/inp,bk2,temp
/gopr
nsub,15,200,5
solv
```

**Fast cool down to 50F**

```plaintext
/nopr
/inp,fr3,temp
/inp,bk3,temp
/gopr
nsub,7,100,3
solv
```

**Tank cool down transient to 50F**

```plaintext
/nopr
/inp,fr4,temp
/inp,bk4,temp
/gopr
nsub,5,100,2
solv
```

**Uniform 50F**

```plaintext
/nopr
/inp,fr5,temp
/inp,bk5,temp
/gopr
nsub,47,150,20
bf,all,temp,50
save
solv
```

`*Enddo`

**End of 22 Year Thermal Cycles with 460° waste height from 20 years**

Input file: Extended38yr.inp

```plaintext
/fil,set_slice_0
resu
/sol
any,,rest
```

**Thermal load - Initial ramp**
fhrt=7.5/24

time, 4+fhrt+365*20

*** Fast heat to 125F

/nopr
/inp,frh,temp
/inp,bkh,temp
/gopr
/nsub,3,10,2
/solv

time, 2.125+4+fhrt+365*20

*** One of Two steps to 210F

/nopr
/inp,frh1,temp
/inp,bkh1,temp
/gopr
/nsub,3,10,2
/solv

time, 4.25+4+fhrt+365*20

*** Two of Two steps to 210F

/nopr
/inp,frh2,temp
/inp,bkh2,temp
/gopr
/nsub,3,10,2
/solv

time, 26+1+365*20

*** Steady State @ 210F

/nopr
/inp,frss,temp
/inp,bkss,temp
/gopr
/nsub,150,1000,10
/solv

time, 41+1+365*20

*** Steady state @ 210F

/nopr
/inp,frss1,temp
/inp,bkss1,temp
/gopr
/nsub,150,1000,15
/solv

time, 354+365*57

*** Hold for 38 Years

/nsub,300,10000,10
/save
/solv

time, 354+2.125+365*57

*** Cool to ambient

/nopr
/inp,frcl,temp
/inp,bkcl,temp
/solv

time, 354+2.125+365*57

*** First of Two steps to 125F

/nopr
/inp,frc1,temp
/inp,bkcl1,temp
/solv
!**** Second of two steps to 125F

!**** Fast cool down to 50F

!**** Tank cool down transient to 50F

!**** Uniform 50F

End of 58 year cycle

Input file: TwoYrCycTo60Yr.inp

nsub,3,10,2
solv

!***  First of two steps to 210F

!***

/time,3+2.125+fhrt*365*i
!***

/nopr
/inp,frhl,temo
/inp,bkhl,temo
/gopr
/nsub,20,100,6
solv

!***

/time,3+4.25+fhrt+365*i
!***

/nopr
/inp,frh2,temo
/inp,bkh2,temo
/gopr
/nsub,20,100,6
solv

!***  Second of two steps to 210F

!***

/time,3+23+365*i
!***

/nopr
/inp,frss,temp
/inp,bkss,temp
/gopr
/nsub,20,100,6
solv

!***  210F

!***

/time,3+38+365*i
!***

/nopr
/inp,frss1,temp
/inp,bkss1,temp
/gopr
/nsub,150,1000,10
solv

!***  Steady state @ 210F

!***

/time,3+351+365*i
!***

/nopr
/inp,frssl,temp
/inp,bkssl,temp
/gopr
/nsub,150,1000,30
solv

!***  Creep for 1 Year

!***

/time,3+351+2.125+365*i
!***

/nopr
/inp,frcl,temp
/inp,bkcl,temp
/gopr
/nsub,300,10000,6
solv

!***  Cool to ambient

/time,3+351+2.125+365*i
!***

/nopr
/inp,frc1,temp
/inp,bkc1,temp
/gopr
/nsub,15,200,5
solv

!***  First of two steps to 125F

!***
!!*** Second of two steps to 125F
!!***
/nopr
/inp.frc2,temp
/inp.bkc2,temp
/gopr
nsub,15,200,5
solv

!!*** Fast cool down to 50F
!!***
/nopr
/inp.frc3,temp
/inp.bkc3,temp
/gopr
nsub,7,100,3
solv

!!*** Tank cool down transient to 50F
!!***
/nopr
/inp.frc4,temp
/inp.bkc4.temp
/gopr
nsub,5,100,2
solv

!!*** Uniform 50F
!!***
nsub,47,150,20
bf.all,temp,50
save
solv
*enddo

! End of 60 Year Thermal Cycles with 460" waste height from 20 years

C.2.3 ACI Load Factors

Input file: set_sliced6a.inp

!!! Load factors 12/19/06
!!! 1.4 g
!!! 1.4 pressures
!!! 1.4 waste
!!! 1.83*1.4 soil density
!!! 1.7 distributed & concentrated load
!!!
/fil,set_slice_0
resu

/sol
anty,,rest
!!!
time, 365*61 + 4
nsub, 10, 100, 5

acel, 1.4
pres_surf = 40 * 1.7
point_cent = 200000 * 1.7
pres_annulus = -20 * 1.4
pres_int = -12 * 1.4
h2o
hwaste = 35.17 * 12
height_waste = hwaste / 3
gamma_waste = 1.83 * 1.4

Input file: set_sliceh.inp

!***
!*** Year 60 10/19/06 1.4D+1.7L+1.05T
!*** Adjust mpch (new SS temps) & Day 48 Steady State
6/8/04
!*** Adjust substeps 6/7/04
!*** 2 year thermal cycle ****inp modified**** 5/19/04
!*** multiple heating and cooling load steps
!***
/fil, set_slice_0
/resu
/sol
/anty, rest

!*** Thermal load - Initial ramp
!***
flrt = 7.5 / 24

time, 3 + flrt + 365 * 60 + 1
!***
!*** Fast heat to 125 F
!***
/nopr
/inp, flr, temp
/inp, bkb, temp
/gopr
bfsc, temp, 1.05, 50
nsub, 3, 10, 2
solv

time, 3 + 2.125 + fhrt * 365 * 60 + 1
!!!*
!!!** First of two steps to 210F
!!!**
/nopr
/inp, frh1, temp
/inp, bkhl, temp
/gopr
bfsc, temp, 1.05, 50
nsub, 20, 100, 6
solv

time, 3 + 4.25 + fhlt + 365 * 60 + 1
!!!*
!!!** Second of two steps to 210F
!!!**
/nopr
/inp, frh2, temp
/inp, bkhl, temp
/gopr
bfsc, temp, 1.05, 50
nsub, 20, 100, 6
solv

time, 3 + 3.8 + 365 * 60 + 1
!!!*
!!!** Steady state at 210F
!!!**
/nopr
/inp, frss, temp
/inp, bkss, temp
/gopr
bfsc, temp, 1.05, 50
nsub, 180, 2000, 40
solv

time, 3 + 354 + 365 * 60 + 1
!!!*
!!!** Hold for 1 Year
!!!*
/inp, frssl, temp
/inp, bkssl, temp
/gopr
bfsc, temp, 1.05, 50
nsub, 150, 1000, 25
solv

!!!** Cool to ambient

time, 3 + 351 + 2.125 + 365 * 60 + 1
!!!*
!!!** First of two steps to 125F
!!!**
C.3 Lower Bound Soil Model Input Files

There is only one input file that is unique to the Lower Bound Soil analysis. It is listed below.

Input file: setparms.mac

```plaintext
!****
!****  Low Bound soil properties  7/14/04
!****
!****  Run 2, Load Case 1 - 4
!****  (8.3' soil, 125 lb/ft3)
!****  (0.06'' primary tank corrosion)
!****  4/16/03
```
**JED mods 3/20/03**

**add clr - concentrated load radius**

**add backfill properties 3/24**

**backfill properties f(depth) 4/1**

**finish**

```
/clear
/fil,punta
/prepare7
/titel.5% K; low soil E, high concrete E with no Creep

! DST - AY

pi=acos(-1)
```

```plaintext
clr=10*12
or=12*41.5
ir=12*40
i2=12*37.5
i3=37*12+3
hl=0
h2=-8.125
h3=381.5
h4=h3+70.875
h5=h3+15*12
h6=h5+15
covext=2
covint1=4
covint2=1.5
```

```plaintext
r1=105*12+.25 !Exterior dome radius - center
r2=74*12+4 !Exterior dome radius - outer
r3=3*12+8.375 !Radius primary tank to dome
r4=37*12+3

! This file sets the values of all parameters that may be changed

! These were originally defined in define Soil_layers.mac:

```
overburden=8.3*12 !overburden height above dome apex (ft)
subdepth=168*12 !subgrade soil depth (ft)
totalwidth=240*12 !total soil width (radius) from tank centerline to edge (ft)
```

```
rl=105*12+.25 !Exterior dome radius - center
th1=7+45+14/60/60 !Angle at tangent of external radii
r50=l-.06 !shell thickness (in) (R1 of Figure 11 in RPP-13990)
r51=3.8-.06 !shell thickness (in) (R2,R6,R7,R9 of Figure 11 in RPP-13990)
r52=7.8-.06 !shell thickness (in) (R3 of Figure 11 in RPP-13990)
r53=3.4-.06 !shell thickness (in) (R4 of Figure 11 in RPP-13990)
r54=1-.06 !shell thickness (in) (R5,R8 of Figure 11 in RPP-13990)
r55=1/4 !shell thickness (in) (R10 of Figure 11 in RPP-13990)
```
"! This was originally defined in set esys_3d.mac:

r56=3/8  ! shell thickness (in) of secondary liner above 357.5 in

! These were originally defined in set materials.mac:

![1] steel (for liner, jbolts, studs, anchors, bearing plates)
  steel\_ex=27.7e6  ! elastic modulus [psi]
  steel\_prxy=0.3  ! Poisson ratio
  steel\_alpx=6.38  ! thermal expansion coefficient [microstrain/degree F]
  steel\_gamma=490  ! unit weight [lbf/ft^3]
  steel\_yield=36000  ! yield strength [psi]
  steel\_tan=0.01  ! rebar tangent modulus [%]

![2] structural concrete
  conc\_ex=3.8e6  ! elastic modulus [psi]
  conc\_prxy=0.15  ! Poisson ratio
  conc\_alpx=3.7  ! thermal expansion coefficient [microstrain/degree F]
  conc\_gamma=145  ! unit weight [lbf/ft^3]
  conc\_open=0.1  ! shear transfer coefficient for open crack
  conc\_closed=0.98  ! shear transfer coefficient for closed crack
  conc\_crush=3000  ! uniaxial crushing stress [psi]
  conc\_crack=0.1*conc\_crush  ! tensile cracking stress [psi]

![3] rebar
  rebar\_ex=29.0e6  ! elastic modulus [psi]

![4] insulating concrete
  insul\_ex=165e3  ! elastic modulus [psi]
  insul\_prxy=0.15  ! Poisson ratio
  insul\_alpx=3.7  ! thermal expansion coefficient [microstrain/degree F]
  insul\_gamma=50  ! unit weight [lbf/ft^3]
  insul\_open=0.1  ! shear transfer coefficient for open crack
  insul\_closed=0.98  ! shear transfer coefficient for closed crack
  insul\_crush=200  ! uniaxial crushing stress [psi]
  insul\_crack=20  ! tensile cracking stress [psi]

![6] slab rebar
  srebar\_ex=29.0e6  ! elastic modulus [psi]
  srebar\_prxy=0.3  ! Poisson ratio
  srebar\_alpx=6.  ! thermal expansion coefficient [microstrain/degree F]
  srebar\_gamma=490  ! unit weight [lbf/ft^3]
  srebar\_yield=49000  ! yield strength [psi]
  srebar\_tan=0  ! rebar tangent modulus [psi]

**** Backfill
I These were originally defined in define_loads.mac:

* [5] backfill soil
backfill_phi=34.5 ! soil friction angle deg
backfill_dil=34.5 ! backfill dilatancy angle deg
backfill_cte=0 ! thermal expansion coef me/f

! *** No waste, pressures or ext. load
psf
point_cent=0 ! point load at center lb
pres_annulus=0 ! annulus pressure inches h2o
pres_int=0 ! annulus internal pressure inches

h2o
hwaste=35.17*12 ! total waste height
height_wastel = hwaste/3 ! height of waste 1 inches
gamma_waste1=0 ! specific gravity of waste 1
height_waste2=hwaste/3 ! height of waste 2 inches
gamma_waste2=0 ! specific gravity of waste 2
height_waste3=hwaste/3 ! height of waste 3 inches
gamma_waste3=0 ! specific gravity of waste 3

! define soil layers
*dim,soil_emod,,16
*dim,soil_pr,,16
*dim,soil_z0,,16
*dim,soil_z1,,16
*dim,bf_emod,,8
!*dim,bf_pr,,8
*dim,bf_z0,,8
*dim,bf_z1,,8
bf_dinc=(h6+overburden+18.5)*8
sdinc=(subdepth+60)*8

!do,i,1,8
soil_z0(i)=i*bf_dinc ! vertical distance from surface
soil_z1(i)=(i-1)*bf_dinc
soil_z0(i+8)=i*sdinc+bf_dinc*8
soil_z1(i+8)=(i-1)*sdinc+bf_dinc*8
bf_z0(i)=i*bf_dinc
bf_z1(i)=(i-1)*bf_dinc
*endo

! Elastic modulus
soil_emod(1)=44000,46000,48711,51423,53833,56544,59255,61665,66835,75000
soil_emod(11)=78900,82851,87169,91403,95000,99000
bf_emod(1)=8000,10000,12864,15727,18273,21136,24000,26000

! Poisson's ratio
soil_pr(1)=.24,.24,.24,.24,.24,.24,.24,.24,.24,.24
bf_pr=.27

! *** Soil 110 pcf - undisturbed
! *** Soil 125 pcf - backfill/overburden
s_gam=110 ! lbf/ft^3 density of soil layers (excluding backfill)
b_gam=125 ! lbf/ft^3 density of soil layers (excluding backfill)
save

C.4 Upper Bound Soil Model Input Files
There is only one input file that is unique to the Upper Bound Soil analysis. It is listed below.

**Input file: set_parms.mac**

```plaintext
!***
!*** Upper bound soil 11/21/05
!*** Best estimate soil properties 3/19/04
!*** Run 2, Load Case 1 - 4
!*** (8.3' soil, 125 lb/ft^3)
!*** (0.06" primary tank corrosion)
!*** 4/16/03
!***
!*** JED mods 3/20/03
!*** add clr - concentrated load radius
!*** add backfill properties 3/24
!*** backfill properties f(depth) 4/1

finish
/clear
/fil,pu1:
/prep7
/titl,Baseline, Upper Bound Soil
!
! DST - AY

pi=acos(-1)

cr=10*12 !Concentrated load radius
or=12*41.5 !Outside radius concrete wall
ir=12*40 !Inside radius concrete wall
ir2=12*37.5 !Radius primary tank

h1=0
h2=-8.125
h3=381.5 !Height dome tangent (31'9-1/2")
ht4=h3+70.875 !Height exterior corner (+ 5'10-7/8" = 37'8-3/8")

r1=105*12+.25 !Exterior dome radius - center
th1=7+(45+14/60)/60 !Angle at tangent of external radii
r2=74*12+4 !Exterior dome radius - outer
r3=3*12+8.375 !Radius primary tank to dome

ib=37*12+3 !Radius insulating concrete
```

! This file sets the values of all parameters that may be changed

! These were originally defined in define_soil_layers.mac:

overburden=8.3*12 !overburden height above dome apex (ft)
subdepth=168*12 !subgrade soil depth (ft)
totalwidth=240*12 !total soil width (radius) from tank centerline to edge (ft)

r50=1-06 !shell thickness (in) (R1 of Figure 11 in RPP-13990)
r51=3/8-.06  !shell thickness (in) (R2,R6,R7,R9 of Figure 11 in RPP-13990)

r52=7/8-.06  !shell thickness (in) (R3 of Figure 11 in RPP-13990)

r53=3/4-.06  !shell thickness (in) (R4 of Figure 11 in RPP-13990)

r54=1/2-.06  !shell thickness (in) (R5,R8 of Figure 11 in RPP-13990)

r55=1/4  !shell thickness (in) (R10 of Figure 11 in RPP-13990)

This was originally defined in set_esys_3d.mac:

r56=3/8  !shell thickness (in) of secondary liner above 357.5 in

These were originally defined in set_materials.mac:

[1] steel (for liner, jbolts, studs, anchors, bearing plates)

steel_ex=27.7e6  !elastic modulus [psi]

steel_prxy=0.3  !Poisson ratio

steel_alpx=6.38  !thermal expansion coefficient [microstrain/degree F]

steel_gamma=490  !unit weight [lbf/ft^3]

steel_yield=36000  !yield strength [psi]

steel_tan=0.01  !rebar tangent modulus [% of elastic modulus]

[2] structural concrete

concrete_ex=3.8e6  !elastic modulus [psi]

concrete_prxy=0.15  !Poisson ratio

concrete_alpx=3.7  !thermal expansion coefficient [microstrain/degree F]

concrete_gamma=145  !unit weight [lbf/ft^3]

[3] concrete

concrete_open=0.1  !shear transfer coefficient for open crack

concrete_closed=0.98  !shear transfer coefficient for closed crack

concrete_crush=3000  !uniaxial crushing stress [psi]

concrete_crack=0.1*concrete_crush  !tensile cracking stress [psi]

[4] rebar

rebar_ex=29.0e6  !elastic modulus [psi]

rebar_prxy=0.3  !Poisson ratio

rebar_alpx=6.0  !thermal expansion coefficient [microstrain/degree F]

rebar_gamma=490  !unit weight [lbf/ft^3]

rebar_yield=71000  !yield strength [psi]

rebar_tan=0  !rebar tangent modulus [psi]

[5] insulating concrete

insul_ex=165e3  !elastic modulus [psi]

insul_prxy=0.15  !Poisson ratio

insul_alpx=3.7  !thermal expansion coefficient [microstrain/degree F]

insul_gamma=50  !unit weight [lbf/ft^3]

insul_open=0.1  !shear transfer coefficient for open crack

insul_closed=0.98  !shear transfer coefficient for closed crack

insul_crush=200  !uniaxial crushing stress [psi]

insul_crack=20  !tensile cracking stress [psi]

[6] slab rebar

srebar_ex=29.0e6  !elastic modulus [psi]

srebar_prxy=0.3  !Poisson ratio
srebar_alpx=6.  !thermal expansion coefficient
srebar_alfx=[microstrain/degree F]
srebar_gamma=490  !unit weight [lbf/ft^3]
srebar_yi=49000  !yield strength [psi]
srebar_tan=0  !rebar tangent modulus [psi]

*** Backfill
! These were originally defined in define_loads.mac:
! [5] backfill soil
backfill_phi=34.5  !soil friction angle deg
backfill_dil=34.5  !backfill dilatancy angle deg
backfill_cte=0  !thermal expansion coef me/f

*** No waste, pressures or ext. load
press_surf=0  !ground surface uniform pressure
point_cent=0  !point load at center lb
press_annulus=0  !annulus pressure inches h2o
h2o
hwaste=35.17*12  !total waste height
height_waste1=hwaste/3  !height of waste 1 inches
gamma_waste1=0  !specific gravity of waste 1
height_waste2=hwaste/3  !height of waste 2 inches
gamma_waste2=0  !specific gravity of waste 2
height_waste3=hwaste/3  !height of waste 3 inches
gamma_waste3=0  !specific gravity of waste 3

!define soil layers
*dim,soil_z0,,16
*dim,soil_z1,,16
*dim,bf_emod,,8
!*dim,bf_pr,,8
*dim,bf_z0,8
*dim,bf_z1,8

bf_dinc=(h6+overburden+18.5)/8
sd_dinc=(subdepth+50)/8

*do,i,1,8
soil_z0(i)=i*bf_dinc  !vertical distance from surface
soil_z1(i)=(i-1)*bf_dinc
soil_z0(i+8)=i*sd_dinc+bf_dinc*8
soil_z1(i+8)=(i-1)*sd_dinc+bf_dinc*8
bf_z0(i)=i*bf_dinc
bf_z1(i)=(i-1)*bf_dinc
*enddo

!Elastic modulus
soil_emod(1)=75000,78000,80524,83049,85292,87817,90341,925585,97398,105000
soil_emod(11)=140494,176448,215742,254268,287000,315000
bf_emod(1)=16000,20000,26136,32273,37772,43864,50000,54000

!Poisson's ratio
soil_pr(1)=.24,.24,.24,.24,.19,.19,.19,.19,.19,.19,.19
soil_pr(11)=.19,.19,.28,.28,.28,.28
bf_pr=.27

*** Soil 110 pcf - undisturbed
*** Soil 125 pcf - backfill/overburden
s_gam=110 \text{ lb/ft}^3 \text{ density of soil layers (excluding backfill)}

b_gam=125 \text{ lb/ft}^3 \text{ density of soil layers (excluding backfill)}

\text{save}

\textbf{C.5 Modified Anchor Bolt Files}

\textit{Input file: set_slicea.mac}

\begin{itemize}
\item \texttt{AP 210F, Waste Height=422, SpG =1.83 for 20 years} 10/11/2006
\item \texttt{AP 210F, Waste Height=460, SpG =1.83 for 40 years} 10/11/2006
\item \texttt{AP modifications 8/9/04}
\item \texttt{Liquid level 460", SpG 1.83} 8/11/04
\item \texttt{Liquid level 460", SpG 2.0} 7/26/04
\item \texttt{Liquid level 460", SpG 1.7} 7/19/04
\item \texttt{2nd liner extension 0.25 thick} 7/21/04
\item \texttt{2nd liner extension contact \& concrete} 7/21/04
\item \texttt{Augmented stiffness 5\% Econc (350) 7/19/04}
\item \texttt{5\% pivot, bcso,mmd} 6/25/04
\item \texttt{Usensub 6/24/04}
\item \texttt{cnvtol,f(t),.005,0} 6/16/04
\item \texttt{Augmented stiffness 29\% Econc (350) 6/14/04}
\item \texttt{Augmented stiffness 30000 6/11/04}
\item \texttt{6/10/04 changes}
\item \texttt{Do not merge insulating concrete \& 2nd liner @ OD of concrete}
\item \texttt{Add 1st radius element to contact of 1st liner \& ins conc}
\item \texttt{Add contact 2nd liner \& slab concrete}
\item \texttt{Correct node select for type,61 real,70 6/9/04}
\item \texttt{Reorient Beam188 on z=/= 0 face}
\item \texttt{Fix Liner-Dome common nodes 5/6/04}
\item \texttt{Delete "j-bolts" in wall 5/6/04}
\item \texttt{Move j-bolt real definition to pnnla6.mac 3/30/04}
\item \texttt{Changed Liner Coupling per J. Deibler 3/29/04}
\item \texttt{Augmented stiffness 15000 3/24/04}
\item \texttt{Default convergence criteria 3/22/04}
\item \texttt{Best estimate soil properties 3/19/04}
\item \texttt{Soil-Concrete - 5 regions 2/23/04}
\item \texttt{Correct Drucker-Prager - soil}
\item \texttt{Correct mat,l temperature dependent modulus}
\item \texttt{Replace shell64 with shell181}
\item \texttt{Primary tank pressure -12" H2O (was -6) 10/30/03}
\item \texttt{125 pcf overburden, 110 pcf undisturbed soil 10/30/03}
\item \texttt{Define additional soils for load factor restart 11/4/03}
\item \texttt{No cracking insulating concrete}
\item \texttt{fix mpch (esel,r.mat,,2) 1 y+ 15 day creep 5/14/03}
\item \texttt{Load step 5 creep for 330 days}
\item \texttt{New load step 6 => mpch +5 days}
\item \texttt{"sets" degraded concrete properties 5/14/03}
\item \texttt{Turn off concrete crushing 5/5/03}
\item \texttt{Run 2, Load Step 1, 2 \& thermal}
\item \texttt{(8.3' soil, 125 lb/ft3) 12/03/03}
\item \texttt{(0.06' primary tank corrosion wall, floor) 4/16/03}
\item \texttt{4/16/03}
\item \texttt{4/16/03}
\end{itemize}
i_rebuild=1
*if i_rebuild,eq,1,then
  pnnla
  pnnla2
  pnnla3
  pnnla4
  pnnla5
  pnnla6
  pnnla7
  pnnla8
  pnnla9
*else
  resume,pnnla9,db
endif
/prep7

allsel
cpdele,all,all

! get misc area components for applying loads, etc.
/input,set_areas_slice,mac

! add steel plate below wall (on slab)
r,45,1/4
csys,22
vsel,s,mat,,2
aslv
asel,r,loc,z,-8.125
asel,r,loc,x,480,498

aatt,1,45,22
mat,1
real,45
amesh,all

define contact elements (all have default friction of 0.3)
c,60,170
et,61,173
mu,mu,61,.3
mu,mu,62,.01
mu,mu,63,.01
mu,mu,64,.4
mu,mu,65,.3
mu,mu,66,.2
mu,mu,67,.05
mu,mu,68,.3
mu,mu,69,.05
mu,mu,70,.6
mu,mu,71,.4

! soil_concrete contact - dome
r,61,,1,1
real,61
type,61
mat,61
cmsel,s,aconc_soil
nsla,,1
nel,r,loc,z,452,600
esln
eaurf
type,60
cmsel,s,asoil
nsla,,1
cmse,a,foundcon
esln
esurf
type,60
cmse,s,asoi
nsla,1
nsel,r,loc,z,-31,-30
,r,loc,x,440,531
esln
esurf
type,60
cmse,s,asoi
nsla,1
esln
esurf
!secondary liner contact
r,62,,1,,1
real,62
type,60
mat,62
cmse,s,aconc_shell
csys,0
asel,r,loc,y,459,99999
nsla,1
esln
esel,r,mat,,2
esurf
type,61
cmse,s,area_prim
asel,r,loc,y,459,99999
nsla,1
esln
esurf
!primary liner contact with insulating concrete
r,64,,1,,1
real,64
type,60
mat,64
cmse,s,area_insul_top
nsla,1
esln
esel,r,mat,,4
esurf
type,61
cmsel,s,area_prim
csys,0
asel,r,loc,y,0
nsla,,l
esln
rnsle 1*6/10/04
esurf

!secondary liner contact with foundation concrete 6/10/04
r,71,,,1,,1
real,71
type,60
mat,71
cmsel,s,slab_top
asel,r,loc,x,-480,-440
nsla,,l
esln
esur
type,61
cmsel,s,area_secon
asel,r,loc,x,-470,-440
,r,loc,y,-9,-8
nsla,,l
esln
rsle
esur

!merge insulating concrete bottom nodes and secondary liner nodes
cmsel,s,area_insul_bot
cmsel,s,area_secon
csys,0

asel,u,loc,y,20,5999
nsla,,l
cpintf,u,,l

!slab top/insulating concrete
r,65,,,1,,1
real,65
type,60
mat,65
cmsel,s,slab_top
nsla,,l
esln
esur
type,61
cmsel,s,area_insul_bot
nsla,,l
esln
esur

!wall/slab contact
r,66,,,1,,1
real,66
type,60
mat,66
asel,,986,992
cmsel,s,slab_top_wall,area
nsla,,l
esln
csel,r,mat,2
esurf
type,61
asel,,214
,a,,706
define the local coordinate systems and rebar orientations
/input/set_esys_3d.mac

apply loads
/input/apply_loads_slice.mac
allsel

apply axisymmetric boundary conditions
/csys,22
nsel,s,loc,y,180
nsel,a,loc,y,180+swp_th-.001,183
csys,0
nsel,a,loc,x,0

/apply loads_slice,mac
d,all,wy,0
d,all,rotx,0
d,all,rotz,0
allsel

nsel,s,loc,x,0
d,all,roty,0

merge liner/concrete nodes at dome centerline
ksel,s,,2
ksel,a,,329
nsel
nummrg,node
allsel

!copy jbolts, etc for slice model
/csys,22
csel,s,type,,20,21
csel,e_bolt0,elem
egen,2,500000,all,,0,0,0,0,,swp_th
csel,s,mat,,1
csel,u,real,,45
nummrg,node

nsel,u,,22789,22790

r,30,.19635/2,.3068e-2/2,.3068e-2/2,.5,.5
csel,s,type,,20,21
csel,e_bolt0
nummrg,node
r,41,3/16 !insulating concrete confining ring thickness
/prep7
csel,s,mat,,5
nsel,,1
csys,0
cnsel,a,ntemp
cmsel,a,ntemp,node
cnsel,s,vtemp
vsel,u,,loc,y,-9999,-8.12
cm,vtemp,volu
*get,nv,volu,count
*do,i,1,nv
  *get,iv,volu,,num,min
eslv
nsle
cmsel,a,ntemp
nummrg,node
cm,ntemp,node
cnsel,s,vtemp
vsel,u,,iv
/cm,vtemp,volu
*enddo

!*** Delete primary-secondary tank coupling at tangent
!*** JED 3/31/03
!***
er,41,3/16

*get,top_elev,node,,mxloc,y
cm,soil_elem,elem
*do,i,1,16
  set_slayer,soil_z0(i),soil_z1(i),soil_emod(i),soil_pr(i)
*enddo
max_mat=100
!set backfill/overburden material
*do,i,1,8
  set_backfill,bf_z0(i),bf_z1(i),bf_emod(i),bf_pr
*enddo
!Don't do this!! 5/6/04
!make sure anchors/jbolts/studs etc are merged with concrete
!esel,,type,12,13
!,a,type,20,21
!,a,type,24,25
!nsel
!esel,u,,22789,22790 !*** 3/26/04
!numm,node
!***
!*** Augmented Stiffness 2/27/04
!***
et,32,45
*get,ec350,ex,2,temp,350
mp,ex,12,ec350*0.05 17/19/04
,prxy,12,15
esel,,type,12,15
eigen,2,0,all,,10
esel,,mat,,12
emod,all,type,32

* Use springs for anchor bolts 8/9/07

```plaintext
alls
csys
et,35,40,,2 !Anchor bolt axial
  ,36,40,,1 !Anchor bolt shear
r,21,29e6*(pi*.5**2/4)/6 !Axial stiffness
*do,i,1,18
r,i*24*2*pi/24*swp_th/360*65000/2
*enddo
csys,11
nsel,r,loc,z
loc,a,99,,,,,swp_th
csys
*do,i,1,15
cmse,anchb
csys
nsel,r,loc,z
 ,r,loc,x,-i*24+.5,-i*24+1.5
type,35
real,21
 drot=atan(-nx(ndnext(l))*180/480/(480**2-nx(ndnext(l))**2)**.5)
 loca,50+i,ny(ndnext(1)),drot
 nrot,all
e,ndnext(0),ndnext(ndnext(0))
type,36
real,i
e,ndnext(0),ndnext(ndnext(0))
*enddo
*do,i,1,18
```
cmse,ancb
csys
nsel,u,loc,z
,r,loc,x,-i*24,-i*24+2
type,35
real,21
drot=atan(-nx(ndnext(l))*180/480/(480**2-nx(ndnext(l))**2)**.5)
esys,99
cloc,70+i,ny(ndnext(l)),nx(ndnext(l)),drot
nrot,all
e,ndnext(0),ndnext(0)
type,36
real,i
e,ndnext(0),ndnext(0)
*enddo

!*** Fix BC
esel,,type,,35
nsle
ddel,all,all
d,all,uz
,all,rots
,all,roty
alls

!*** 2nd liner extension issues 7/21/04
asel,,928,,1
eigen,2,100000,all,,4,,0,0
emod,nocheck
alls
elem,15784,-1,114183,104465
,15955,-3,104465,114183
,28888,-3,104465,114183
acle,928
real,62
type,60
mat,62
asel,,928,,1
esln
esel,r,type,,12
esurf
type,61
esel,,type,,23
,r,real,,45
nsle
esurf
dsym,symm,y,5
alls

!*** AP modifications 8/9/04
!*** Thickness from set_parms.mac
!* r50=1-.06 !shell thickness (in) (R1 of Figure 11 in RPP-13990)
!* r51=3/8-.06 !shell thickness (in) (R2,R6,R7,R9 of Figure 11 in RPP-13990)
!* r52=7/8-.06 !shell thickness (in) (R3 of Figure 11 in RPP-13990)
!* r53=3/4-.06 !shell thickness (in) (R4 of Figure 11 in RPP-13990)
!* r54=1/2-.06 !shell thickness (in) (R5,R8 of Figure 11 in RPP-13990)
!* r55=1/4 !shell thickness (in) (R10 of Figure 11 in RPP-13990)
!* r56=3/8 !shell thickness (in) of secondary liner above 357.5 in

!*** Additional liner thickness
,r,57.9/16-.06
,.58,15.16-.06
!***  Redefine secondary liner thickness
r,55,3/8
,56,1/2
,59,9/16

!*** Primary liner
csys
esel,,real,,51
nsle
nsel,t,loc,y,380,468.5
csln,,1
esel,t,real,,51
emod,all,real,,54
esel,,real,,54
nsle
nsel,t,loc,y,142,238
csln,,1
esel,t,real,,54
emod,all,real,,57
esel,,real,,52
nsle
nsel,t,loc,y,,12
,t,loc,x,-450,-437
csln,,1
esel,t,real,,52
emod,all,real,,58
esel,,real,,51
nsle
nsel,t,loc,y,-1,1
csln,,1
esel,t,real,,51
emod,all,real,,54

!*** Secondary liner
esel,,real,,55,56
nsle
nsel,t,loc,y,24,460
csln,,1
esel,t,real,,55,56
emod,all,real,,55
esel,,real,,55
nsle
nsel,t,loc,y,3.875,24
csln,,1
esel,t,real,,55
emod,all,real,,56
esel,,real,,55
nsle
nsel,t,loc,y,-9,3.875
t,loc,x,-480,-467
csln,,1
esel,t,real,,55
emod,all,real,,59
esel,,real,,55
nsle
nsel,t,loc,x,-468,-420
csln,,1
esel,t,real,,55
emod,all,real,,56

!*** Temperatures
!***  Uniform 80F (8/29/07)
!***
tref,80
tunif,80
finish
/sol
/solcontrol,off
neqit,50
time,1
algeom, on
nrop, unsym
cnvt,f,,005,0 16/16/04
,m,,005,0 16/16/04
crpl, 0.05
nsub, 10, 100, 5
!delt, 1.01, 2
!outres, all, all
!nrre, on, 250
eqsl,sparse, 0.5, -1
bcso, nund
alls el
save
solve

time, 2
!*** Add waste and pressure loads
!*** Add surface loads
!***
press_surf=0, !ground surface uniform pressure psf
point_cent=0, !point load at center lb
press_annulus=-20, !annulus pressure inches
h2o
press_int=12, !annulus internal pressure inches h2o
hwaste=422, !total waste height
height_waste1=hwaste/3, !height of waste 1 inches
gamma_waste1=1.83, !specific gravity of waste 1
height_waste2=hwaste/3, !height of waste 2 inches
gamma_waste2=1.83, !specific gravity of waste 2
height_waste3=hwaste/3, !height of waste 3 inches
gamma_waste3=1.83, !specific gravity of waste 3

/imp, apply_loads_slice.mac
delt, 1.01, 25
solv
time, 3
!***
!*** Add surface loads
press_surf=40, !ground surface uniform pressure psf
point_cent=200000, !point load at center lb
press_annulus=-20, !annulus pressure inches
h2o
press_int=-12, !annulus internal pressure inches h2o
hwaste=422, !total waste height
height_waste1=hwaste/3, !height of waste 1 inches
gamma_waste1=1.83, !specific gravity of waste 1
height_waste2=hwaste/3, !height of waste 2 inches
gamma_waste2=1.83, !specific gravity of waste 2
height_waste3=hwaste/3, !height of waste 3 inches
gamma_waste3=1.83, !specific gravity of waste 3
height_waste3=h\textunderscore waste\_3
\text{inches}
gamma_waste3=1.83
\text{specific gravity of waste 3}

\text{/inp,apply\_loads\_slice,mac}
\text{save}
\text{solv}

\text{Input file: set\_slice\_b7.mac}
\text{!Removed temperature scaling NK 11/29/2007}

\text{/fil,set\_slice\_0}
\text{resu}
\text{/titl,AP, secant modulus, 80-150F}

\text{/sol}
\text{anty,,rest}
\text{time,18 !LS 4}
\text{!*** Intermediate heating step}
\text{/nopr}
\text{!inp,frh1,temp}
\text{!inp,bkh1,temp}
\text{/gopr}
\text{delt,5,01,2}
\text{solv}
\text{time,33 !LS 5}
\text{!*** Steady state @ 150F}
\text{/nopr}
\text{!inp,frss,temp}

\text{/inp,bkss,temp}
\text{/gopr}
\text{delt,5,01,2}
\text{solv}
\text{time,358 !LS 6}
\text{!*** Hold for 1 Year}
\text{delt,5,01,150}
\text{solv}
\text{time,363 !LS 7}
\text{!*** Intermediate cooling step}
\text{/nopr}
\text{!inp,frcl,temp}
\text{!inp,bkc1,temp}
\text{/gopr}
\text{delt,5,01,2}
\text{solv}
\text{time,368 !LS 8}
\text{!**** Uniform 80F}
\text{bf,all,temp,80}
\text{delt,5,01,2}
\text{solv}
\text{!*** Cycle once}
\text{time,383 !LS 9}
\text{!*** Intermediate heating step}
\text{/nopr}
\text{!inp,frh1,temp}
/inp, bkhl, temp
/gopr

delt, 5, 01, 2
solv

time, 3+30+365 !LS 10

!***
!**** Steady state @ 150F
!***
/nopr
/inp, frss, temp
/inp, bkss, temp
/gopr

delt, 5, 01, 2
solv

time, 358+365 !LS 11

!***
!**** Creep for 1 Year
!***
delt, 5, 01, 150
solv

time, 363+365 !LS 12

!*** Intermediate cooling step
/nopr
/inp, frcl, temp
/inp, bkcl, temp
/gopr

delt, 5, 01, 2
solv

time, 383+365 !LS 13

!***
!**** Cool to ambient

/bf, all, temp, 80
/delt, 5, 01, 2
/save
/solv

time, 3+30+730 !LS 14

!*** Intermediate heating step
/nopr
/inp, frhl, temp
/inp, bkhl, temp
/gopr

delt, 5, 01, 2
solv

time, 3+30+730 !LS 15

!***
!**** Steady state @ 150F
!***
/nopr
/inp, frss, temp
/inp, bkss, temp
/gopr

delt, 5, 01, 2

solv
time,358+19*365 !LS 16
!*** Creep for 18 Years
!***
delt,.5,.01,1000
solv
time,363+19*365 !LS 17
!*** Intermediate cooling step
/nopr
/inp,frcl,temp
/inp,bkc1,temp
/gopr
delt,.5,.01,2
solv
!*** Cool to ambient
time,3+20*365 !LS 18
!***
!**** Uniform 80 F
!***
hf,all,temp,80
delt,.5,.01,2
save
solv

Input file: set_sliceb8.mac
! Increase waste to 460 

/fil,set_slice_0
resu
/sol
anty,rest
time,365*20+1
!***
!**** Add waste, pressure and surface loads
!***
pres_surf=40 !ground surface uniform pressure psf
point_cent=200000 !point load at center lb
pres_annulus=-20 !annulus pressure inches h2o
pres_int=-12 !annulus internal pressure inches h2o
hwaste=460 !total waste height
height_waste1=hwaste/3 !height of waste 1 inches
gamma_waste1=1.83 !specific gravity of waste 1
height_waste2=hwaste/3 !height of waste 2 inches
gamma_waste2=1.83 !specific gravity of waste 2
height_waste3=hwaste/3 !height of waste 3 inches
gamma_waste3=1.83 !specific gravity of waste 3

/inp,apply_loads_slice,mac
solv

time,365*20+15 !LS 19
!*** Intermediate heating step
**Initialization**

```
/delr 5.01,2
/solv
```

**Final Solution**

```
/time 20*365+30

!*** Steady state @ 135°F
```

**Uniform 80°F**

```
/time 21*365+15

!*** Intermediate heating step
```

**Intermediate cooling step**

```
/time 30+21*365

!*** Steady state @ 135°F
```

**Creep for 1 Year**

```
/time 355+21*365

!***
```

```
/delr 5.01,2
/solv
```

**Final Solution**

```
/time 20*265+30

!*** Steady state @ 135°F
```

**Hold for 1 Year**

```
/time 20*365+355

! *** Hold for 1 Year
```

**Intermediate cooling step**

```
/time 20*365+360

!*** Intermediate cooling step
```

```
/delr 5.01,2
/solv
```

**Final Solution**

```
/time,21*365

!*** Uniform 80°F
```

**Creep for 1 Year**

```
```

```
/delr 5.01,2
/solv
```

**Final Solution**

```
/time,355+21*365

!***
```

```
/delr 5.01,2
/solv
```

**Final Solution**

```
/time,355+21*365

!***
```

```
/delr 5.01,2
/solv
```

**Final Solution**

```
/time,355+21*365

!***
```
!!!***
delt., 5, 01, 150
solv

time, 360 + 21 * 365  !LS 27
!!!*** Intermediate cooling step
/nopr
/inp, frcl, temp
/inp, bkcl, temp
/go pr

delt., 5, 01, 2
solv

!!!*** Cool to ambient

time, 22 * 365  !LS 28
!!!*** !**** Uniform 80F
!!!***
/bf, all, temp, 80
delt., 5, 01, 2
solv

time, 22 * 365 + 15  !LS 29
!!!*** Intermediate heating step
/no pr
/inp, frhl, temp
/inp, bkhl, temp
/go pr

delt., 5, 01, 2
solv

time, 30 + 22 * 365  !LS 30
!!!***
!!!*** Steady state @ 135F
!!!***
/no pr
/inp, frss, temp
/inp, bkss, temp
/go pr

delt., 5, 01, 2
solv

time, 355 + 59 * 365  !LS 31
!!!***
!!!*** Creep for 38 Year
!!!***
delt., 5, 01, 2000
solv

time, 360 + 59 * 365  !LS 32
!!!*** Intermediate cooling step
/no pr
/inp, frcl, temp
/inp, bkcl, temp
/go pr

delt., 5, 01, 2
solv

!!!*** Cool to ambient

time, 60 * 365  !LS 33
C.6 Postprocessing Files

There are five postprocessing files associated with the ACI evaluation, the ASME evaluation of the primary and secondary liner, and the anchor bolts. They are listed below.

Input file: pacill.inp

```plaintext
!***
!**** Uniform 80°F
!***
bf, all, temp, 30
delt., 5, 01, 2
save
solv
```

```plaintext
C.6 Postprocessing Files

There are five postprocessing files associated with the ACI evaluation, the ASME evaluation of the primary and secondary liner, and the anchor bolts. They are listed below.

**Input file: pacill.inp**

```
!***
!**** ACI postprocessing
!***  9/2/04 Automate for year 61
!***  8/3/04 Delete section 64
!***  1/15/04 Revised
!***  9/8/03 Add 6 locations to foundation
!***  9/4/03 Use pcal.intg for hoop direction
!******************************
!***  9/3/03 Add titles - change as necessary!!
!******************************
!***  8/23/03 (FSUM)
!***

*dim, dox., 15
dox(1) = 30, 61, 90, 120, 152, 154.91, 158.75, 163.9, 168.1, 172.35, 176.177
*dim, wh., 23
wh(1) = 382.1, 361.5, 346.1, 335, 321, 306, 300, 281.260.5, 236
wh(11) = 212.7, 200, 186.8, 171.0, 151.6, 145.9, 120.5, 100.5, 80.60
wh(21) = 39.9, 21.4, 35
*dim, dsx., 16
dsx(1) = 514, 503, 489, 477, 461.5, 440, 421.4, 390, 358, 338
dsx(11) = 277.7, 218.5, 180, 129.9, 95.7, 54
*do, m, 138, 147
set, m

*cof, ls%m%, aci
*afun, deg
!*** Titles
ttl = 'Baseline'
tt2 = 'Year 61'
tt3 = 'ls%m%'
tt4a = '40 psf uniform,'
tt4b = '100 ton concentrated,'
tt4c = '-20 in. annulus,'
tt4d = '-6 in. vapor space'
tt5 = '1.4(D + F) + 1.7(L + H)'
ct1 = 'Section'
ct2 = 'shear'
ct3 = 'F-merid'
ct4 = 'M-merid'
ct5 = 'F-hoop'
ct6 = 'M-hoop'
```

```
ct7='Tmin '
cf8='Tmax '
cf9='Tave '
cft0='xbar '
cft1='ybar '
cft2='sect thk'
ttb=' '

*vwri,ttl
%c
ttb,tt2
%c
ttb,tt3
%c
ttb,tt4a,tt4b,tt4c,tt4d
%c
ttb,ttb
(a8)
*vwri,ttb
(a8)
*vwri,ttb
(a8)
*vwri,ct1,ct2,ct3,ct4,ct5,ct6,ct7,ct8,ct9,ct10,ct11,ct12
(12a8)
*vwri,ttb
(a8)

***
*** Dome

k=0

ceys
esel,,type,,12,15
nsle

*** Find center of outer arc
cdl=distkp(6,18)
cda=asin(cdl/(2*r2))
cthet=atan((ky(6)-ky(18))/(kx(6)-kx(18)))
cgam=90-cda-cthet
cdelx=r2*cos(cgam)
cdelx=r2*sin(cgam)
orcirx=kx(18)+cdelx
orciry=ky(18)-cdely

*do,i,1,15
k=k+1
esel,,type,,12,15
nsle
ceys
x1=dox(i)
thed1=acos(x1/480)
y1=h5-180+180*sin(thed1)
*if,i,le,5,then
thed1=asin(x1/(rl-15))
x2=rl*sin(thed1)
y2=h6-rl+rl*cos(thed1)
*else
thed1=atan((y1-orciry)/(x1+orcirx))
x2=r2*cos(thd1)-oricrx
y2=r2*sin(thd1)+oricry
thd1=90-thd1
*endif
path,sect %k%,2,200
ppat,1,-x1,y1
,2,-x2,y2

nsel,r,loc,y,400,599
loca,45,-x1,y1,thdl-90
nsel,r,loc,y,-3,500
estm,1
esel,r,type,,12,15
*if,i,eq,8,then
esel,a,,8995
*elseif,i,eq,9,then
esel,a,,9181
*elseif,i,eq,11,then
esel,a,,9200
*elseif,i,eq,12,then
esel,a,,9491
*elseif,i,eq,13,then
esel,a,,8825
*elseif,i,eq,14,then
esel,a,,8999
*endif

cm,upper,elem

pdef,temp,bfe,temp
pcalc,intg,itemp,temp,s
*get,delt,path,,last,s

nsel,r,loc,y,-3.0
,r,loc,z
*if,i,eq,10,then
nsel,u,,2990
*endif

*get,ncount,node,,count
cm,sectn,node
slocxt=0
slocy=0
secx=0
secy=0
csys
rsys
*do,j,l,ncount
ncur=admnext(j)
slocxt=slocxt+nx(ncur)+ux(ncur)
slocy=slocy+ny(ncur)+uy(ncur)
secx=secx+nx(ncur)
secy=secy+ny(ncur)
sel,u,,ncur
*endo
cm,sectn

*get,ncount,node,,count
slocxt=0
slocy=0
secx=0
secy=0
csys
rsys
*do,j,l,ncount
ncur=admnext(j)
slocxt=slocxt+nx(ncur)+ux(ncur)
slocy=slocy+ny(ncur)+uy(ncur)
secx=secx+nx(ncur)
secy=secy+ny(ncur)
sel,u,,ncur
*endo
cm,sectn

*get,ncount,node,,count
slocxt=0
slocy=0
secx=0
secy=0
csys
rsys
*do,j,l,ncount
ncur=admnext(j)
secw=xbar*swp_th/2*pi/180
*get,ncount,node,,count
slocxt=0
slocy=0
secx=0
secy=0
csys
rsys
*do,j,l,ncount
ncur=admnext(j)
secw=xbar*swp_th/2*pi/180
esel., type., 12, 15
cmse., u., upper
fsum
*get, smerl, fsum., item, fx
*get, pmerl, fsum., item, fy
*get, mmerl, fsum., item, mz
smer = (smeru - smerl) / 2
pmer = (pmeru - pmerl) / 2
mmer = (mmeru - mmerl) / 2

!** Calculate hoop area
esln
esel., r., type., 12, 15
*if, i, eq, 8, then
esel., u., 8996
*elseif, i, eq, 9, then
esel., u., 9182
*elseif, i, eq, 10, then
esel., u., 9203
*elseif, i, eq, 11, then
esel., u., 9199
*elseif, i, eq, 12, then
esel., u., 8942
*elseif, i, eq, 13, then
esel., u., 8824
*elseif, i, eq, 14, then
esel., u., 8998
*endif
nsle
nsel., r., loc., z
*get, ecount, elem., count
hparea = 0
*do, j, 1, ecount
ecur = elnext(j)
hparea = hparea + arface(ecur)
esel., u., ecur
*endo
hparea = hparea / 2
hpw = hparea / delt
esel., type., 12, 15
cmse., sectn
fsum., rsys
*get, php, fsum., item, fz
*get, mhp, fsum., item, my
tave = tot / delt
smer = smer / secw * 12 / 1000
pmer = pmer / secw * 12 / 1000
mmer = mmer / secw / 1000
php = php / hpw * 12 / 1000
mhp = mhp / hpw / 1000

*vwv, i, k, smer, pmer, mmer, php, mhp, tmin, tmax, tave, xbar, ybar, delt (11f8.1, f8.2)
*endo
d*** Haunch
csys
esel., type., 12, 15
nsle
d*** Find center of outer arc
csys
cdl = distkp(6, 18)
\[
cda = \text{asin}(c d / (2 \times r^2)) \\
c\theta = \text{atan}((k(y(6) - k(y(18)))/(k(x(6) - k(x(18))))) \\
cgam = 90 - cda - c\theta \\
cdelx = r^2 \times \text{cos}(cgam) \\
cdely = r^2 \times \text{sin}(cgam) \\
orcirx = k(x(18)) + cdelx \\
orciry = k(y(18)) - cdely \\
\]

\[
\text{for } i = 1 \text{ to } 9 \\
k = k + 1 \\
esel(type) 12, 15 \\
nse \\
csys \\
x1 = 480 \times \text{cos}(thx(i)) \\
y1 = 480 \times \text{sin}(thx(i)) \times 0.375 + h3 \\
\text{if } i = 1 \text{ to } 4, \text{then} \\
thd1 = \text{atan}((y1 - orciry)/(x1 - orcirx)) \\
x2 = orcirx - r^2 \times \text{cos}(thd1) \\
y2 = orciry - r^2 \times \text{sin}(thd1) \\
\text{elseif } i = 5, \text{then} \\
thd1 = \text{atan}((y1 - orciry)/(x1 - orcirx)) + 5 \\
x2 = orcirx - r^2 \times \text{cos}(thd1 - 4.85) \\
y2 = orciry - r^2 \times \text{sin}(thd1 - 4.85) \\
\text{elseif } i = 6, \text{then} \\
thd1 = \text{atan}((y1 - orciry)/(x1 - orcirx)) + 11 \\
x2 = orcirx - r^2 \times \text{cos}(thd1 - 10.5) \\
y2 = orciry - r^2 \times \text{sin}(thd1 - 10.5) \\
\text{elseif } i = 7, \text{then} \\
x2 = -498 \\
y2 = 427.6 \\
thd1 = \text{atan}((y2 - y1)/(x2 - x1)) \\
\text{elseif } i = 8, \text{then} \\
x2 = -498 \\
y2 = 408.8 \\
thd1 = \text{atan}((y2 - y1)/(x2 - x1)) \\
\text{else} \\
x2 = -498 \\
y2 = 393.5 \\
\text{endif} \\
\]

\[
\text{path, sect } %k%, 2, 200 \\
ppat, 1, x1, y1 \\
, 2, x2, y2 \\
\text{nsel, r, loc, y, 380, 599} \\
loc, 45, x1, y1, thd1 \\
\text{nsel, r, loc, y, -3, 500} \\
\text{esln, 1} \\
esel, r, type, 12, 15 \\
\text{elseif } i = 6, \text{then} \\
esel, a, 9403, 9434, 31 \\
esel, a, 9480, 9640, 160 \\
\text{elseif } i = 7, \text{then} \\
esel, a, 9455 \\
\text{endif} \\
cm, upper, elem \\
sys, 45 \\
pdef, temp, bfe, temp \\
pcalc, intg, itemp, temp, s \\
\text{get, delt, path, last, s} \\
\text{nsel, r, loc, y, -3, 0} \\
r, loc, 2
*if,i,eq,4,then
nsel,u,,2692,2694,2
*elseif,i,eq,6,then
nsel,a,,3807,3820,13
*elseif,i,eq,7,then
nsel,u,,3822,3824,2
u,,2707
*endif
*get,ncount,node,,count
cm,sectn,node
slocxt=0
slocyt=0
secx=0
secy=0
csys
rsys
*do,j,1,ncount
ncur=ndnext(j)
slocxt=slocxt+nx(ncur)+ux(ncur)
slocyt=slocyt+ny(ncur)+uy(ncur)
secx=secx+nx(ncur)
secy=secy+ny(ncur)
nsel,u,,ncur
*endo
rsys,45
slocx=slocxt/ncount
slocy=slocyt/ncount
xbar=-secx/ncount
ybar=secy/ncount
cmse,sectn

spoi,slocx,slocy
fsum,rsys

*** Sum moments about neutral axis
*if,k,gt,18,and,k,lt,23,then
*get,mzn,fsum,,item,mz
flag=1
*if,mzn,gt,0,then
flag=-1
*endif
*elseif,k,eq,19
slocx=slocx+flag*.85*cos(thdl)
slocy=slocy+flag*.85*sin(thdl)
*elseif,k,eq,20
slocx=slocx+flag*.8*cos(thdl)
slocy=slocy+flag*.8*sin(thdl)
*elseif,k,eq,21
slocx=slocx+flag*.82*cos(thdl)
slocy=slocy+flag*.82*sin(thdl)
*else
slocx=slocx+flag*.77*cos(thdl)
slocy=slocy+flag*.77*sin(thdl)
*endif
*endif
spoi,slocx,slocy
fsum,rsys

get,smeru,fsum,,item,fx
get,pmeru,fsum,,item,fy
get,nmeru,fsum,,item,mz
get,min,path,,min,temp
get,max,path,,max,temp
get,tot,path,,last,item
esel,,type,,12,15
cmse,,upper
fsum
smer = (smeru - smerl) / 2
pmer = (pmeru - pmerl) / 2
mmer = (mmeru - mmerl) / 2

!** Calculate hoop area
esln
esel, r, type,, 12, 15
*if, i, eq, 4, then
esel, a,, 8478
*elseif, i, eq, 6, then
esel, u,, 9378, 9479, 101
*endif
nsle
nsel, r, loc, z
*get, ecount, elem,, count
hparea = 0
*do, j, 1, ecount
ecur = ednext(j)
hparc = hparea + arface(ecur)
esel, u,, ecur
*endo
ddo
hparea = hparea / 2
hpw = hparea / delt

esel, type,, 12, 15
cmse, sectn/fsim, rsys
*get, php, fsum, item, fz
*get, mhp, fsum, item, my

tave = tot / delt
smer = smer / secw * 12 / 1000
pmer = pmer / secw * 12 / 1000
mmer = mmer / secw / 1000
php = php / hpw * 12 / 1000
mhp = mhp / hpw / 1000

secw = xbar * swp_th / 2 * pi / 180
tave = tot / delt
smer = smer / secw * 12 / 1000
pmer = pmer / secw * 12 / 1000
mmer = mmer / secw / 1000
php = php / hpw * 12 / 1000
mhp = mhp / hpw / 1000

2vwri, k, smer, pmer, mmer, php, mhp, tmin, tmax, tave, xbar, ybar, delt
(11/18.1, 18.2)
*endo
ddo

!***
!*** Wall
csys
esel, type,, 12, 15
nsle
*do, i, 1, 23
k = k + 1
esel, type,, 12, 15
u, type,, 14
nsle
csys
x1 = -480
y1 = wh(i)
x2 = -498
y2 = wh(i)

path, sect %k%,, 2,, 200
ppat, 1, x1, y1
2, x2, y2
*if,i,eq,2,then
esel,a,,11133
*elseif,i,eq,3,then
esel,a,,8559,11138,2579
*elseif,i,eq,4,then
esel,a,,10972
*elseif,i,eq,9,then
esel,a,,8590
*elseif,i,eq,10,then
esel,a,,11091,11257,166
*elseif,i,eq,11,then
esel,a,,11242
*elseif,i,eq,12,then
esel,a,,11238
*elseif,i,eq,14,then
esel,a,,11087,11229,142
*elseif,i,eq,15,then
esel,a,,11156,11223,67
*elseif,i,eq,16,then
esel,a,,11158,11221,63
*elseif,i,eq,17,then
esel,a,,11213
*elseif,i,eq,18,then
esel,a,,11173
*elseif,i,eq,19,then
esel,a,,10931,11048,117
*elseif,i,eq,20,then
esel,a,,11194
endif
cm, upper, elem
rsys
pdef,temp,bfe,temp
pealc,intg,itemp,temp,s
*get,delt,path,,last,s
nsel,r,loc,y,wh(i)-3,wh(i)
.x,loc,z
.x,loc,x,-498,-480
*get,ncount,node,,count
cm,sectn,node
sloext=0
slocyt=0
secx=0
secy=0
csys
rsys
*do,j,1,ncount
ncur=ndnext(j)
sloext=sloext+nx(ncur)+ux(ncur)
slocyt=slocyt+ny(ncur)+uy(ncur)
secx=secx+nx(ncur)
secy=secy+ny(ncur)
nset,ui,ncur
*enddo
sloext=sloext/ncount
slocyt=slocyt/ncount
xbar=secx/ncount
ybar=secy/ncount
cmse, sectn
secw=xbar*swp_th/2*pi/180

spoi,,slocx,slocy
fsum,rsys
*get,smeru,fsum,,item,fx
*get,pmeru,fsum,,item,fy
*get,mmeru,fsum,,item,mz
*get,tmin,path,,min,temp
*get,tmax,path,,max,temp
*get,ttot,path,,last,item
*get,tmin,path,,min,temp
*get,tmax,path,,max,temp
esel,type,,12,15
cmse,u,upper

fsum
*get,smerl,fsum,,item,fx
*get,pmerl,fsum,,item,fy
*get,mmerl,fsum,,item,mz
smer=(smeru-smerl)/2
pmer=(pmeru-pmerl)/2
mmer=(mmeru-mmerl)/2

!!! Calculate hoop area
esln
esel,r,type,,12,15
*if,i,eq,2,then
esel,u,,11134
*elseif,i,eq,3,then
esel,u,,8558,11139,2581
*elseif,i,eq,4,then
esel,u,,10973
*elseif,i,eq,8,then
esel,u,,10973
*elseif,i,eq,9,then

*elseif,i,eq,10,then
esel,u,,8605,11106,2501
*elseif,i,eq,11,then
esel,u,,11241
*elseif,i,eq,12,then
esel,u,,11237
*elseif,i,eq,14,then
esel,u,,11076,11228,142
*elseif,i,eq,15,then
esel,u,,11157,11222,65
*elseif,i,eq,16,then
esel,u,,11159,11220,61
*elseif,i,eq,17,then
esel,u,,11212
*elseif,i,eq,18,then
esel,u,,11174
*elseif,i,eq,19,then
esel,u,,10930,11049,119
*elseif,i,eq,20,then
esel,u,,11193
*endif
esle

nsel,r,loc,z
*get,ecount,elem,,count
hparea=0
*do,j,1,ecount
ecur=elnext(j)
hparea=hparea+ararea(ecur)
esel,u,,ecur
*endo
hparea=hparea/2
hpw=hparea/delt
esel., type., 12,15
emse., secn
fsum,rsys
*get,php,fsum.,item,fz
*get,mhp,fsum.,item,my

secw=xbar*swp_th/2*pi/180
tave=ttot/delt
smer=smer/secw*12/1000
pmer=pmer/secw*12/1000
mmer=mmer/secw/1000
php=php/hpw*12/1000
mhp=mhp/hpw/1000

*vweri,k,smer,pmer,mmer,php,mhp,tmin,tmax,tave,xbar,ybar,delt
(11f8.1,f8.2)
*enddo

***
*** Found

ccys
esel., type., 12,15
nsle
*do,i,1,16
k=k+1
esel., type., 12,15
nsle
csys
x1=dsx(i)
*if,i.le,5,then
y1=-30.125
*endif

*y1=18.625
*endif

x2=dsx(i)
y2=h2
*if,i.le,2,then
y2=-6.625
*endif

path,.sect %k%,2,200
ppat,1,-x1,y1
 .2,-x2,y2
nsel,r,loc,y,-40,y2
nsel,r,loc,x,-dsx(i)-3,1
csln.,1
esel.i,type.,12,15
*if,i.eq,7,then
esel.a,,12008
*elseif,i.eq,13,then
esel.a,,12088
*elseif,i.eq,16,then
esel.a,,11793,12283,490
*endif
cm,lower,clern

pdef,temp,bfe,temp
cale,intg,itemp,temp,s
*get,delt,path.,last,s
nsel
nsel,r,loc,x,-dsx(i)-3,-dsx(i),r,loc,z
*if,i,eq,6,then
nsel,u,,9483
*elseif,i,eq,7,then
nsel,u,,9344
*elseif,i,eq,16,then
nsel,a,,281
*endif
*get,ncount,node,,count
cm,sectn,node
slocxt=0
slocyt=0
secx=0
secy=0
csys
rsys
*do,j,l,ncount
ncur=ndnext(j-1)
slocxt=slocxt+nx(ncur)+ux(ncur)
slocyt=slocyt+ny(ncur)+uy(ncur)
secx=secx+nx(ncur)
secy=secy+ny(ncur)
nsel,u,,ncur
*endo
dosloxx=dsloct/ncount
doslclx=aksolgx/ncount
xbar=-secx/ncount
ybar=-secy/ncount
cmse,,sectn
secw=xbar*swp.th/2*pi/180
spoi,,slocx,slocy
fsum
*get,smerl,fsum,,item,fy
*get,pmerl,fsum,,item,fx
*get,nmerl,fsum,,item,mz
*get,tmin,path,,min,temp
*get,tmax,path,,max,temp
*get,ttot,path,,last,tem
esel,,type,,12,15
cmse,u,lower
fsum
*get,smeru,fsum,,item,fy
*get,pmeru,fsum,,item,fx
*get,nmeru,fsum,,item,mz
smer=(smerl-smeru)/2
pmer=(pmerl-pmeru)/2
mmer=(nmeru-nmerl)/2
*** Calculate hoop area
esln
esel,r,typ,,12,15
*if,i,eq,6,then
esel,u,,12148
*elseif,i,eq,7,then
esel,u,,11797,12007,210
*elseif,i,eq,13,then
esel,u,,12101
*endif
nsel
nsel,r,loc,z
*get,ecount,elem,,count
hparca=0
*do,j,1,ecount
ecur=elnex(j)
hparea=hparea+arface(ecur)
esel,u,ecur
*endo
hparea=hparea*2
hpw=hparea/delt

esel,,type,,12,15
cmse,,sectn
fsum,rsys
*get,php,fsum,,item,fz
*get,mhp,fsum,,item,mx

tave=ttot/delt
smes=smer/secw*12/1000
pmer=pmer/secw*12/1000
mmer=-mmer/secw/1000
php=php/hpw*12/1000
mhp=mhp/hpw/1000

*vwri,k,smer,pmer,mmer,php,mhp,tmin,tmax,tave,xbar,ybar,delt
(11f8.1,f8.2)
*endo
cfc
*endo

Input file: postprimcomb.inp
/post1
set,148
lcwr,1
locx,199,1,280.75,90
esel,,14927,14943,16
,14962,15000,19
,15018,15037,19
,15050,15056,6
,15061,15064,3
,15070,15076,6
,15081,15086,5
,15092,15097,5
,15103,15115,6
,15120,15168,6
,15172,15180,4
,15185,15197,12
,15211,15227,16
,15247,15258,11
,15264,15276,12
,15303,15324,21
rsys,solu

*do,k,138,147
set,,k
loop,sub,1
shell,lop
ETAB,sint,s,int
ETAB,loey,cent,y
shell,bot
ETAB,sintb,s,int
ETAB,loey,cent,y
csor,ctab,loey,1
/out,primsec%k,%lis
PRET,loey,sint,sintb
/output
*endo
Input file: postprimcomb1.inp

/post1
set, 148
loca, 199, 1, 280.75, 90
esel, ..., 14927, 14943, 16
...a, 14962, 15000, 19
...a, 15018, 15037, 19
...a, 15050, 15056, 6
...a, 15061, 15064, 3
...a, 15070, 15076, 6
...a, 15081, 15086, 5
...a, 15092, 15097, 5
...a, 15103, 15115, 6
...a, 15120, 15168, 6
...a, 15172, 15180, 4
...a, 15185, 15197, 12
...a, 15211, 15227, 16
...a, 15247, 15258, 11
...a, 15264, 15276, 12
...a, 15303, 15324, 21
rsys, solu
shel, mid
etab, sxm, s, x
ETAB, sym, s, y
ETAB, sxym, s, xy
ETAB, sintm, s, int
ETAB, locy, cent, y
shel, top
etab, sx, t, s, x
ETAB, syt, s, y
ETAB, sxyt, s, xy

ETAB, sintt, s, int
ETAB, locy, cent, y
shel, bot
etab, sxb, s, x
ETAB, syb, s, y
ETAB, sxyb, s, xy
ETAB, sintb, s, int
ETAB, locy, cent, y
pret, locy, sxm, sym, sxym, sintm
PRET, locy, sxt, syt, sxyt, sintt
PRET, locy, sxb, syb, sxyb, sintb

Input file: postseccomb1.inp

/post1
csys

esel, ..., 15185, 15211, 26
...a, 15227, 15247, 20
...a, 15258, 15264, 6
...a, 15276, 15798, 522
...a, 15303, 15324, 21
...a, 15804, 15814, 10
...a, 15654, 15666, 12
...a, 15687, 15708, 21
...a, 15723, 15737, 14
...a, 15750, 15953, 203
...a, 15785, 15788, 3
...a, 15819, 15837, 18
...a, 15851, 15866, 15
...a, 15877, 15897, 20
...a, 15795, 15912, 117
...a, 15764
!*** J-bolts

*do, k, 138, 148
set, k
cetab, locy, cent, y
shel, mid
cetab, epsm, eppto, 1
, epscm, eppto, 3
sadd, epscm, epscm, -1
shel, top
cetab, epsbt, eppto, 1
, epscbr, eppto, 3
sadd, epscbr, epscbr, -1
shel, bot
cetab, epsbb, eppto, 1
, epscbb, eppto, 3
sadd, epscbb, epscbb, -1
cesor, cetab, locy, 1
/out, comp1%k%, lis
pret, locy, epsm, epscm, epsbt, epscbr, epsbb, epscbb
/out
*enndo

Input file: jbolt2.inp

!!! J-bolts
!!! 6/1/04
!!!

!!! writes data for all load steps in a single file! modified
09/02/04 - Siva!
!!! NB!! 6/1/04
!!! This version uses (sfyi**2 + sfzi**2)**1/2
!!! because beams on z <> 0 face are

!!! incorrectly oriented (should use nod1k in set_slicea.mac)
!!!
/fil, set_slice_0
resu
/post1

*do, k, 138, 148
set, k
*cfo, lsteps, asmc, append
ttl='Load Step'
*vwri, ttl
gsc

*vwri, k
(11f8.1, f8.1)
ct='J-bolt pos'
c1t1='F-axial'
c1t2='F-shear'
c1t3='U-axial'
c1t4='U-shear'

*vwri, ct, ct1, ct2, ct3, ct4
(12a12)
esel,, real,, 50, 56
nsle
eshn
esel, r, type,, 30
nsle
cetab, fix, smisc, 1
C.7 Detailed Anchor Bolt Model File

! Same as C2 with more divisions for bolt circumference.
! Coarse Model
! Without using VSYM for symmetry KNK 11/06/07
! Quarter model with symmetry KNK 11/05/07
! Bolt, Stud, Plate and Concrete dimensions from m7c.inp and
! Weld flash dimensions from m2.inp
! Detailed anchor bolt model

faxial(i)=(ex1*4+ex2*4)/2  !** 4" J-bolt length
usheary=(esheary1**2+eshearz1**2)**0.5
ushearz=(esheary2**2+eshearz2**2)**0.5
ushear(i)=(usheary*4+ushearz*4)/2
esel,u,,e2
esor,etab,jloc,1

fax=faxial(i)
fsheary=fsheary(i)
uax=uaxial(i)
ush=ushear(i)

*vwri,fax,fsheary,uax,ush
(12g12.5,12.5)
*endo
cfc
*endo

finish
*clear
/fil,APAnchorBoltC8
/tit,AP anchor-bolt with Weld Flash
/prep7

!==========PARAMETERS==========

!----Nelson 3/4" Stud-----
D=3/4 ! Stud Diameter
S=0.119 ! Depth of Solid Weld Base
L=0.406 ! The Imperfect Thread Depth
E=1.062 ! Weld Diameter
F=0.25 ! Height of Weld Flash
A=0.937
BurnOff=0.187

!---Anchor Bolt-------
D1=0.5 ! Bolt Diameter

!---Other Constants------
pi=22.0/7.0

!==========ELEMENT TYPES==========

et,1,45 ! Stud (TBL)
et,2,45 ! Bolt
et,3,45 ! Plate
et,4,45 ! Concrete
et,5,45 ! Weld Flash
et,7,TARGE170
et,8,CONTA174
et,9,MESH200,6

!==========MATERIALS==========

!**TBL STUD and Weld Flash
mp,ex,1,29.0e6
,nu,xy,1,0.29
!,dens,1.490/12**3
tb,bkin,1
tbda,,68300

!**Bolt
mp,ex,2,29.0e6
mp,nu,xy,2,0.29
!,dens,1.490/12**3
tb,bkin,2
tbda,,68300

!**Plate
mp,ex,3,29.0e6
,nu,xy,3,0.29
!,dens,1.490/12**3
tb,bkin,3
tbda,,68300

!**Concrete
mp,ex,4,5.083e6
,nu,xy,4,0.15
!,dens,1.145/12**3
tb,bkin,4
tbda,,5000*5889/3000

!========== FE MODEL==========

pcir,D1/2,,90
,D/2,E/2,90
A.1,7,6,2
adde.all
bblc4,0,0,8,8
asbl,1,all
nummrg, KP
numcmp, AREA

 type,9
asel,,1
lsla
lesize, all,,8
amesh,1
asel,,2
amap,2,6,2,1,7

type,1
mat,1
esiz,,3
asel,,1,2
vext, all,,5

asel,,9
esiz,,3
vext,9,,F-S ! Height of Weld Flash= 0.25
esiz,,5
vext,13, I

asel,,5
agen,2,all,,1+F-S,0
asel,,18
type,1
mat,1

 esiz,,8
vext,18,,1,094
asel,,23
type,9
amesh,all
type,2
mat,2
vext,23,,1,094

asel,,29
type,2
esize,,20
vext,29,,6-0,312-1,75
wpoffs,,kz(35)
pcir,D/2,D/2,90
,D/2,D/1,90
asel,,loc,z,kz(35)
umm,kp
type,9
esize
amap,37,34,37,38,36
amap,38,37,41,42,38
asel,,loc,z,kz(35)
type,2
esize,,2
vext, all,,312
wpstyl, defa
wprotat,,90
wpstyl,, all
larc,4,17,7,3
lsel, all
al,7,86,30,23
lesize,7...,4
lesize,86...,8
asel,,,,51
Isla
type,9
ames,51
type,5
mat,1
vdra,51,...,6

nummrtg,node

asel,,,,loc,z,kz(40)
agen,2,all
ksel,,,,9,11
kgen,2,all,...,kz(40)
ksel,,,,57,61
a,57,59,60,61,58

asel,,,,57,59
type,9
amesh,all

lesize,104...,16,6
lesize,107...,16,1/6
Isel,,,,105,106
lesize,all...,12

asel,,,,60
Isla
type,9
amesh,all

asel,,,,57,60
esize,2
type,4
mat,4
vext,all...,1

asel,,,,60
esize,2
vext,all...,0.312

asel,,,,37,38
agen,2,all

asel,,,,78
asel,a,,,,84,85
esize,20
vext,all...,1*(6-0.312-1.75)

asel,,,,97
agen,2,all
type,9
asel,,,,101
amesh,all
esize,8
type,4
mat,4
asel,,,,86,101,101-86
vext,all...,1.094
esize,5
asel,,,,102,108,6
vext,all...,1*I
asel,,,55
agen,2,all
wpstyl,defa
k,,E/2+D/2-D1/2
l,116,120
wpres,,90
tarc,112,120,116,0.3

lsel,,,215,216
adrag,,all,,,212

asel,,,124,126
asel,a,,119
lsla
kssl
nummrg,kp
al,215,216,206,211
al,217,213,204,220

asel,,,124,128
asel,a,,119
va,125,126,119,124,127,128
vsweep,24,119,125

esel,,type,,4
mde
ksln
nummrg, node
nummrg,kp

kset,,,9,11
kgen,2,all
allsel

a,120,81,82,92,122
a,120,81,108,107
a,81,82,109,108
a,82,92,110,109
a,92,122,111,110
allsel
va,101,109,120,129,126,98,113
vsweep,25,113,98

asel,,,1,2
asel,a,,52
asel,a,,98
asel,a,,125
agen,2,all

asel,,,130,134
lsla
kssl
nummrg,kp
type,9
amesh,132,134,2
asel,,,133
lsla
lesize,222,,16,6
lesize,225,,16,1/6
lesel,223,224
lesize,all,,,12
amesh,133
asel,,,130,134
esize,,2
type, 3
mat, 3
vext, all, all, -0.375
allsel

!-------------------End of Quarter Model-------------------
esel, type, 1, 8
nsle
nsym, x, 100000, all
esym, 100000, all

*do, ElType, 1, 5
esel, type, ElType
nsle
ksln
nummrg, node
nummrg, kp
*endo

esel, type, 1, 5
esel, u, type, 4
nsle
ksln
nummrg, node
nummrg, kp

!allsel
!numcmp, node
!numcmp, kp

!============CONTACT DEFINITIONS=============

*** Plate -> Concrete

esel, type, 3
nsle
csys, 1
nsel, r, loc, z
r, loc, x, 0.53, 20
type, 7
real, 10
esurf !Plate
esel, type, 4
nsle
nsel, r, loc, z
r, loc, x, 0.53, 20
type, 8
esurf !Concrete

*** TBL -> Concrete - radial
esel, type, 1
nsle
csys, 1
nsel, r, loc, x, D/2
r, loc, z, F, 1.75
type, 7 ! Convex surface --> Contact
real, 11
esurf !TBL
esel, type, 4
nsle
nsel, r, loc, x, D/2
r, loc, z, F, 1.75
type, 8
esurf !Concrete

*** TBL -> Concrete - axial
esel, type, 1
**nsle**
nself, r, loc, z, 1.75
type, 8  ! Concrete
esurf

*** Shank <> Concrete
esel, type, 2
nsle
nself, r, loc, x, 0.25
type, 7  ! Convex surface ----> Contact
esurf  ! Shank
esel, type, 4
nsle
nself, r, loc, x, 0.25
type, 7  ! Convex surface ----> Contact
esurf

*** Bolt - radial <> Concrete
esel, type, 2
nsle
nself, r, loc, x, 0.5
type, 7  ! Convex surface ----> Contact
esurf  ! Bolt Head Side
esel, type, 4
nsle
nself, r, loc, x, 0.5
type, 8  ! Concrete
esurf

*** Bolt - axial <> Concrete
esel, type, 2
nsle
nself, r, loc, x, 0.5
type, 7  ! Flat, Stiffer ----> Target
esurf  ! Bolt Head Top
esel, type, 4
nsle
nsel, c, loc, x, 0, 0.5
r, loc, z, 6.0
type, 3
esurf ! Concrete

!*** Weld Flash <> Concrete

!----Code for Selecting Nodes on the Surface of Weld Flash
asesel,, 55,, 1
cm, A55Nodes, node
*get, NdCt, NODE, 0, COUNT
*dim, WFnodes1, NdCt
*dim, WFnodes2, NdCt
*do, indx, l, NdCt
*get, NdNum, NODE, 0, NUM, MIN
WFnodes1(indx) = NdNum
nsel, u,, NdNum
*enddo
CSYS
esel, type, 5
nsle
*do, indx, 1, NdCt
WFnodes2(indx) = NODE(-1*X(WFnodes1(indx)), Y(WFnodes1(indx)), Z(WFnodes1(indx)))
*enddo
nsel, none
*do, indx, 1, NdCt
nsel, a,, WFnodes1(indx)
nsel, a,, WFnodes2(indx)
*enddo

real, 17
esurf ! Weld Flash

!----Code for Selecting Nodes on Concrete Touching the Surface of Weld Flash
asesel,, 124,, 1
cm, A124Nodes, node
*get, NdCt2, NODE, 0, COUNT
*dim, WFnodes1b, NdCt2
*dim, WFnodes2b, NdCt2
*do, indx, 1, NdCt2
*get, NdNum, NODE, 0, NUM, MIN
WFnodes1b(indx) = NdNum
nsel, u,, NdNum
*enddo
CSYS
esel, type, 4
nsle
*do, indx, 1, NdCt2
WFnodes2b(indx) = NODE(-1*X(WFnodes1b(indx)), Y(WFnodes1b(indx)), Z(WFnodes1b(indx)))
*enddo
nsel, none
*do, indx, 1, NdCt2
nsel, a,, WFnodes1b(indx)
nsel, a,, WFnodes2b(indx)
*enddo

type, 7
esurf ! Convex surface----> Contact

esurf ! Weld Flash

BOUNDARY CONDITIONS
CSYS

*** Symmetry BC
nsel,loc,y
d,all,uy
*** UX
esel,.type.,4
nsle
nsel,r,loc,x,8
d,all,ux
*** UZ
nsel,loc,z,-0.375
d,all,uz

=============LOADS================

*** Load
esel,.type.,3
nsle
nsel,r,loc,x,-8
d,all,ux,-0.5

allsel
esel,.type.,1,8
nsle
save

=============SOLUTION==============

/sol
auto,on
delt.,01.,0001
outy,all,all
solv