Appurtenance Influence on Type III Hanford Single-Shell Tank Structural Integrity[a] - 12255

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ABSTRACT

The interim stabilized Hanford Single-Shell Tanks (SSTs) are currently undergoing a state of the art analysis to assess the structural integrity of the waste storage tanks, for cleanup and closure operations, considering their adverse thermal histories and an updated seismic hazard for the Hanford Site near Richland, Washington. The SSTs contain a variety of ancillary pits, piping, piping supports, risers, equipment, and penetrations known as appurtenances. These appurtenances may alter the structural response and ultimately could affect the structural integrity of the SSTs. An important challenge to the structural analysis of the SSTs is to determine the impact of these appurtenances on structural integrity. To achieve this, the various appurtenances were reviewed and a bounding appurtenance configuration for the SST Type III tanks was analyzed using finite element models for both thermal and operating loads as well as seismic loads. Tank structural demands from the finite element analyses were evaluated according to American Concrete Institute (ACI-349) code requirements to determine the tank structural integrity. The appurtenances configuration is found to increase the demand to capacity ratios in local regions near the appurtenances. Away from the appurtenances the influence on structural integrity is minor.

INTRODUCTION

In response to Hanford's plutonium production, a total of 149 underground tanks were constructed between 1943 and 1964 to contain the nuclear waste in twelve separate tank farms in the 200 East and West areas of the Hanford Site. Forty-eight of these underground tanks, each with a 758,000-gallon capacity and 75-foot internal diameter, were built among four tank farms (BY, S, TX, and TY) between 1947 and 1952 and are designated as the Type III single-shell tanks (SSTs). SSTs were first used in the TX Tank Farm in 1949 [1]. By 1980, however, discharge operations to the SSTs ended pursuant with the congressional mandate. Interim stabilization was completed by 2004 when target supernate and interstitial liquid were removed from all SSTs [2].

The objective of the Single-Shell Tank Analysis of Record (SST AOR) Project is to perform a comprehensive structural analysis of record for each of the four tank types of the Hanford SSTs.

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Each SST is an underground, reinforced concrete structure with a carbon steel liner along the base and cylindrical walls. Material property data for concrete, soil, and reinforcing steel are provided in the Evaluation Criteria report [3]. The design and operating loads for the SSTs are established by their construction specifications, safety analysis reports, or other basis documents for the tank farm of interest [3]. These loads include: a soil overburden of 11-ft of 125 lbs/ft^3 density; a 200 kip surface load concentrated in a 20 ft diameter circle over the center of the tank; a 40 lbs/ft^2 uniform surface load to account for snow and ashfall; a 1.7 specific gravity waste load on the inside of the tank that varies with the waste history; a waste thermal history that peaks at 300°F; and seismic inputs appropriate for Performance Category 2 structures specific to the Hanford site (see Rinker et al. [4] for more details).

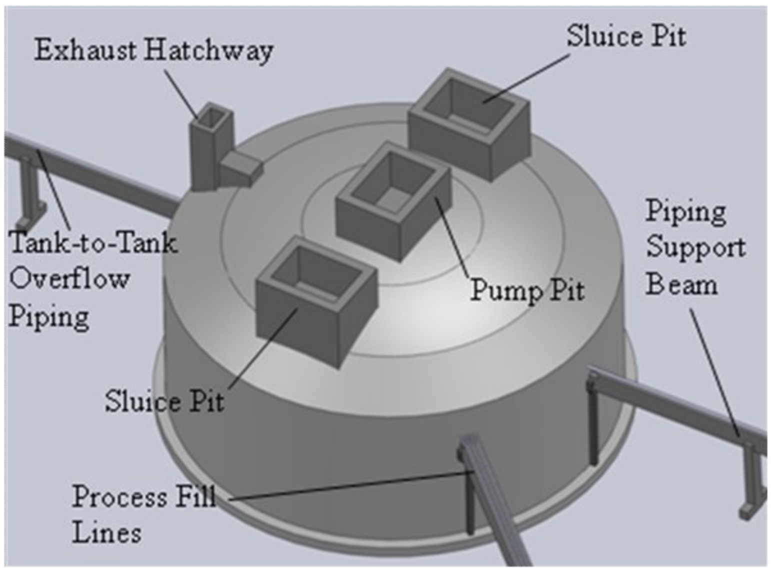

Fig 1. Typical Type III SST appurtenance configuration.

In addition to the common loadings described above, the forty-eight Type III SSTs are loaded by a variety of unique combinations of appurtenances. Fig 1 shows a Type III SST with a typical appurtenance configuration. To encompass all of the possible appurtenance combinations Type III bounding configurations were identified. For the bounding configuration two finite element models are developed: a seismic analysis model and a thermal and operating loads analysis (TOLA) model. The TOLA model includes a Type III thermal history, concrete cracking and thermal degradation, reinforcement yielding, and soil plasticity. Additionally, operating loads such as internal waste pressure and concentrated and distributed soil surface loads are applied to the TOLA model. The seismic model treats the tank concrete as linear elastic based on the present day degraded concrete properties. Also, in the seismic model the soil is treated as linear elastic while special techniques are used in the soil above the tank dome and along the tank wall to avoid soil arching and achieve the proper at-rest soil pressure on the tank walls. Seismic time histories (in the horizontal and vertical directions) are applied to the seismic model.

The American Concrete Institute (ACI) has code requirements for nuclear safety-related concrete structures (ACI-349-06) [5] that are used to evaluate the structural integrity of the SSTs. ACI-349-06 [5] recommends evaluating factored load combinations against reduced tank section capacities to account for both loading and material uncertainties. From both the TOLA and seismic models the structural demands (forces and moments) are extracted from sections throughout the tank under the appropriate load combinations. These demands are compared against the ACI-349-06 [5] capacities at each of the sections. This ratio of demand to capacity is reported as a measure of structural integrity.

The TOLA and seismic models were analyzed independently, and then selected TOLA and seismic results were combined to obtain demand-to-capacity ratios in accordance with the American Concrete Institute Code Requirements for Nuclear Safety Related Concrete Structures, ACI 349-06,[5]. The resulting demands on the FE models were compared to the capacities at various locations on the tank profile. Baseline TOLA and seismic models only considered an axisymmetric tank with axisymmetric loads (with the exception of the seismic loading being non-axisymmetric). However, there are a number of appurtenance features on the tanks that may influence the SST structural integrity which cannot be accounted for in these baseline models. To examine the role of appurtenances non-axisymmetric TOLA and seismic models were evaluated using bounding Type III appurtenance configurations.

METHOD

Type III appurtenance review

The Type III tanks have a variety of appurtenances in the vicinity of the tanks. These appurtenances include: the process fill line piping and supports; the tank-to-tank cascade overflow piping and supports; dome penetrations and risers; exhaust hatchways; pits and pit equipment; and surface pads and structures. Among the fourty-eight Type III SSTs there are many unique configurations of appurtenances. Rather than modeling and evaluating all existing configurations, a more efficient approach of evaluating a bounding configuration is taken. To do this it is first necessary to identifiy which appurtenances will have a significant impact on the structural response of the SSTs.

Rinker et al. [4], Appendix B, provided an extensive review of the Type III appurtenances. It was found that the pipe-in-pipe connections of the tank-to-tank piping and fill line piping were designed to not transfer any significant load to the tanks. Similarly, the connections between the underground pipe support beams and the tank do not allow for any significant transfer of load. Of structures on or above the the tank domes (exhaust hatchways, pits, pads, and other equipment), those identified as adding the largest net weight to the dome are considered bounding. For the Type III SSTs the net weights of all these structures are included in the dome loading records [6-9]. A central pump pit with a net weight of 23.2kips and two offset sluice pits each with a net weight of 58.8kips were identified as the bounding pit appurtenances. The penetrations in the Type III SSTs were similar to those analyzed in the Type II AOR [10] thus no analysis of penetrations on Type III SSTs was warranted.

Type III appurtenance models

The Type III appurtenance review identified the need to analyze the structural integrity of a tank with a central pump pit (net weight 23.2 kips), and two offset sluice pits (each with a net weight of 58.8 kips). A symmetric model is set up in order to allow less than a full tank to be modeled as shown in Fig 2. The symmetry allows only 1/4th of the tank – or a 90° slice – to be actually modeled for the TOLA model. The offset pit in the TOLA model is aligned with the 0° boundary. With this symmetric arrangement however, the seismic model could produce different results based on whether the offset pits are arranged along the 0° to 180° boundary or arranged at the 90° slice depending on the direction of the seismic induced horizontal ground motion.

Error! Reference source not found. shows an isometric view of part of the TOLA finite element model. The 1/4th of pump pit is shown in red over the center while one-half of the offset sluice pit is shown in blue. These pits rest on the tank dome. The tank concrete is shown in several different colors representing the different material degradations experienced by the concrete that was exposed to different peak temperatures. The soil layers around the buried tank are also shown. The finite element mesh used to discretize the solution to the displacements, stresses, and strains, in and around the tank is shown as black lines in Fig 3. Fig 4 shows part of the two seismic models used, including the soil directly above the dome and the pump pit and sluice pits. The sluice pits are shown in blue and the pump pit is shown in pink. The different soil layers used above the tank dome are also shown as different colors. Again, the finite element meshes used for both seismic models are shown as black lines in Fig 4.

No such configuration exists on the Type III tanks; the actual configuration modeled is conservative. The total concentrated load on the soil surface is then reduced by the total net weight of all the pits on the tank in accordance with the current Tank Farm dome load control requirements. The total height of the overburden soil is maintained at 11 ft above the dome apex. The other typical loads described in the Introduction section are applied as well. Aside from the presence of appurtenances, which can only be modeled with non-axisymmetric models, there are some other differences between the baseline and appurtenance models. Because of its large size, the TOLA appurtenance model takes a long time to solve. To reduce solution time, a simplified thermal history without concrete creep was used. In contrast the baseline TOLA model used a very detailed thermal history. Both thermal histories peak at 310°F. Several baseline TOLA models were run, including one without concrete creep which can be used for comparison in most cases, but the seismic models were all run with concrete properties that included creep.

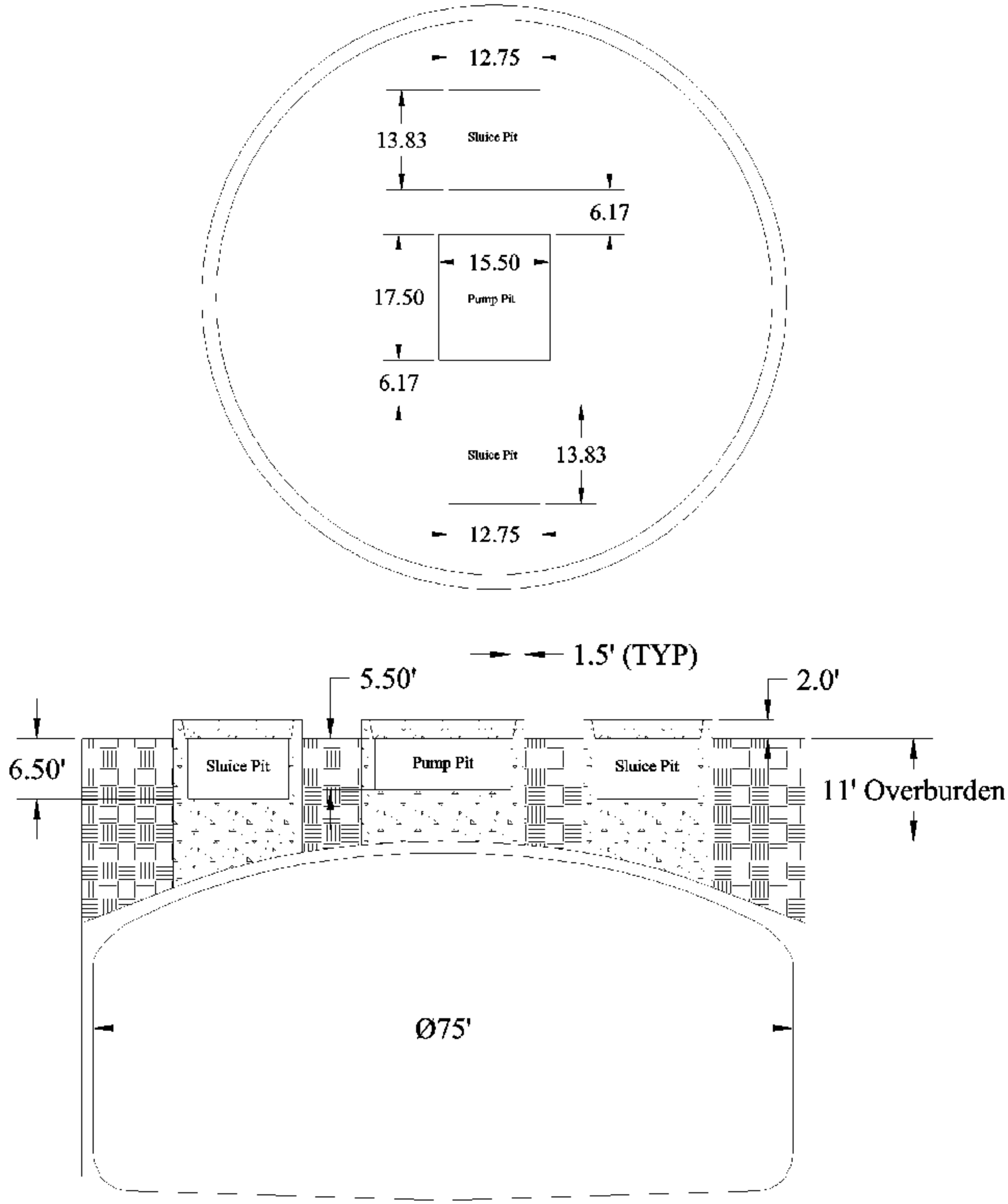

Fig 2. Type III SST appurtenance configuration evaluated in appurtenance model. Dome plan view (top). Tank section centerline cut view (bottom). Dimensions shown are in ft.

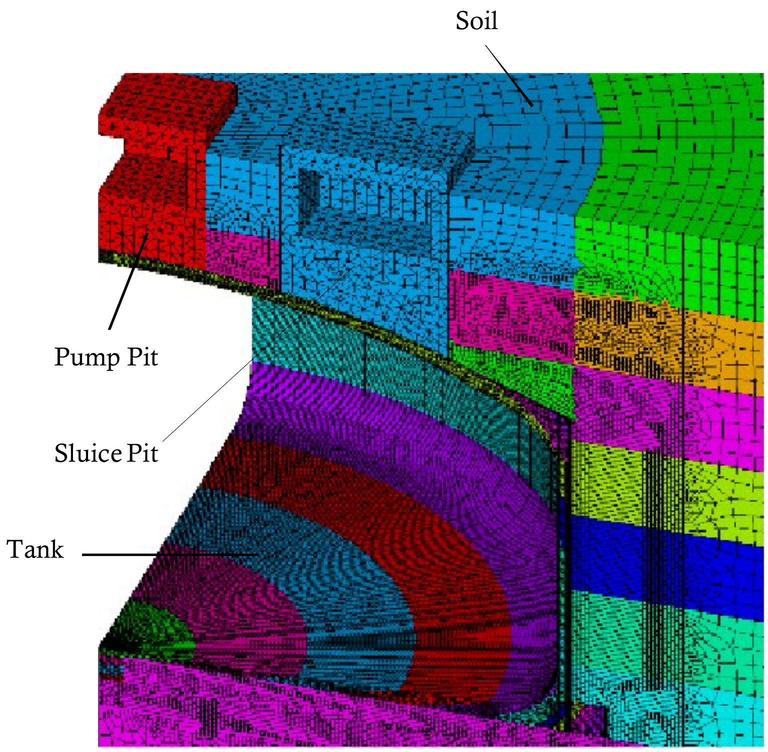

Fig 3. Close up isometric view of the Type III TOLA appurtenance model showing pits, tank, and soil along with the finite element mesh used.

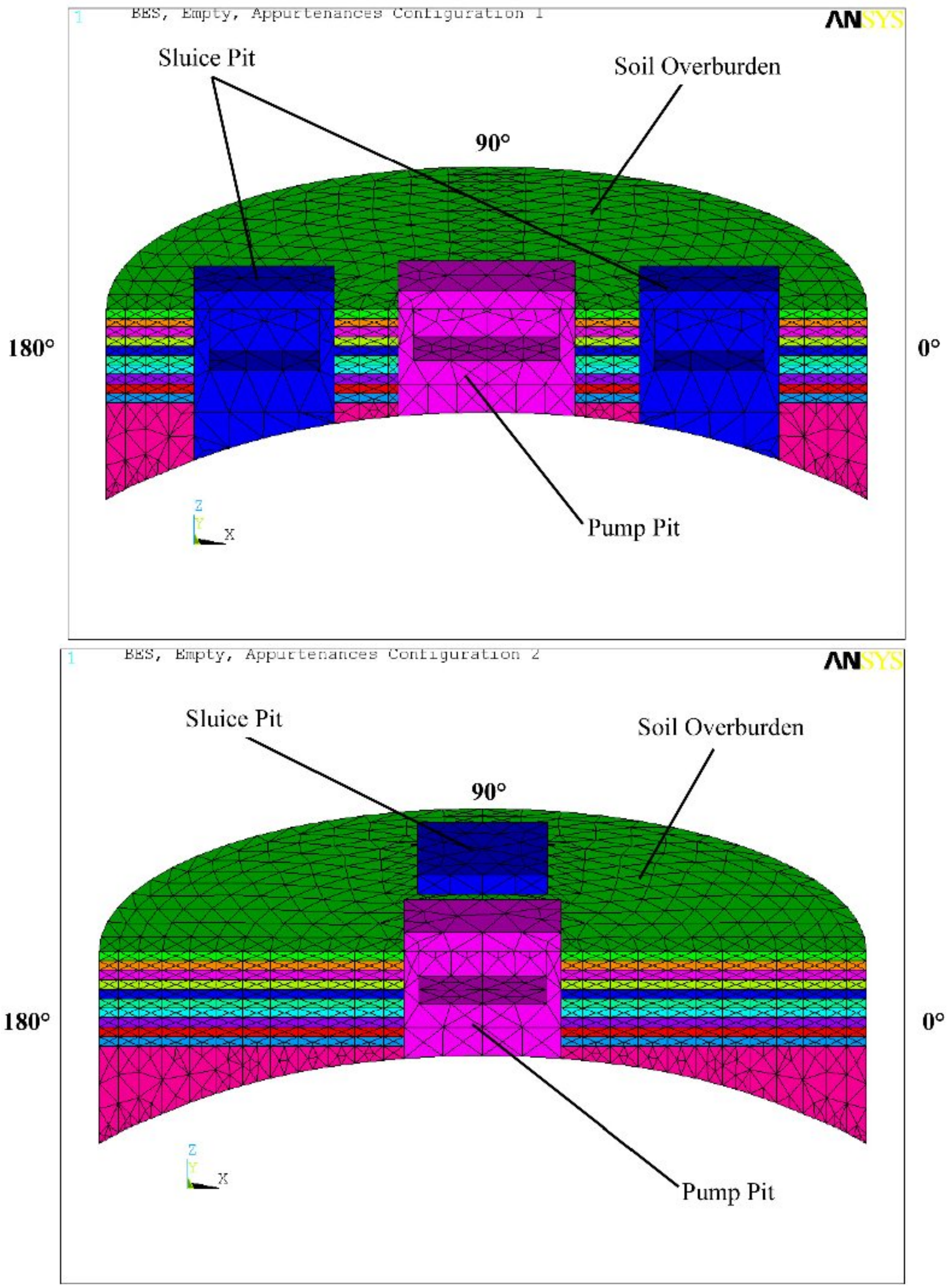

Fig 4. Above the dome portions of the Type III seismic appurtenance models showing the pits and overburden soil along with the finite element mesh used.

ACI-349 tank evaluation

To evaluate the structural integrity of the tanks the ACI-349-06 [5] code requirements are used. A set of demands, forces and moments, on a section of reinforced concrete is compared to the corresponding section capacity. ACI-349-06 [5] calls for both an increase in the demands, through factored load combinations, and a decrease in capacities, through strength reduction factors. Johnson et al. [3] and Rinker et al. [10] determined there are three applicable factored load combinations from Appendix C of ACI-349-06 for the SST AOR:

Load Combination 1 (LC1)	U = l.4D + 1.4F + 1.7L + 1.7H
Load Combination 4 (LC4)	$U = D + F + L + H + T_o + E_{ss}$
Load Combination 9 (LC9)	$U = 1.05D + 1.05F + 1.3L + 1.3H + 1.05T_o$

where
- U = Total factored load combination
- D = Dead loads including tank self weight, piping and equipment dead loads. (Where the structural effects of differential settlement, creep, or shrinkage may be significant, they shall be included with the dead load D.)
- L = Live loads, including impact effects of moving loads
- F = Lateral and vertical pressure of liquids
- H = Loads due to weight and pressure of soil, water in soil, or other materials, or related internal moments and forces
- T_o = Internal moments and forces caused by temperature distribution within the concrete during normal operation and shutdown
- E_{ss} = Safe Shutdown Earthquake (SSE) effects = Design-Basis Event/Earthquake (DBE) effects

The capacities of the concrete sections are reduced by factors described in Appendix C of ACI-349-06 [5] ranging from 70% to 90% of the full section strength:

- Tension-controlled sections 0.90
- Compression-controlled sections
  - Members with spiral reinforcement 0.75
  - Other reinforced members 0.70
- Shear and torsion 0.85
- Bearing on concrete 0.70

Since the section capacity depends on the section geometry as well as the maximum temperature experienced by the concrete each slice of the tank is divided into 44 sections as shown in Fig . Sections 1-13 are located in the tank dome. Sections 11-15 are in the haunch. Sections 16-30 are in the wall. Sections 31-44 are in the tank outer footing and slab. For the TOLA model, these 44 sections are evaluated on each slice from the 0° boundary (boundary containing offset pit) to the 90° boundary in 3° increments. For the seismic models these 44 sections are evaluated from the 0° boundary to the 180° boundary in 9° increments consistent with the element mesh.

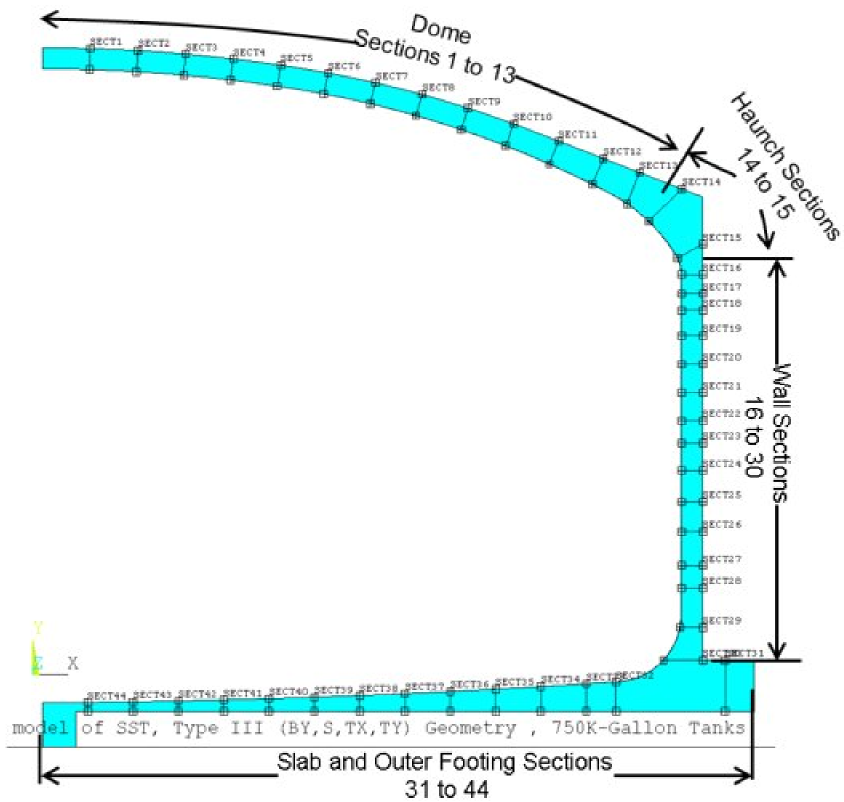

Fig 5. Type III tank section locations evaluated for structural integrity according to ACI-349-06. Sections 1-13 are in the dome; 14 and 15 are in the haunch; 16-30 are in the wall; and 31-44 are on the outer footing and slab.

For each load case combination (LC1, LC4, and LC9) the factored loads (demands) are compared to the section capacities to produce a demand/capacity (D/C) ratio. A D/C ratio less than or equal to 1.0 indicates that the tank meets the structural requirements of ACI-349-06 at that section. A D/C ratio greater than 1.0 indicates that the tank does not meet the requirements of ACI-349-06 at that section.

RESULTS

The Type III appurtenance models were evaluated under the applicable ACI-349-06 [5] factored load case combinations. Force and moment demands (in hoop, meridional, shear directions) are extracted from the TOLA appurtenance model at each tank section shown in Fig 5 for every 3° increment from the 0° model boundary to the 90° model boundary. The tank capacities at each section depend on the concrete and reinforcing steel in that section. ACI-349-06 code provides guidance on how these demands are to be calculated for each direction. Figs 6-8 show the resulting ACI-349-06 D/C ratios for LC1, LC9, and LC4 respectively along the vertical axes. In each figure one horizontal axis indicates the tank section number (ranging from 1 to 44) as detailed in Fig 5. The other horizontal axis indicates the hoop location along the tank which ranges from 0° to 90°. For reference the offset pit is located along the 0° boundary. A higher D/C ratio indicates that the particular tank location is supporting a load closer to its structural capacity. As long as these ratios are less than 1.0 the SSTs are considered structurally sound. This is the case, other than in the slab region, as shown in Figs 6-8.

In general, Figs 6-8 show that LC1 produces the highest D/C ratios. This is expected as LC1 has the highest load factors of the three load combinations evaluated. This also indicates that the factored thermal load T_o, and earthquake load E_{ss}, found only in load combinations LC9 and LC4 respectively are not as significant as the dead, live, soil, and waste loads found in all three load combinations.

In general, Figs 6-8 also show that in the through wall shear direction there are four critical sections as indicated by peaks in the D/C ratios; one in the dome before the haunch, one in the top of the wall below the haunch, one in the outer footing, and one in the slab just inside of the wall. In the meridional direction there are two critical sections; one at the top of the wall, and one at the bottom of the wall. In the hoop direction shows that several consecutive sections from the dome outside of the haunch, through the haunch, and to the top of the wall are critical. All of these peaks are nearly uniform across all the angles (from 0° to 90°) indicating that the presence of the pits have little effect on the structural integrity of these sections. The in-plane shear D/C ratios are generally small and reveal no critical sections. The LC4 seismic loading case shows some different behavior in the slab sections.

Fig shows the ACI-349-06 D/C ratios in through wall shear, meridional, and hoop under LC1. The in-plane shear was calculated but not shown here as the ratios were extremely low. All of the through wall shear, meridional, and hoop D/C ratios are less than 1.0. All three D/C ratios show that there is only a very minor effect of the pits – as evidenced by the relatively uniform ratios across all the angles from 0° to 90° for a given section number.

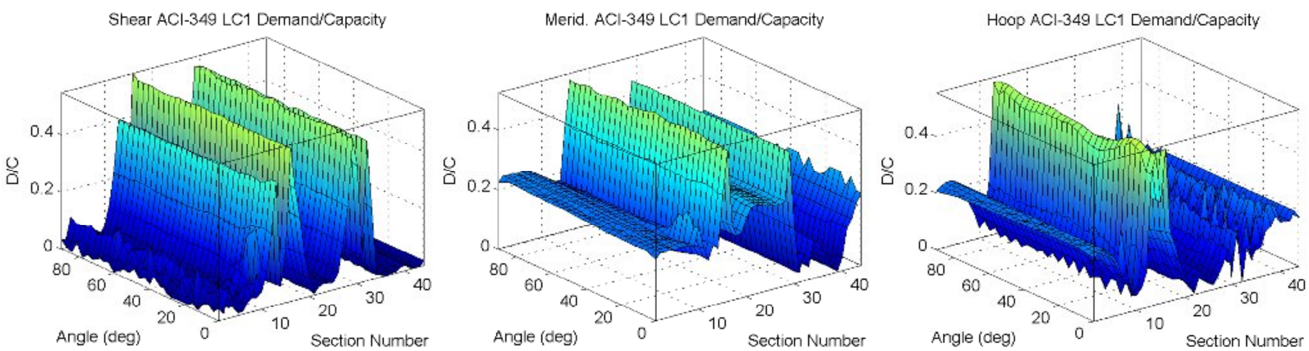

Fig 6. Type III LC1 Demand/Capacity Ratios (left shear; middle meridional; right hoop)

Fig shows the ACI-349-06 D/C ratios for LC9 in the through wall shear, meridional, and hoop directions. Again, the in-plane shear ratios are not shown as the values were extremely low. All the D/C ratios for LC9 are also less than 1.0. The influence of the pits is minimal as evidenced by the relatively uniform ratios across all the angles for a given section.

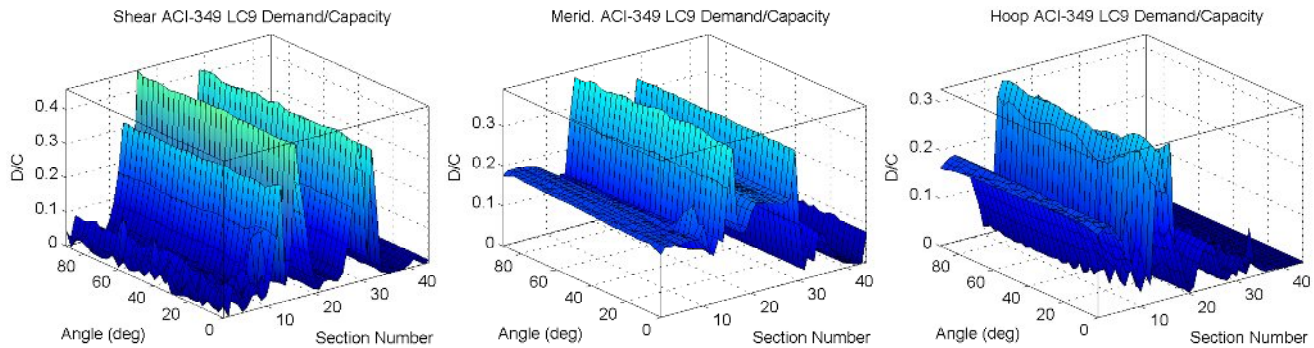

Fig 7. Type III LC9 Demand/Capacity Ratios (left shear; middle meridional; right hoop)

Fig shows the ACI-349-06 D/C ratios for LC4 in the through wall shear, meridional, hoop, and in plane shear directions. By symmetry the TOLA 90°-model demands are mirrored and repeated to match the seismic 180° model locations. Here, because of the two seismic geometry models needed to account for the arbitrary direction of the seismic induced horizontal ground motion, the maximum absolute value demands from either seismic geometry model over all of the angles (from 0° to 180°) were combined with the angle specific TOLA demands (instead of using the angle specific seismic demands with the angle specific TOLA demands). This approach conservatively uses the largest seismic demand experienced in any slice in each section. Again, the worst D/C ratios from all the possible positive and negative seismic induced demand combinations are reported here. As seen in Fig all the through wall shear, meridional, and in plane shear D/C ratios are less than 1.0. The hoop D/C ratios are greater than 1.0 in the slab. However, as demonstrated with the slab removal studies in Rinker et al. [4], the slab could be removed entirely and the rest of the tank would remain structurally sound and stable. Although there is some influence on all four D/C ratios in the dome and haunch from the presence of the offset pits, generally the ratios remain close to uniform over all the angles for a given section.

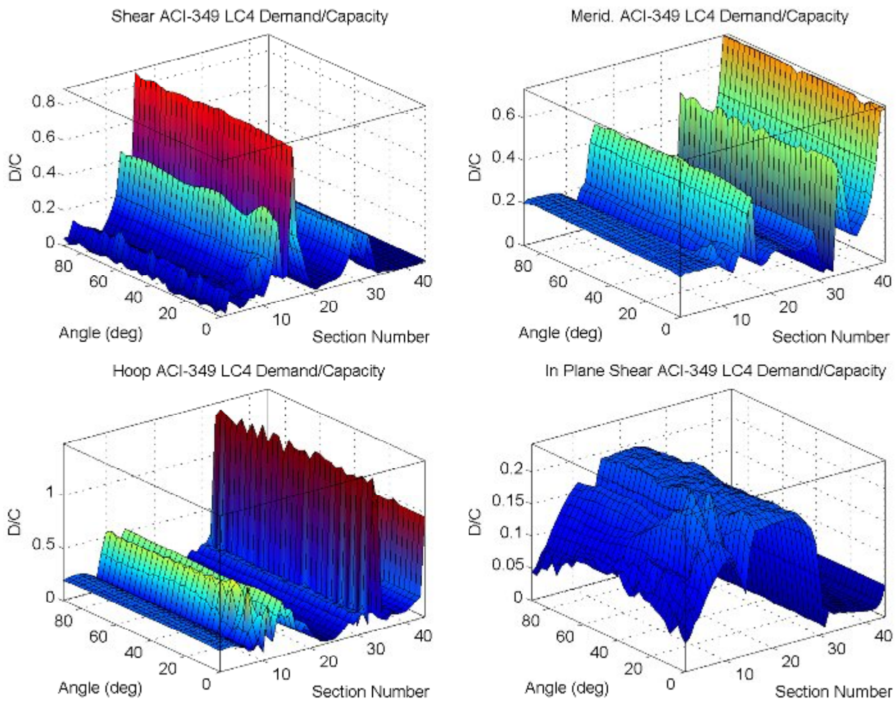

Fig 8. Type III LC4 Demand/Capacity Ratios (top left shear; top right meridional; bottom left hoop; bottom right in-plane shear)

DISCUSSION

After reviewing the appurtenances on Type III SSTs, a bounding appurtenance configuration was selected and modeled using the ANSYS®[11] finite element software. These models were subjected to the typical TOLA and seismic loads and evaluated under ACI-349-06 factored load case combinations. The reported D/C ratios show that the appurtenances did not depreciate the structural integrity of the tanks. All the D/C ratios are less than 1.0 with the exception of LC4 ratios in the hoop direction of the bottom slab, which was shown in the Type III AOR [4] to leave the tank structurally sound and stable even if the slab is assumed to be disconnected at the location with the D/C > 1.

Furthermore, a comparison of the appurtenance D/C ratios shown here with the D/C ratios without the pits shown in Chapters 8 and 9 of the Type III AOR [4] reveals the effect in both location and magnitude of including the pit appurtenance. It should be noted, there are differences between the appurtenance TOLA models and the baseline models. Because of its large size, the appurtenance model was given a much simpler thermal history than the baseline model, though both models peaked at 310°F. Additionally, the appurtenance model used larger element sizes and a different post-processing routine to extract forces and moments from the tank sections. Finally, the LC4 baseline TOLA model included concrete creep, which tends to reduce the overall concrete stresses, while the appurtenance model did not include creep.

Generally, the D/C ratio trends between corresponding load combinations are similar with the greatest increases in D/C ratios near the central and offset pits. Away from these pits the differences between the D/C ratios with pit appurtenance and ratios without pits become minor.

Table I below summarizes the approximate percent change in the peak D/C ratios along the dome and upper haunch region(sections 1-15 in Fig. 5) of the tank with pits modeled relative to the baseline results without pits directly modeled. Table I shows that the presence of pits increases the peak through wall shear D/C ratios in all three load combinations, including +60.4% for LC4. The change in the peak meridional D/C ratios is minor for LC1 and LC9 but +44.9% for LC4. The hoop D/C ratios decreased for all three load combinations.

Table I. Percent change in peak D/C ratios along dome and haunch region with pits relative to baseline results without pits modeled.

Load Combination	Shear (thru-wall)	Meridional	Hoop	Baseline results figure (Type III AOR [4])
LC1	+4.9%	-1.8%	-19.2%	Figure 8.15
LC4	+60.4%	+44.9%	-11.3%	Figure 9.34*
LC9	+4.7%	-2.34%	-21.6%	Figure 8.17

*Baseline model for LC4 included concrete creep.

The decrease in the hoop D/C ratios is likely due to the aforementioned differences between the baseline and appurtenance TOLA models (though further studies would be needed to determine this). However, the differences in the shear and meridional D/C ratios are significant for LC4. For Type III tanks, the bounding appurtenance configuration passed ACI-349-06 standards for structural integrity. The differences in D/C ratios are significant, particularly under seismic loading, indicating that it is necessary to explore the structural integrity effect of appurtenances in all SST AORs.

CONCLUSIONS

The ACI-349-06 evaluation of the Type III SST bounding appurtenance configuration shows the tank is still structurally sound under all evaluated load combinations. When the appurtenance model D/C ratios were compared to those from the baseline axisymmetric model it was found that there were significant differences in the results, particularly under seismic loading conditions. This indicates that the effect of appurtenances on tank structural integrity should at least be considered in all SST AORs.

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