PSEG Nuclear LLC
P.O. Box 236, Hancocks Bridge, New Jersey

PSEG

DEC 1 4 2001

LRN-01-0377

U. S. Nuclear Regulatory Commission
Document Control Desk
Washington, DC 20555

Gentlemen:

REFUELING WATER STORAGE TANK
SALEM GENERATING STATION UNIT 1
DOCKET NO. 50-272

The purpose of this letter is to discuss PSEG Nuclear's compliance with the provisions of IWB-3142.4 of the ASME Code, which may be used to determine the acceptability for continued service of the Salem 1 Refueling Water Storage Tank (RWST).

Salem is committed to the 1995 edition of the ASME Code, including the 1996 addenda. This version of the code includes provision IWB-3142.4, which states that components containing relevant conditions shall be acceptable for continued service if an analytical evaluation demonstrates the component's acceptability.

PSEG contracted MPR Associates to perform bounding calculations for the RWST flaw. They performed area reinforcement calculations and fracture mechanics analyses for postulated worst case cracks located behind the penetration reinforcing pad. These analyses show that for the most severe flaw scenario, even if the postulated worst case cracks were present, structural integrity of the RWST would be retained and sudden catastrophic failure of the RWST due to the crack propagation would not be expected. These calculations are attached in accordance with the provisions of Section IWB-3144 of the ASME Code.

The Salem 1 RWST is in a condition that is similar to a previous condition at South Texas Project. At that time, South Texas Project was committed to the 1983 Edition, Summer 1983 Addenda, of the ASME Code, which did not contain the provision that is in IWB-3142.4. Therefore, South Texas Project submitted a relief request from IWA-5250(a) of ASME Section XI, 1983 Edition, Summer 1983 Addenda, to disposition a through-wall leak in their RWST in accordance with IWB-3142.4 of the 1989 Edition of the ASME Section XI Code. This relief request was approved on June 22, 2000. The approval of the relief request

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Rec'd from NRC 03/12/02

enabled South Texas Project to use a provision of the ASME Code that is already incorporated into Salem's licensing basis.

Based on the above, PSEG Nuclear believes that it is appropriate to use the provisions of IWB-3142.4 to determine that the RWST is acceptable for continued service by the performance of an analytical evaluation that demonstrates the component's acceptability. IWA-5250 states that repair or replacement of components shall be performed in accordance with IWA-4000, but does not specify a timetable. Our current plans are to repair the flaw in the RWST line during the next refueling outage.

If you have any questions or comments on this submittal, please contact Robin Ritzman at (856) 339-1445.

Sincerely,

for Gabor Salamon
Nuclear Safety and Licensing Manager

Attachments

MPR
ASSOCIATES INC.
ENGINEERS

September 17, 2001

QUALITY ASSURANCE DOCUMENT
This document has been prepared, reviewed, and approved in accordance with the Quality Assurance requirements of 10CFR50, Appendix B, as specified in the MPR Quality Assurance Manual.

Prepared by: ____________
Reviewed by: ____________
Approved by: ____________

Mr. Don Longo
PSEG Nuclear
PO Box 236
Hancocks Bridge, NJ 08038

Subject: Salem RWST Nozzle Evaluation for Postulated Cracks

Dear Mr. Longo:

Attached is our evaluation of the implications of postulated cracks in the Salem Unit 1 RWST near the main outlet nozzle. As described in the attached report, we performed fracture mechanics and stress analyses for postulated worst case cracks located behind the penetration reinforcing pad. These analyses show that even if the postulated worst case cracks were present, structural integrity of the RWST would be retained and sudden catastrophic failure due to the crack would not be expected. As a result, we consider the RWST is safe to operate until the next refueling outage when repairs can be performed.

If you have any questions or need additional information, please feel free to call.

Sincerely,

Robert N. Coward

Attachment

cc: D. Bhavnani
T. Roberts

MPR
ASSOCIATES INC.
ENGINEERS

Attachment to
MPR Letter Dated
September 17, 2001

Salem RWST Nozzle Evaluation for Postulated Cracks

INTRODUCTION

Purpose

The purpose of this analysis is to evaluate the implications of a crack in the RWST wall and/or welds behind the reinforcing pad for the main outlet nozzle penetration. Fracture mechanics and stress analyses are performed to demonstrate that, even if the worst case expected crack were present, the presence of the crack is acceptable. Structural integrity of the RWST is maintained and sudden failure resulting from crack growth would not occur.

Background

Evidence has been discovered that the Salem RWST may have a through wall leak in the vicinity of the main outlet nozzle penetration. The evidence includes wetness on the penetration reinforcing pad tell tale hole and contamination detected on the ground in the vicinity of the nozzle. PSEG Nuclear considers that the likely mechanisms for any degradation of the RWST are corrosion or original fabrication defects (e.g., weld porosity). However, the potential for the leakage to be caused by cracking can not be ruled out conclusively. The potential for cracking is important since the presence of a crack could potentially lead to a sudden catastrophic failure of the RWST, while corrosion or weld defects would not.

CONCLUSIONS & RECOMMENDATIONS

Conclusions

The nature of the flaw in the RWST behind the outlet nozzle reinforcement pad is not known. Based on the constraints on inspection during service, the flaw cannot be inspected at this time. Therefore, the flaw evaluation must assume credible worst case flaw scenarios for flaws that could exist under the reinforcement pad.

There are two crack scenarios which are considered to be credible. The first is a linear flaw that begins at the nozzle to shell weld and is aligned along the axial or longitudinal direction of the shell. The second is a crack that extends fully around the nozzle (360°) in the nozzle to shell weld. Each of these is discussed below:

Linear Flaws

An axial or longitudinal crack, that originates at the nozzle to shell weld and extends axially or longitudinally away from the nozzle is naturally limited in size because of the reinforcing pad. The flaw cannot be any larger that the region covered by the pad, or else the flaw would be directly detectable by leakage thought the shell wall.

The limiting criteria for the linear crack is the potential for sudden crack growth leading to failure of the RWST. Fracture mechanics calculations indicate that the critical crack size is significantly larger that the biggest linear defect that can exist underneath of the reinforcement pad. Therefore, significant crack growth and sudden RWST failure will not occur.

Circumferential Flaws

The worst case postulated circumferential cracks at the RWST main outlet nozzle is a circumferential crack that extends fully around the nozzle (360°) at the nozzle to shell weld. The nozzle to reinforcement pad weld can be examined by NDE to ensure that the flaw does not extend into the weld.

The limiting criteria for the circumferential crack is maintaining structural integrity of the RWST if the reinforcing pad carries all load at the nozzle location (i.e., if the nozzle to shell weld has been removed). For normal and seismic loads, the stresses in the RWST wall and the reinforcing pad are less than the most conservative Service Level A limits, so structural integrity of the RWST is maintained.

In summary, the RWST is acceptable for continued operation until repairs can be made, even with postulated worst case through-wall cracks behind the reinforcing pad.

It should be noted that the analyses performed for this evaluation included the assumption that any existing cracks remain within the extent of the main nozzle reinforcing pad. If cracks grow and extend beyond the reinforcing pad additional analysis or immediate repairs will be necessary.

Recommendations

Based on the key conclusions listed above and the analyses performed to support the evaluation, MPR recommends that PSE&G continue to operate the Unit 1 RWST "as-is" until the next refueling outage (when repairs will be made). To ensure safe operation, until that time, MPR recommends the following additional actions:

- Continue to perform regular walkdown visual inspections of the RWST outlet nozzle and monitor leakage flow to ensure that no unexpected increases in leakage are occurring. This will also ensure that any linear flaws have not extended beyond the reinforcement pad.

- Perform NDE of the accessible welds on the outside of the RWST wall. This should include PT of the reinforcement pad to shell weld, and PT or UT (if possible) of the nozzle to reinforcement pad weld. The will ensure that enough weld remains to carry the nozzle loads in the event that the nozzle to shell weld has failed.

As part of the repair effort, MPR recommends that PSE&G prepare for repair or replacement of the outlet nozzle at the next refueling outage. Specifically:

- Initiate plans to repair the Unit 1 RWST during the next refueling outage. The repair procedures should preserve the likely location of the material degradation for future analysis.

- After the RWST repairs, perform failure analyses of the removed section of the RWST to determine the actual degradation mechanism(s).

- Based on the degradation mechanism, evaluate the need for additional actions related to the Unit 2 RWST.

DISCUSSION

Configuration

The RWST is an approximately 38 feet in diameter, about 48 feet tall. The main outlet nozzle (suction for the SI system) is located near the bottom of the tank. The bottom of the nozzle is only 2 inches above the bottom of the tank (and the ground). The penetration is 20 inches in outside diameter. The penetration includes a reinforcing pad around the nozzle. Due to the close proximity of the bottom of the tank, the reinforcing pad is not symmetric about the nozzle horizontal centerline. The top of the reinforcing pad is 3.5 inches from the nozzle, and this dimension is maintained for the area above most of the penetration. Below the centerline, the reinforcing pad is a constant 26 inches wide (in the circumferential direction) and extends to the bottom of the tank.

The RWST wall and the main outlet nozzle are fabricated from SA-240 Type 304 stainless steel plates. The RWST is anchored to the concrete pad with large diameter anchor bolts. The anchors are attached to the tank at two local stiffeners and a ring brace near the bottom. The outlet nozzle is located in between two sets of stiffeners. The general configuration is shown in Figure 1.

Applicable Codes

The RWST was specified (Reference 1) to meet the requirements of AWWA standard for welded steel tanks and Section III of the ASME Code (as of 1974). PSEG Nuclear has stated that there interpretation is that the vessel is comparable to Code Class 3 (Subsection ND); however, this operability analysis will be conducted to Subsection NC, which provides rules for design by analysis.

Approach

The implications of postulated cracks in the RWST wall behind the main outlet nozzle reinforcing pad are evaluated using a combination of fracture mechanics and stress analyses. The overall goal is to determine the worst case postulated crack and then demonstrate that the RWST is acceptable for continued operation in the postulated degraded condition. The evaluation is performed using a standard fracture mechanics analysis approach. The key elements of this approach include:

1. Define the orientation and size of the postulated worst case crack(s).

2. Consider potential crack growth during the remaining operating cycle based on the stresses at the postulated crack locations during normal and upset conditions.

3. Calculate the critical crack sizes for the postulated crack locations (once again based on the stresses during normal and upset conditions).

4. Compare the postulated worst case crack size to the critical crack size (to show that the critical crack size is greater than the expected crack size). This demonstrates that the RWST will not fail in a sudden, catastrophic manner due to crack extension.

Stress analyses are also performed to demonstrate that the outlet nozzle was structurally adequate if the entire nozzle to shell weld is cracked.

Worst Case Crack(s) Configuration

If a crack is present in the RWST near the main outlet nozzle, it would be a through-wall. Such a crack would allow flow from the inside of the tank to the outside. Because a detailed flaw assessment cannot be performed, an assumed worst case crack is selected based on an evaluation of the RWST configuration and potential cracking mechanisms.

Two postulated cracks were identified for evaluation. These cracks are described below.

- Linear crack at the top of the nozzle – This postulated crack would be oriented vertically and extend from the top of the main outlet nozzle to the edge of the reinforcing pad (as shown in Figure 2). The crack is assumed to initiate in the heat affected zone of the wall material at the nozzle/wall weld and grow vertically. Growth of the crack out of the heat affected zone is considered unlikely, but is conservatively assumed for this evaluation. The crack is assumed to extend to the edge of the reinforcing pad. Larger cracks are not credible, because they would be visible from outside the tank.

  This crack has the potential to "unzip" the tank wall and cause a sudden failure. The potential failure mode is brittle fracture or plastic tearing.

- Circumferential crack around the nozzle to shell weld - This postulated crack would be oriented circumferentially around the main outlet nozzle. The crack is assumed to initiate in the heat affected zone of the wall material at the nozzle/wall weld and grow circumferentially staying within the heat affected zone.

  This crack would not lead to a sudden unzipping of the tank. Instead, complete circumferential cracking of this weld would transfer all of the load from the tank wall to the reinforcing pad. The potential failure mode is ductile overload of the reinforcing pad.

Crack Growth

Normally, evaluations of critical crack sizes are performed for the crack size expected at the end of the current operating period (e.g., at the next refueling outage). However, for postulated cracks in the RWST it is not necessary to consider additional crack growth. Two worst case cracks have been identified and are evaluated. One is a circumferential crack around the main outlet nozzle. For this case it is assumed the crack has grown fully around the nozzle and can not grow any more. The second case is a crack that runs from the top of the nozzle vertically to the limit of the reinforcing pad. If this crack were to grow past the reinforcing pad the regular visual inspections of the penetration (to inspect for leakage) would identify the crack growth. If a crack were to grow outside the reinforcing pad, additional analysis or immediate repairs would be necessary.

Thus, consideration of crack growth during operation is not necessary for this evaluation.

Linear Crack Evaluation

The postulated worst case vertical crack is located in the RWST wall between the top of the main outlet nozzle and the top of the reinforcing pad. This is a length of 5 inches. However, one edge of this postulated crack ends at the nozzle penetration (i.e., a hole in the wall). This hole will effectively extend the crack. Thus, for the purposes of fracture mechanics analyses and evaluating this postulated crack, the hole diameter is added to the crack length. Including the penetration hole, the total crack length is 25 inches.

The evaluation of this crack is provided in MPR Calculation 108-149-02, which is provided in Appendix 1. The calculation includes the fracture mechanics calculations that show the postulated worst case crack is considerably shorter than the critical crack size. As a result, sudden failure of the RWST due to crack extension will not occur. A summary of the analysis performed is provided below.

The RWST procurement specification limits the stresses in the RWST walls to 0.9 S_y under all loading conditions (including pressure, seismic, attached piping loads, etc.). Therefore, the stress in the shell is conservatively set to the maximum permitted in the original design specification.

The critical crack size is determined by calculating the stress intensity factor, K_I (from linear elastic fracture mechanics), and comparing the calculated stress intensity factor to the material critical stress intensity factor, K_{IC}. Since the ligament beneath the penetration is assumed to remain intact, the postulated crack is a double edged crack in a plate.

Since austenitic stainless steel is very ductile at all temperatures, there is not a clear value for K_{IC} (like there is for carbon steels). Available test data shows that stainless steel is susceptible to significant crack extension at J_{IC} values over about 405 kJ/m^2, which corresponds to a K_{IC} of 257 ksi$\sqrt{in}$.

For a membrane stress of 0.9S_y, an infinite plate with the double edged crack, and a K_{IC} of 257 ksi$\sqrt{in}$, the calculated critical crack size is 61.8 inches. Based on the geometry, the largest linear crack that could exist under the reinforcement pad is 25 inches. Therefore, it is not possible for a sudden failure to occur, without the linear crack first growing beyond the region under the reinforcement pad.

Circumferential Crack Evaluation

The postulated worst case circumferential crack extends fully around the outlet nozzle and severs the weld between the RWST shell wall and the nozzle. Under this scenario, the reinforcing pad must support the entire pressure ejection load and to carry essentially all of the other loads on the RWST wall (seismic, pipe reaction, etc.). Because of the adjacent stiffeners and flange at the nozzle, the only credible failure mode is an overload failure at the penetration due to pipe nozzle loading.

The limiting criteria for this crack is not crack growth (since the crack has extended fully around the nozzle). Nondestructive examination (NDE) of the nozzle to reinforcement pad weld and the reinforcement pad to shell weld are possible from the exterior of the tank. Assuming that these two welds are inspected and shown to be intact, it is only necessary that the structural integrity of the RWST be maintained in this configuration.

The ANSYS general-purpose finite element program was used to develop a three-dimensional solid model of the penetration nozzle, reinforcing pad and adjacent tank. A linear, static analysis was performed for combined internal pressure and DBE (Design Basis Earthquake) seismic piping loads. This is a faulted loading condition, which is Service Level D. As discussed below, this load combination was evaluated to Service Level A stress limits. Therefore, this Load Combination bounds all other Load Combinations.

The finite element model of the RWST includes the nozzle, reinforcing pad and a 20° segment of the tank wall and the tank wall stiffeners. The solid model was meshed with 10-node tetrahedral finite elements. The tank wall is modeled up to a height of 4 feet. The fillet weld between the outside edge of reinforcing pad and the tank wall is modeled explicitly. The fillet on the full penetration weld between the nozzle and the reinforcing pad is not included. The full penetration weld between the nozzle and the tank wall is modeled as completely failed. Therefore, there is no direct connection between the shell and the nozzle. The load path is from the nozzle, to the reinforcement pad, to the shell wall. This model is shown in Figure 1

The calculated stresses from the model were linearized through the thickness of the components to determine the membrane and bending components of the primary and secondary stresses. The linearized stress results were compared to the applicable stress limits to perform the Code stress evaluation.

The RWST was specified to meet the requirements of the latest AWWA (American Water Works Association) Standards for Welded Steel Tanks, and Section III of the ASME Code. For this assessment, the procedure for design by analysis in the 1974 ASME Code, Section III, Division 1, Subsection NC is used. The allowable stress for the SA-240 tank material is 20 ksi. The stress limits for Service Level A are conservatively applied to assess the adequacy of the outlet nozzle, tank shell, and reinforcement pad.

The analysis results shows that, in all cases, the calculated stresses are less than the Service Level A allowable.

REFERENCES

1. PSE&G Detail Specification No. 70-7148, including Addendum 1.

APPENDICES

1. MPR Calculation 108-249-02, Revision 0, "Evaluation of RWST Main Outlet Nozzle Postulated Linear Crack"

2. MPR Calculation 108-249-03, Revision 0, "Finite Element Analysis of Outlet Nozzle"

FORM-1

VENDOR INFORMATION

PSEG NUCLEAR LLC VTD NUMBER: 325107

- [X] ACTIVE — Approved Documentation
- [ ] APCP — Approved, Pending Change Package (May only be used for Rev. 1)
- [ ] CAN — Canceled, Not Required
- [ ] VOID — No longer applicable, superseded by : ____________________

Discipline Selection

[ ] Electrical [ ] I&C [ ] Mechanical [X] Other Specify: ____________________

Safety Related: [X] Yes [ ] No

Unit Applicability

[X] Salem 1
[ ] Salem 2
[ ] Salem 3
[ ] Salem Common
[ ] Hope Creek
[ ] Hope Creek & Salem
[ ] PSEG Nuclear LLC

System / Title: SALEM RWST NOZZLE EVALUATION FOR POSTULATED CRACKS SAP Sys Code: ____________

Vendor Name: MPR ASSOCIATES INC.

Vendor Code: 139M Vendor No.: 108-249-02

Vendor Category: ____________ (Category Codes are listed in DCRMS.)

Purchase Order No. ____________________

Material Master: ____________________

Originator: DILIP BHAVNANI Dept: MECH. Group: STRESS / CIVIL

Date: 9-18-01 Ext: 1828

If changes are made to this form, initial and date the change and document in the revision summary.

FORM-2

REVISION SUMMARY

PSEG NUCLEAR LLC VTD No. 325107

PS REV	DOC REV	DATE	EVALUATOR *	SUPERVISOR *	DISCIPLINE INTERFACE *	REVISION DESCRIPTION
1	Ø	9-18-01	DILIP BHAXNANI [signature]	DON LONGO [signature]		INITIAL ISSUE.

* SIGN & PRINT NAME

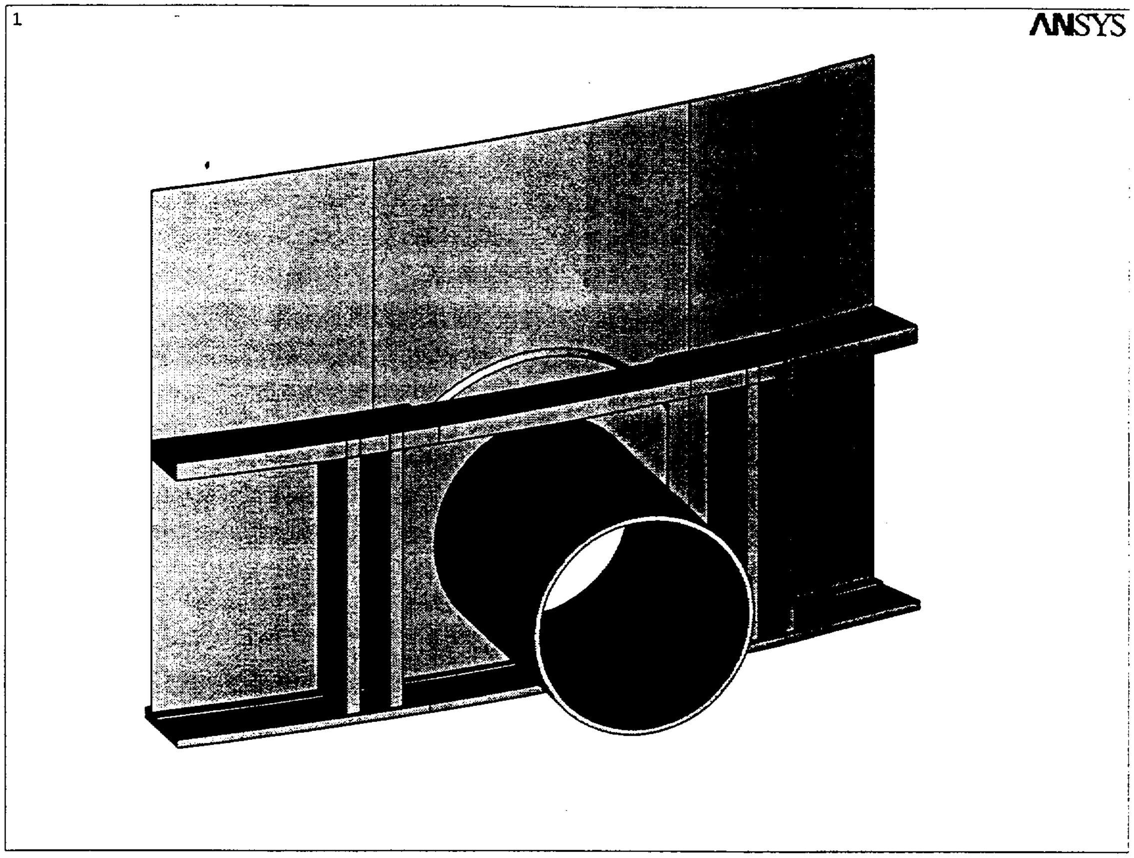

Figure 1. RWST Outlet Nozzle Finite Element Model

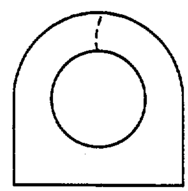

Figure 2. Postulated Linear Crack Location

MPR

MPR Associates, Inc.
320 King Street
Alexandria, VA 22314

CALCULATION TITLE PAGE

Client: PSEG	
Project: Salem 1 RWST Evaluation	Task No. 108-249
Title: Evaluation of RWST Main Outlet Nozzle Postulated Vertical Crack	Calculation No. 108-249-02

Preparer / Date	Checker / Date	Reviewer & Approver / Date	Rev. No.
L. M. Crosbie / 08-23-01	Kerry Kidwell 9/17/01	Robert Cowal 9/17/01	0

QUALITY ASSURANCE DOCUMENT

This document has been prepared, checked, and reviewed/approved in accordance with the Quality Assurance requirements of 10CFR50 Appendix B, as specified in the MPR Quality Assurance Manual.

MPR

MPR Associates, Inc.
320 King Street
Alexandria, VA 22314

RECORD OF REVISIONS

Calculation No.	Prepared By	Checked By	Page: 2
108-249-02	L. M. Craslin	Nessy M. Kidwell	

Revision	Affected Pages	Description
0	All	Initial Issue

Note: *The revision number found on each individual page of the calculation carries the revision level of the calculation in effect at the time that page was last revised.*

Table of Contents

1.0 PURPOSE

The purpose of this calculation is to determine the critical crack length for sudden failure of the Salem 1 RWST tank wall. The postulated crack is a vertical flaw originating at the top of the RWST main outlet nozzle and extending vertically to the top of the nozzle reinforcing pad.

2.0 SUMMARY OF RESULTS

The results of the calculation show that the critical crack length in the RWST is 57 inches. This is greater than the 25 inch long maximum flaw that may exist undetected behind the reinforcing pad.

3.0 CALCULATION

3.1 Approach

A comparison between the postulated vertical crack length in the tank wall behind the reinforcing pad and the critical flaw length for sudden failure will indicate whether a critical flaw could currently exist behind the reinforcing pad. The postulated flaw length is constrained by geometry and includes the diameter of the penetration hole. The critical flaw length is determined using a critical stress intensity factor, K_{IC} and assumed tensile stress. The stress is assumed to be 0.9 of yield (based on the tank design specification), and K_{IC} is estimated using available data.

3.2 Geometry

In this calculation the tank wall is conservatively modeled as an infinite plate with a central crack and constant tensile stress. The crack is assumed to occur in the orientation that allows the longest hidden crack. See Figure 1.

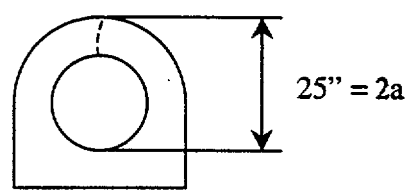

Figure 1 – Reinforcing Pad Diagram

3.3 Stress

In the assumed orientation, the fracture occurs through the base metal of the tank (fabricated using type 304 Stainless Steel). Reference 5, PSEG Detail Specification No. 70-7148, includes the construction specification for the Salem 1 RWST. The required load capacity is defined such that combining hydrostatic loads, earthquakes, tornadoes, wind loads, and walking loads on the roof in the required combinations will not cause more than $(0.9)*\sigma_y$ (yield stress). Thus, 90% of the yield stress for 304 Stainless Steel is used as the maximum stress in the critical crack calculation. According to the Reference 1, the yield stress for 304 S.S. is 30 ksi, so the stress used in this calculation is 27 ksi.

3.4 Material Properties

The required critical stress intensity factor, K_{IC}, is generally determined from fracture test data. However, stainless steel is ductile and does not exhibit critical stress fracture, therefore, K_{IC} was estimated using available data for the initiation toughness (Jc) of stainless steel gas tungsten arc weld (GTAW) material (see Reference 3). The lower limit on fracture toughness for stainless steel is better than that of GTAW material because welding causes contamination and degradation, however, GTAW is very high quality and it's properties will approach those of base metal.

From Reference 3, Figure 11, the J_C factor for 304 stainless steel GTA weld material is approximately 405 kJ/m^2.

$$J_C = \text{Initiation Toughness} = 405\frac{\text{kJ}}{\text{m}^2} = 2312.6\frac{\text{in}-\text{lb}}{\text{in}^2}$$

The stress intensity factor is found through the relation:

$$K_{IC} = \sqrt{J_c E}$$

where: K_{IC} = stress intensity factor $(\text{psi}\sqrt{\text{in}})$

$E = 28.3 * 10^3 \text{ksi}$ = Young's Modulus of Elasticity (Reference 1).

$$K_{IC} \cong 256000 \text{ psi} \sqrt{\text{in}}$$

3.5 Critical Flaw Length

For a central crack in an infinite sheet under uniaxial tensile stress, the stress intensity factor is given by:

$$K_O = \sigma\sqrt{\pi a} \qquad \text{(Reference 4).}$$

where: K_O = stress intensity factor ($\text{psi}\sqrt{\text{in}}$)
σ = tensile stress (psi)
$2a$ = crack length (in)

To find the critical crack length, a_c, K_O is set to K_{IC}, and the stress σ is set to the maximum stress tending to open the crack (which as discussed earlier is 90% of the yield stress, 30 ksi).

$$\text{Therefore: } a_c = \frac{\text{Critical Crack Length}}{2} = \frac{\left(\frac{K_{IC}}{\sigma}\right)^2}{\pi} = \frac{\left(\frac{(256000\text{psi}\sqrt{\text{in}})}{(0.9)(30000\text{psi})}\right)^2}{\pi} \cong 28.6\,\text{in}$$

Therefore, the Critical Crack length is approximately 57 inches.

A 57 inch crack is greater than the 25 inch maximum flaw that may exist behind the reinforcing pad.

4.0 REFERENCES

1. 1974 ASME Code, Section III, Division 1, Subsection NC, Appendix I, Table I-1.2.

2. Nooter Corporation Drawing No. JN-D 36427, Revision 4, Sheet 3 of 12. (PSEG Print No. 147770).

3. Mills, William J., "Fracture Toughness of Stainless Steel Welds," *Fracture Mechanics: Nineteenth Symposium, ASTM STP 969,* Thomas A. Cruse, Ed., American Society for Testing and Materials, Philadelphia, 1988, pp. 330-355.

4. Rooke, D.P, and D. J. Cartwright. Compendium of Stress Intensity Factors. London: Her Majesty's Stationary Office, 1976, p. 10.

5. PSEG Detail Specification No. 70-7148. Salem Nuclear Generating Station. 1-8-1974.

FORM-1

VENDOR INFORMATION

PSEG NUCLEAR LLC VTD NUMBER: 325108

[X]	ACTIVE	Approved Documentation
[ ]	APCP	Approved, Pending Change Package (May only be used for Rev. 1)
[ ]	CAN	Canceled, Not Required
[ ]	VOID	No longer applicable, superseded by : ________

Discipline Selection

[ ] Electrical [ ] I&C [ ] Mechanical [X] Other Specify: ________

Safety Related: [X] Yes [ ] No

Unit Applicability

[X] Salem 1
[ ] Salem 2
[ ] Salem 3
[ ] Salem Common
[ ] Hope Creek
[ ] Hope Creek & Salem
[ ] PSEG Nuclear LLC

System / Title: FINITE ELEMENT ANALYSIS OF OUTLET NOZZLE. SAP Sys Code: ________

Vendor Name: MPR ASSOCIATES, INC.

Vendor Code: 139M Vendor No.: 108-249-03

Vendor Category: ________ (Category Codes are listed in DCRMS.)

Purchase Order No. ________

Material Master: ________

Originator: DILIP BHAVNANI Dept: MECH. Group: STRESS/CIVIL

Date: 9-18-01 Ext: 1828

If changes are made to this form, initial and date the change and document in the revision summary.

FORM-2

REVISION SUMMARY

PSEG NUCLEAR LLC VTD No. 325108

PS REV	DOC REV	DATE	EVALUATOR *	SUPERVISOR *	DISCIPLINE INTERFACE *	REVISION DESCRIPTION
1	Ø	9/18/01	DILIP BHAUNAN	DON LONGO		INITIAL ISSUE

* SIGN & PRINT NAME

MPR
ASSOCIATES INC.
ENGINEERS

September 17, 2001

QUALITY ASSURANCE DOCUMENT
This document has been prepared, reviewed, and approved in accordance with the Quality Assurance requirements of 10CFR50, Appendix B, as specified in the MPR Quality Assurance Manual.
Prepared by: [signature]
Reviewed by: [signature]
Approved by: [signature]

Mr. Don Longo
PSEG Nuclear
PO Box 236
Hancocks Bridge, NJ 08038

Subject: Salem RWST Nozzle Evaluation for Postulated Cracks

Dear Mr. Longo:

Attached is our evaluation of the implications of postulated cracks in the Salem Unit 1 RWST near the main outlet nozzle. As described in the attached report, we performed fracture mechanics and stress analyses for postulated worst case cracks located behind the penetration reinforcing pad. These analyses show that even if the postulated worst case cracks were present, structural integrity of the RWST would be retained and sudden catastrophic failure due to the crack would not be expected. As a result, we consider the RWST is safe to operate until the next refueling outage when repairs can be performed.

If you have any questions or need additional information, please feel free to call.

Sincerely,

Robert N. Coward

Attachment

cc: D. Bhavnani
T. Roberts

320 KING STREET ALEXANDRIA, VA 22314-3230 703-519-0200 FAX: 703-519-0224 http://www.mpr.com

MPR ASSOCIATES INC. ENGINEERS

Attachment to
MPR Letter Dated
September 17, 2001

Salem RWST Nozzle Evaluation for Postulated Cracks

INTRODUCTION

Purpose

The purpose of this analysis is to evaluate the implications of a crack in the RWST wall and/or welds behind the reinforcing pad for the main outlet nozzle penetration. Fracture mechanics and stress analyses are performed to demonstrate that, even if the worst case expected crack were present, the presence of the crack is acceptable. Structural integrity of the RWST is maintained and sudden failure resulting from crack growth would not occur.

Background

Evidence has been discovered that the Salem RWST may have a through wall leak in the vicinity of the main outlet nozzle penetration. The evidence includes wetness on the penetration reinforcing pad tell tale hole and contamination detected on the ground in the vicinity of the nozzle. PSEG Nuclear considers that the likely mechanisms for any degradation of the RWST are corrosion or original fabrication defects (e.g., weld porosity). However, the potential for the leakage to be caused by cracking can not be ruled out conclusively. The potential for cracking is important since the presence of a crack could potentially lead to a sudden catastrophic failure of the RWST, while corrosion or weld defects would not.

CONCLUSIONS & RECOMMENDATIONS

Conclusions

The nature of the flaw in the RWST behind the outlet nozzle reinforcement pad is not known. Based on the constraints on inspection during service, the flaw cannot be inspected at this time. Therefore, the flaw evaluation must assume credible worst case flaw scenarios for flaws that could exist under the reinforcement pad.

There are two crack scenarios which are considered to be credible. The first is a linear flaw that begins at the nozzle to shell weld and is aligned along the axial or longitudinal direction of the shell. The second is a crack that extends fully around the nozzle (360°) in the nozzle to shell weld. Each of these is discussed below:

Linear Flaws

An axial or longitudinal crack, that originates at the nozzle to shell weld and extends axially or longitudinally away from the nozzle is naturally limited in size because of the reinforcing pad. The flaw cannot be any larger that the region covered by the pad, or else the flaw would be directly detectable by leakage thought the shell wall.

The limiting criteria for the linear crack is the potential for sudden crack growth leading to failure of the RWST. Fracture mechanics calculations indicate that the critical crack size is significantly larger that the biggest linear defect that can exist underneath of the reinforcement pad. Therefore, significant crack growth and sudden RWST failure will not occur.

Circumferential Flaws

The worst case postulated circumferential cracks at the RWST main outlet nozzle is a circumferential crack that extends fully around the nozzle (360°) at the nozzle to shell weld. The nozzle to reinforcement pad weld can be examined by NDE to ensure that the flaw does not extend into the weld.

The limiting criteria for the circumferential crack is maintaining structural integrity of the RWST if the reinforcing pad carries all load at the nozzle location (i.e., if the nozzle to shell weld has been removed). For normal and seismic loads, the stresses in the RWST wall and the reinforcing pad are less than the most conservative Service Level A limits, so structural integrity of the RWST is maintained.

In summary, the RWST is acceptable for continued operation until repairs can be made, even with postulated worst case through-wall cracks behind the reinforcing pad.

It should be noted that the analyses performed for this evaluation included the assumption that any existing cracks remain within the extent of the main nozzle reinforcing pad. If cracks grow and extend beyond the reinforcing pad additional analysis or immediate repairs will be necessary.

Recommendations

Based on the key conclusions listed above and the analyses performed to support the evaluation, MPR recommends that PSE&G continue to operate the Unit 1 RWST "as-is" until the next refueling outage (when repairs will be made). To ensure safe operation, until that time, MPR recommends the following additional actions:

- Continue to perform regular walkdown visual inspections of the RWST outlet nozzle and monitor leakage flow to ensure that no unexpected increases in leakage are occurring. This will also ensure that any linear flaws have not extended beyond the reinforcement pad.

- Perform NDE of the accessible welds on the outside of the RWST wall. This should include PT of the reinforcement pad to shell weld, and PT or UT (if possible) of the nozzle to reinforcement pad weld. The will ensure that enough weld remains to carry the nozzle loads in the event that the nozzle to shell weld has failed.

As part of the repair effort, MPR recommends that PSE&G prepare for repair or replacement of the outlet nozzle at the next refueling outage. Specifically:

- Initiate plans to repair the Unit 1 RWST during the next refueling outage. The repair procedures should preserve the likely location of the material degradation for future analysis.

- After the RWST repairs, perform failure analyses of the removed section of the RWST to determine the actual degradation mechanism(s).

- Based on the degradation mechanism, evaluate the need for additional actions related to the Unit 2 RWST.

DISCUSSION

Configuration

The RWST is an approximately 38 feet in diameter, about 48 feet tall. The main outlet nozzle (suction for the SI system) is located near the bottom of the tank. The bottom of the nozzle is only 2 inches above the bottom of the tank (and the ground). The penetration is 20 inches in outside diameter. The penetration includes a reinforcing pad around the nozzle. Due to the close proximity of the bottom of the tank, the reinforcing pad is not symmetric about the nozzle horizontal centerline. The top of the reinforcing pad is 3.5 inches from the nozzle, and this dimension is maintained for the area above most of the penetration. Below the centerline, the reinforcing pad is a constant 26 inches wide (in the circumferential direction) and extends to the bottom of the tank.

The RWST wall and the main outlet nozzle are fabricated from SA-240 Type 304 stainless steel plates. The RWST is anchored to the concrete pad with large diameter anchor bolts. The anchors are attached to the tank at two local stiffeners and a ring brace near the bottom. The outlet nozzle is located in between two sets of stiffeners. The general configuration is shown in Figure 1.

Applicable Codes

The RWST was specified (Reference 1) to meet the requirements of AWWA standard for welded steel tanks and Section III of the ASME Code (as of 1974). PSEG Nuclear has stated that there interpretation is that the vessel is comparable to Code Class 3 (Subsection ND); however, this operability analysis will be conducted to Subsection NC, which provides rules for design by analysis.

Approach

The implications of postulated cracks in the RWST wall behind the main outlet nozzle reinforcing pad are evaluated using a combination of fracture mechanics and stress analyses. The overall goal is to determine the worst case postulated crack and then demonstrate that the RWST is acceptable for continued operation in the postulated degraded condition. The evaluation is performed using a standard fracture mechanics analysis approach. The key elements of this approach include:

1. Define the orientation and size of the postulated worst case crack(s).

2. Consider potential crack growth during the remaining operating cycle based on the stresses at the postulated crack locations during normal and upset conditions.

3. Calculate the critical crack sizes for the postulated crack locations (once again based on the stresses during normal and upset conditions).

4. Compare the postulated worst case crack size to the critical crack size (to show that the critical crack size is greater than the expected crack size). This demonstrates that the RWST will not fail in a sudden, catastrophic manner due to crack extension.

Stress analyses are also performed to demonstrate that the outlet nozzle was structurally adequate if the entire nozzle to shell weld is cracked.

Worst Case Crack(s) Configuration

If a crack is present in the RWST near the main outlet nozzle, it would be a through-wall. Such a crack would allow flow from the inside of the tank to the outside. Because a detailed flaw assessment cannot be performed, an assumed worst case crack is selected based on an evaluation of the RWST configuration and potential cracking mechanisms.

Two postulated cracks were identified for evaluation. These cracks are described below.

- Linear crack at the top of the nozzle – This postulated crack would be oriented vertically and extend from the top of the main outlet nozzle to the edge of the reinforcing pad (as shown in Figure 2). The crack is assumed to initiate in the heat affected zone of the wall material at the nozzle/wall weld and grow vertically. Growth of the crack out of the heat affected zone is considered unlikely, but is conservatively assumed for this evaluation. The crack is assumed to extend to the edge of the reinforcing pad. Larger cracks are not credible, because they would be visible from outside the tank.

  This crack has the potential to "unzip" the tank wall and cause a sudden failure. The potential failure mode is brittle fracture or plastic tearing.

- Circumferential crack around the nozzle to shell weld - This postulated crack would be oriented circumferentially around the main outlet nozzle. The crack is assumed to initiate in the heat affected zone of the wall material at the nozzle/wall weld and grow circumferentially staying within the heat affected zone.

  This crack would not lead to a sudden unzipping of the tank. Instead, complete circumferential cracking of this weld would transfer all of the load from the tank-wall to the reinforcing pad. The potential failure mode is ductile overload of the reinforcing pad.

Crack Growth

Normally, evaluations of critical crack sizes are performed for the crack size expected at the end of the current operating period (e.g., at the next refueling outage). However, for postulated cracks in the RWST it is not necessary to consider additional crack growth. Two worst case cracks have been identified and are evaluated. One is a circumferential crack around the main outlet nozzle. For this case it is assumed the crack has grown fully around the nozzle and can not grow any more. The second case is a crack that runs from the top of the nozzle vertically to the limit of the reinforcing pad. If this crack were to grow past the reinforcing pad the regular visual inspections of the penetration (to inspect for leakage) would identify the crack growth. If a crack were to grow outside the reinforcing pad, additional analysis or immediate repairs would be necessary.

Thus, consideration of crack growth during operation is not necessary for this evaluation.

Linear Crack Evaluation

The postulated worst case vertical crack is located in the RWST wall between the top of the main outlet nozzle and the top of the reinforcing pad. This is a length of 5 inches. However, one edge of this postulated crack ends at the nozzle penetration (i.e., a hole in the wall). This hole will effectively extend the crack. Thus, for the purposes of fracture mechanics analyses and evaluating this postulated crack, the hole diameter is added to the crack length. Including the penetration hole, the total crack length is 25 inches.

The evaluation of this crack is provided in MPR Calculation 108-149-02, which is provided in Appendix 1. The calculation includes the fracture mechanics calculations that show the postulated worst case crack is considerably shorter than the critical crack size. As a result, sudden failure of the RWST due to crack extension will not occur. A summary of the analysis performed is provided below.

The RWST procurement specification limits the stresses in the RWST walls to 0.9 S_y under all loading conditions (including pressure, seismic, attached piping loads, etc.). Therefore, the stress in the shell is conservatively set to the maximum permitted in the original design specification.

The critical crack size is determined by calculating the stress intensity factor, K_I (from linear elastic fracture mechanics), and comparing the calculated stress intensity factor to the material critical stress intensity factor, K_{IC}. Since the ligament beneath the penetration is assumed to remain intact, the postulated crack is a double edged crack in a plate.

Since austenitic stainless steel is very ductile at all temperatures, there is not a clear value for K_{IC} (like there is for carbon steels). Available test data shows that stainless steel is susceptible to significant crack extension at J_{IC} values over about 405 kJ/m^2, which corresponds to a K_{IC} of 257 ksi$\sqrt{\text{in}}$.

For a membrane stress of 0.9S_y, an infinite plate with the double edged crack, and a K_{IC} of 257 ksi$\sqrt{\text{in}}$, the calculated critical crack size is 61.8 inches. Based on the geometry, the largest linear crack that could exist under the reinforcement pad is 25 inches. Therefore, it is not possible for a sudden failure to occur, without the linear crack first growing beyond the region under the reinforcement pad.

Circumferential Crack Evaluation

The postulated worst case circumferential crack extends fully around the outlet nozzle and severs the weld between the RWST shell wall and the nozzle. Under this scenario, the reinforcing pad must support the entire pressure ejection load and to carry essentially all of the other loads on the RWST wall (seismic, pipe reaction, etc.). Because of the adjacent stiffeners and flange at the nozzle, the only credible failure mode is an overload failure at the penetration due to pipe nozzle loading.

The limiting criteria for this crack is not crack growth (since the crack has extended fully around the nozzle). Nondestructive examination (NDE) of the nozzle to reinforcement pad weld and the reinforcement pad to shell weld are possible from the exterior of the tank. Assuming that these two welds are inspected and shown to be intact, it is only necessary that the structural integrity of the RWST be maintained in this configuration.

The ANSYS general-purpose finite element program was used to develop a three-dimensional solid model of the penetration nozzle, reinforcing pad and adjacent tank. A linear, static analysis was performed for combined internal pressure and DBE (Design Basis Earthquake) seismic piping loads. This is a faulted loading condition, which is Service Level D. As discussed below, this load combination was evaluated to Service Level A stress limits. Therefore, this Load Combination bounds all other Load Combinations.

The finite element model of the RWST includes the nozzle, reinforcing pad and a 20° segment of the tank wall and the tank wall stiffeners. The solid model was meshed with 10-node tetrahedral finite elements. The tank wall is modeled up to a height of 4 feet. The fillet weld between the outside edge of reinforcing pad and the tank wall is modeled explicitly. The fillet on the full penetration weld between the nozzle and the reinforcing pad is not included. The full penetration weld between the nozzle and the tank wall is modeled as completely failed. Therefore, there is no direct connection between the shell and the nozzle. The load path is from the nozzle, to the reinforcement pad, to the shell wall. This model is shown in Figure 1

The calculated stresses from the model were linearized through the thickness of the components to determine the membrane and bending components of the primary and secondary stresses. The linearized stress results were compared to the applicable stress limits to perform the Code stress evaluation.

The RWST was specified to meet the requirements of the latest AWWA (American Water Works Association) Standards for Welded Steel Tanks, and Section III of the ASME Code. For this assessment, the procedure for design by analysis in the 1974 ASME Code, Section III, Division 1, Subsection NC is used. The allowable stress for the SA-240 tank material is 20 ksi. The stress limits for Service Level A are conservatively applied to assess the adequacy of the outlet nozzle, tank shell, and reinforcement pad.

The analysis results shows that, in all cases, the calculated stresses are less than the Service Level A allowable.

REFERENCES

1. PSE&G Detail Specification No. 70-7148, including Addendum 1.

APPENDICES

1. MPR Calculation 108-249-02, Revision 0, "Evaluation of RWST Main Outlet Nozzle Postulated Linear Crack"

2. MPR Calculation 108-249-03, Revision 0, "Finite Element Analysis of Outlet Nozzle"

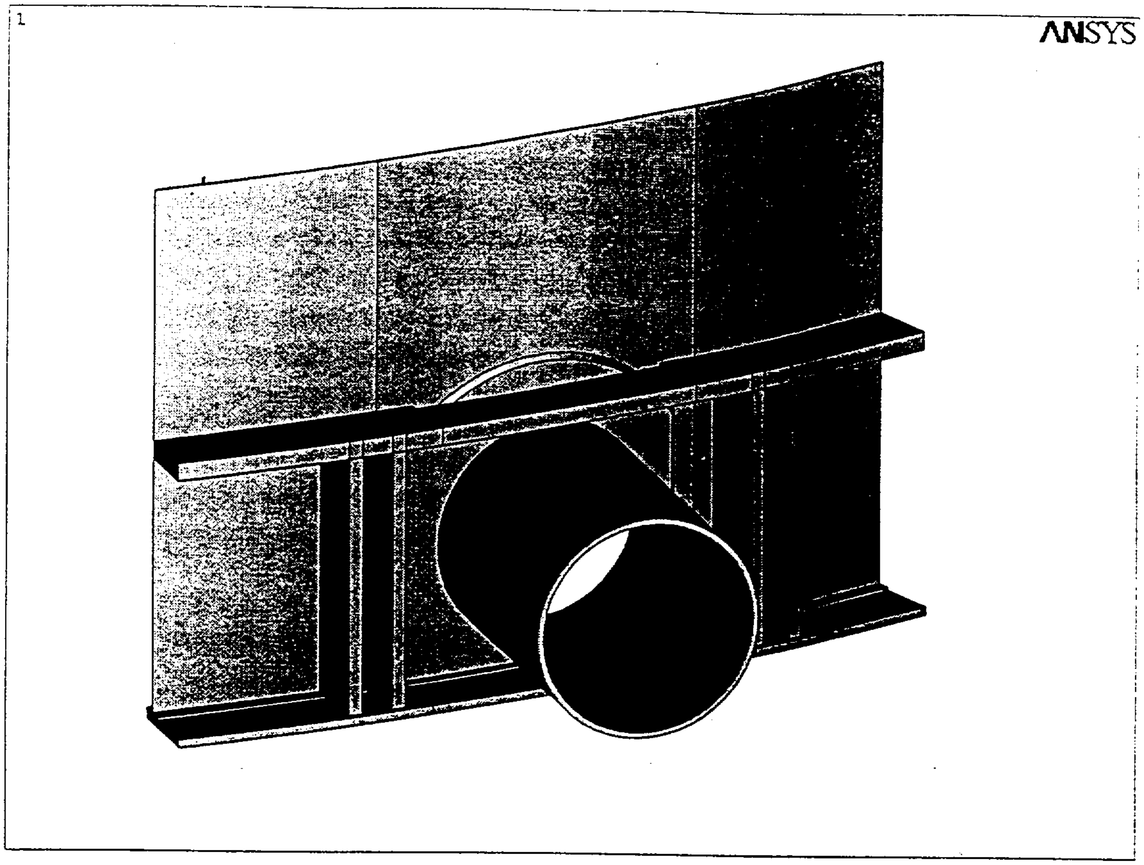

Figure 1. RWST Outlet Nozzle Finite Element Model

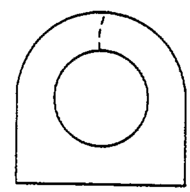

Figure 2. Postulated Linear Crack Location

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CALCULATION TITLE PAGE

Client: PSE&G Nuclear	Page 1 of 15
Project: Salem RWST Tank	Task No. 108-249
Title: Finite Element Analysis of Outlet Nozzle	Calculation No. 108-249-03

Preparer / Date	Checker / Date	Reviewer & Approver / Date	Rev. No.
E.B. Bird 9-17-01 Edward Bird	L.M. Crosbie 9/17/2001 Leanne Crosbie	Robert Cowak 9/17/01	0

QUALITY ASSURANCE DOCUMENT
This document has been prepared, checked, and reviewed/approved in accordance with the Quality Assurance requirements of 10CFR50 Appendix B, as specified in the MPR Quality Assurance Manual.

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RECORD OF REVISIONS

Calculation No.	Prepared By	Checked By	Page: 2
108-249-03	E. B. [signature]	L. M. [signature]	

Revision	Affected Pages	Description
0	All	Initial Issue

Note: *The revision number found on each individual page of the calculation carries the revision level of the calculation in effect at the time that page was last revised.*

Table of Contents

PURPOSE

The purpose of this calculation is to document a finite element analysis of the Salem Unit 1 RWST (Refueling Water Storage Tank) outlet nozzle penetration. The analysis was performed because the RWST may have a through-wall flaw near the outlet nozzle penetration (under the reinforcing pad). This calculation evaluates the tank for a postulated failure of the nozzle to shell weld.

The weld behind the reinforcing pad between the outlet nozzle and tank is assumed to have failed completely. The outlet nozzle was evaluated for combined internal pressure and DBE seismic loads. The DBE seismic load is a Service Level D load, however, the more conservative Level A stress limits will be used. The design by analysis rules and stress limit criteria from Section III, NC of the 1974 ASME Code are used for the evaluation.

SUMMARY OF RESULTS

Table 1 compares calculated stress intensities to the allowable stress intensities. In all cases, the calculated stresses are less than the allowable.

Table 1. Stress Results

Location	Stress Criteria	Calculated Stress (ksi)	Allowable Stress (ksi)	Stress Index
Tank Wall	$P_L < 1.5S_m$	27.8	30.0	0.93
	$P_L + Q < 3.0S_m$	45.7	60.0	0.76
Reinforcing Pad	$P_L < 1.5S_m$	8.3	30.0	0.28
	$P_L + Q < 3.0S_m$	44.1	60.0	0.74
Nozzle Wall	$P_L < 1.5S_m$	11.0	30.0	0.37
	$P_L + Q < 3.0S_m$	36.9	60.0	0.62

DISCUSSION

Analysis Approach

The ANSYS general-purpose finite element program (Reference 1) was used to develop a three-dimensional solid model of the penetration nozzle, reinforcing pad and adjacent tank. A linear, static analysis was performed for combined internal pressure and DBE (Design Basis Earthquake) seismic piping loads. Seismic and pressure loads are included in the tank specification (Reference 2).

The calculated stresses from the model were linearized through the thickness of the components to determine the membrane and bending components of the primary and secondary stresses. The linearized stress results were compared to the applicable stress limits to perform the Code stress evaluation.

Stress Criteria

The RWST was specified to meet the requirements of the latest AWWA (American Water Works Association) Standards for Welded Steel Tanks tanks, and Section III of the ASME Code (as of 1974), as well as all state and local requirements (Reference 2).

For this assessment, the procedure for design by analysis in the 1974 ASME Code, Section III, Division 1, Subsection NC (Reference 3) will be used. The allowable stress S_m for the SA-240 tank material is 20 ksi. The general membrane stress in the tank and outlet nozzle penetration are considered to be essentially unaffected by the loss of the nozzle-to-tank weld. Consequently, they are not evaluated here. There is no primary bending (P_b=0) for the loads considered in this analysis. The remaining stress criteria and limits are:

Primary Local Membrane	$P_L < 1.5S_m$
Primary + Secondary, Membrane + Bending	$P_L + Q < 3S_m$

Service level A allowables are used with service level D loads. Consequently, other potential load combinations (e.g. OBE seismic) are bounded.

Tank Configuration

The RWST is a cylindrical tank approximately forty-eight feet tall and thirty-eight feet in diameter. The main outlet nozzle (suction for the SI system) is located near the bottom of the tank. The nozzle is a ½ inch thick pipe section with a twenty-inch outside diameter. The bottom of the nozzle is two inches above the bottom of the tank (and the ground).

The penetration includes a ½ inch thick reinforcing pad around the nozzle. Due to the close proximity of the bottom of the tank, the reinforcing pad is not symmetric about the horizontal nozzle centerline. The top of the reinforcing pad is 5.5" from the nozzle, and this dimension is maintained for the area above most of the penetration. Below the centerline, the reinforcing pad is a constant twenty-six inches wide (in the circumferential direction) and extends to the bottom of the tank.

Finite Element Model Description

The finite element model of the RWST includes the nozzle, reinforcing pad and a 20-degree segment of the tank wall and the tank wall stiffeners. The tank wall is modeled up to a height of 4 feet. The fillet weld between the outside edge of reinforcing pad and the tank wall is modeled explicitly. The fillet on the full penetration weld between the nozzle and the reinforcing pad is not included. The full penetration weld between the nozzle and the tank wall is modeled as completely failed; no connection between components is included.

The solid model was meshed with 10-node tetrahedral finite elements. Figure 1 shows the solid model, Figures 2 and 3 show the finite element model.

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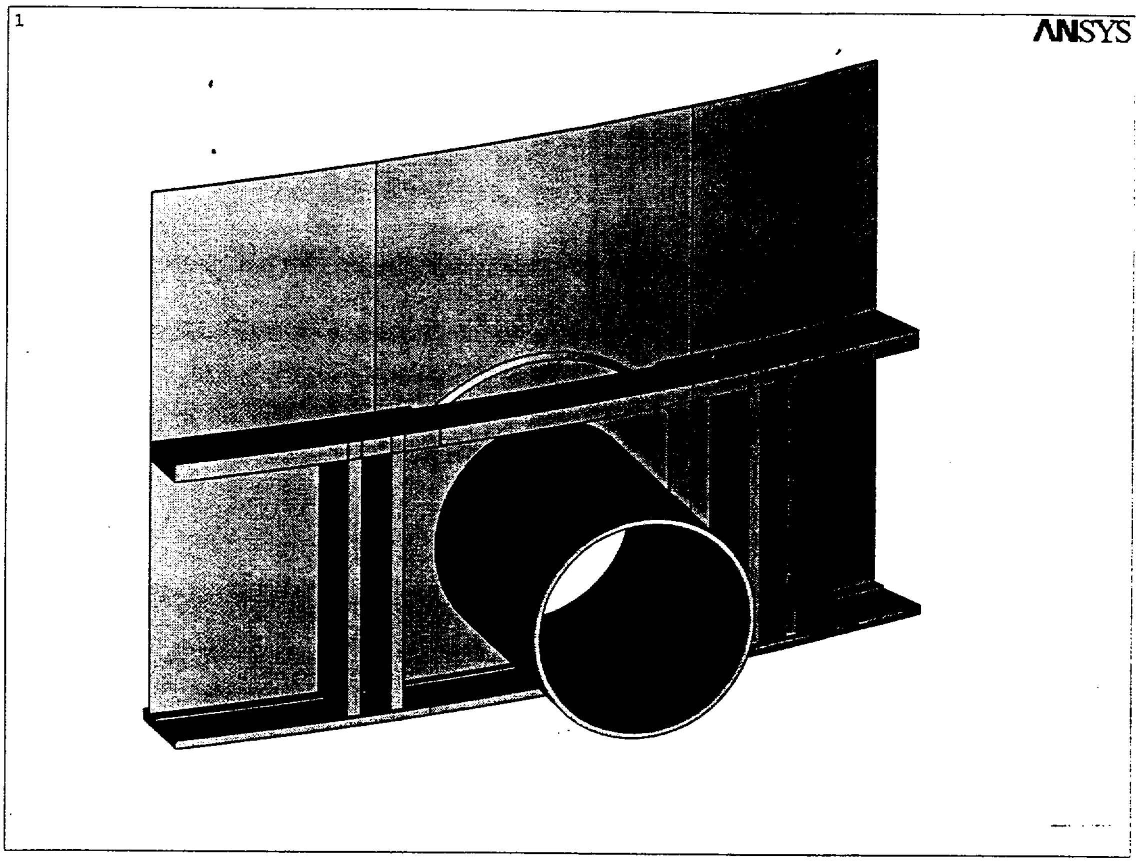

Figure 1. RWST Solid Model

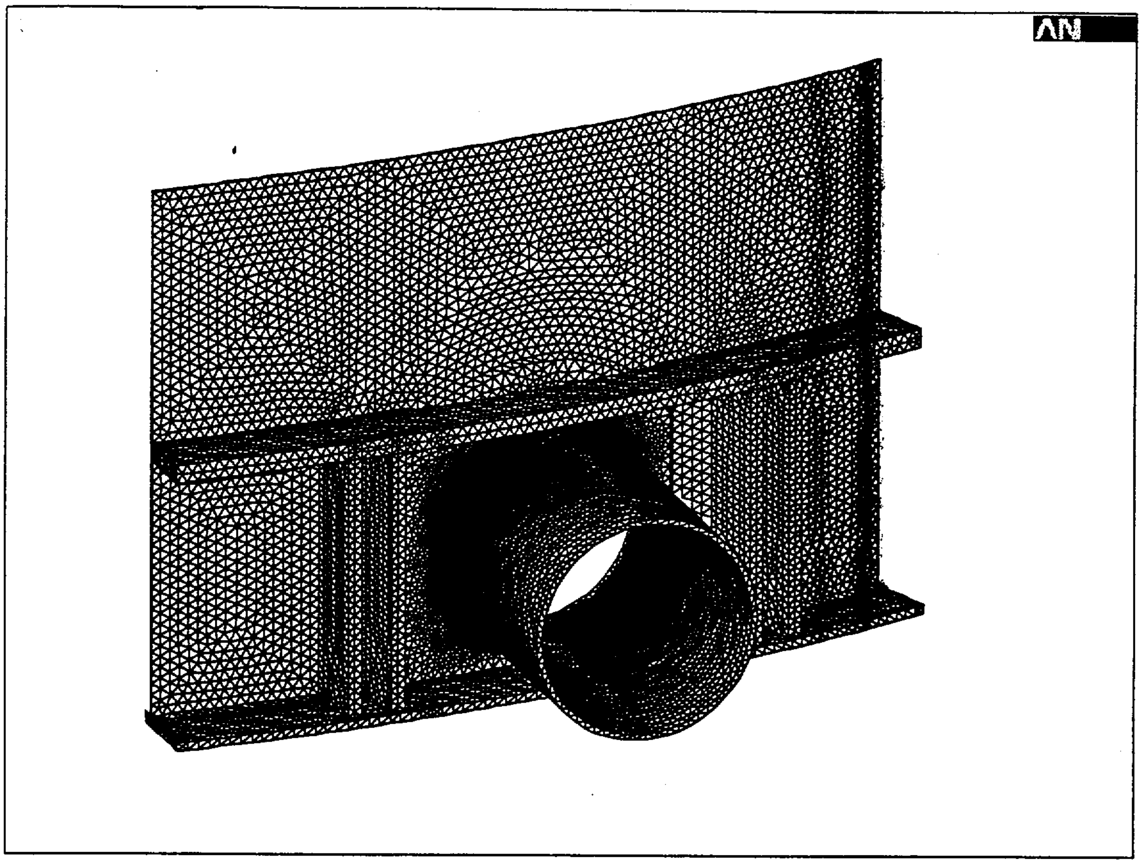

Figure 2. RWST Finite Element Model

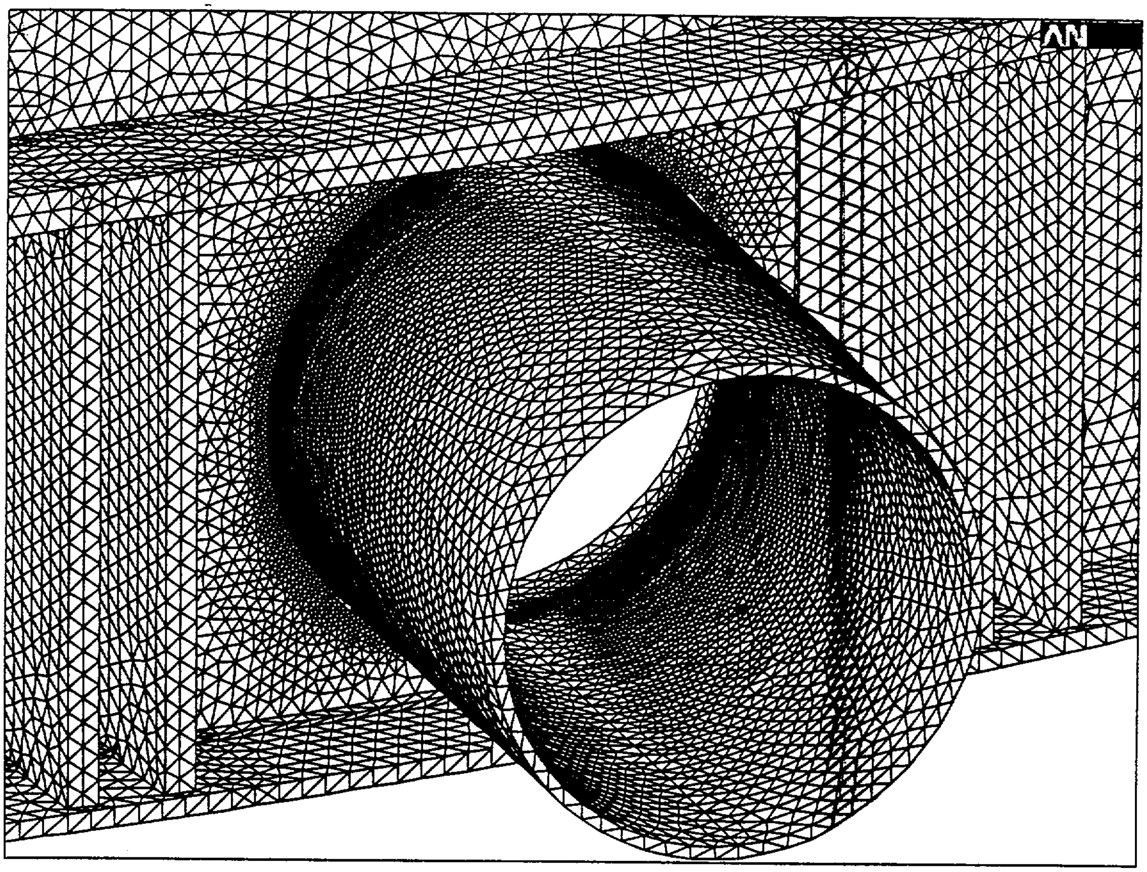

Figure 3. RWST Finite Element Model Detail

Geometry

The finite element model geometry is based on Reference 4. Key geometric parameters used in the development of the model are listed below.

```
tank inside diameter = 38 ft
tank thickness = 0.25 inch
tank height modeled = 48 inches

pad thickness = 0.5 inches
pad width = 26 inches
pad radius = 15.5 inches (estimated)

distance from ground to center of pipe = 12 inches
nozzle outside diameter = 20 inches
nozzle thickness = 0.5 inches
nozzle length = 24 inches
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nozzle offset = 36 inches

belly band thickness = 1.625 inches
belly band width = 6 inches
belly band height = 23.5 inches

flange thickness = 0.625
flange offset = 2 inches
flange angle = 9 degrees

bottom flange inside diameter = 37 foot - 9.5 inches
bottom flange width = 8 inches
bottom flange thickness = 0.75 inches (estimated)

tank bottom plate lip = 1.25 inches
```

Material Properties

The tank is constructed of SA-240 Type 304 stainless steel plate. The pipe material is SA-358 Type 304 stainless steel. The allowable stress intensity (S_m) is 20 ksi for both materials. The elastic modulus used in the analysis for both materials is 28.3×10^6 psi. A value of 0.3 was used for Poisson's ratio.

Loads and Boundary Conditions

The RWST internal pressure is assumed to be 20 psig. The full tank height in the model is loaded at 20 psig although the hydrostatic head would vary with the water depth. Pressure is applied to the tank inside surface and the nozzle inside surface. An axial pressure is applied to the end of the nozzle that represents the longitudinal stress in the nozzle wall produced by internal pressure.

DBE seismic piping forces and moments from the Safety Injection design piping calculation (Reference 5) were applied to the outlet nozzle. The moments were applied to a node located along the axis and at the end of the nozzle. This node was coupled to the end of the nozzle by constraint equations. The piping forces were applied to the nodes at the intersection of the nozzle and reinforcing pad to avoid introducing additional artificial moments. The forces and moments applied are listed below.

Fx = 1,042 lbs	Mx = 48,692 in-lbs
Fy = -2,664 lbs	My = -55425 in-lbs
Fz = 922 lbs	Mz = -253,453 in-lbs

The model is restrained in the axial direction (uz) at the base of the bottom flange. At the top of the tank wall where the remaining height of the tank is not modeled, the nodes are coupled in the axial direction. Along the vertical sides of the model, at azimuthal positions 0 degrees and 20 degrees; a symmetry boundary condition is applied. The symmetry condition permits only radial and axial displacement of the nodes on the edges of the model.

Stress Results

Figures 4 through 7 show contours of stress intensity in the complete model and in each of the model components (tank wall, pad and nozzle). The stress results are linearized through the thickness of each component at the location of peak stress intensity (Reference 6). Linearized stresses are listed in Table 1 in the Summary of Results Section.

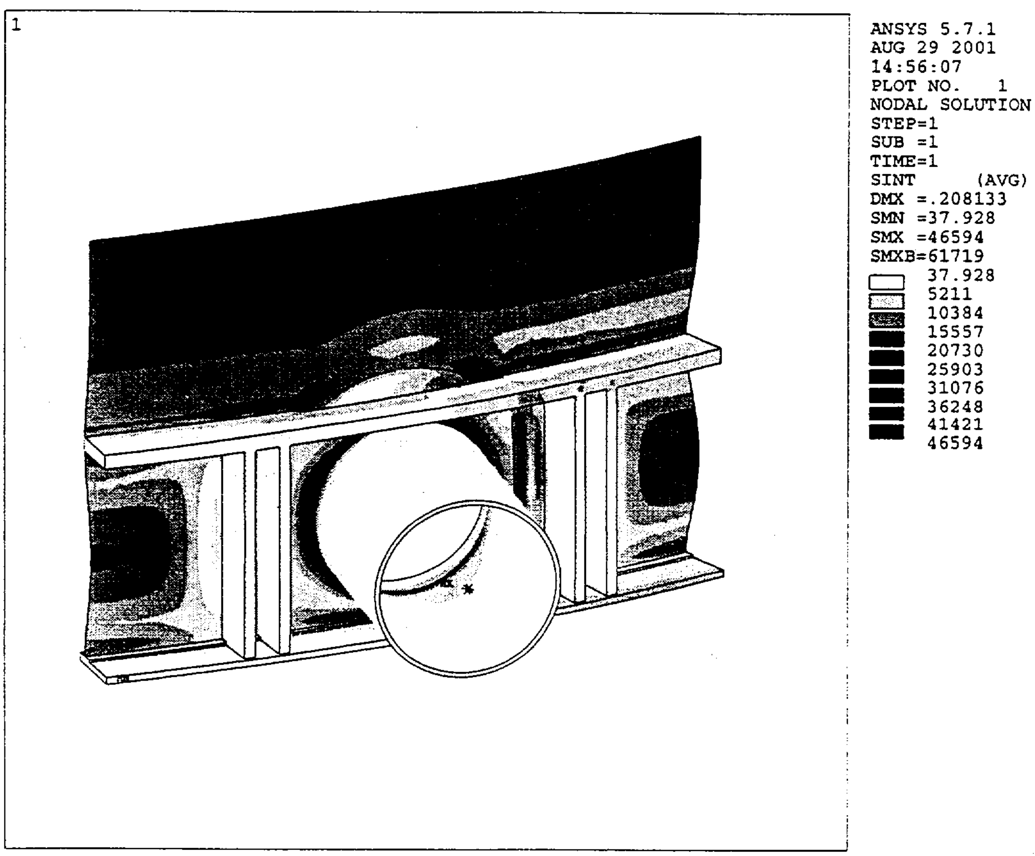

Figure 4. Stress Results

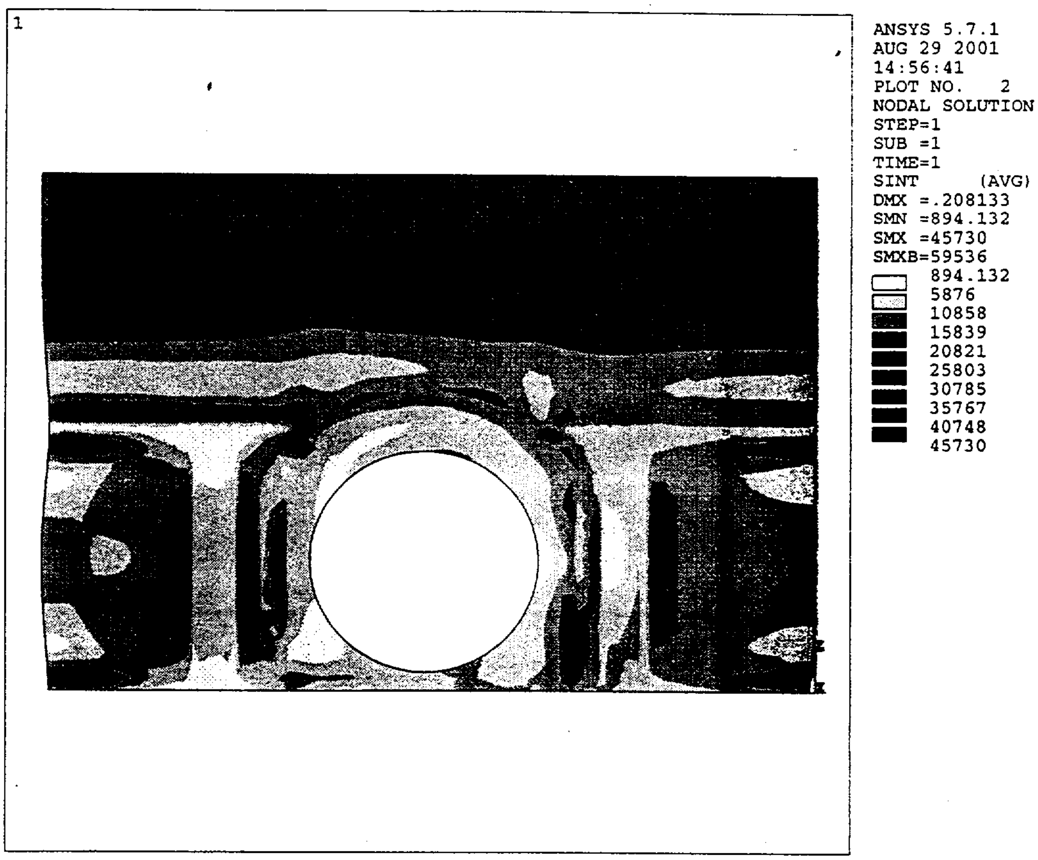

Figure 5. Stress Results in the Tank Shell (Viewed from Inside the Tank)

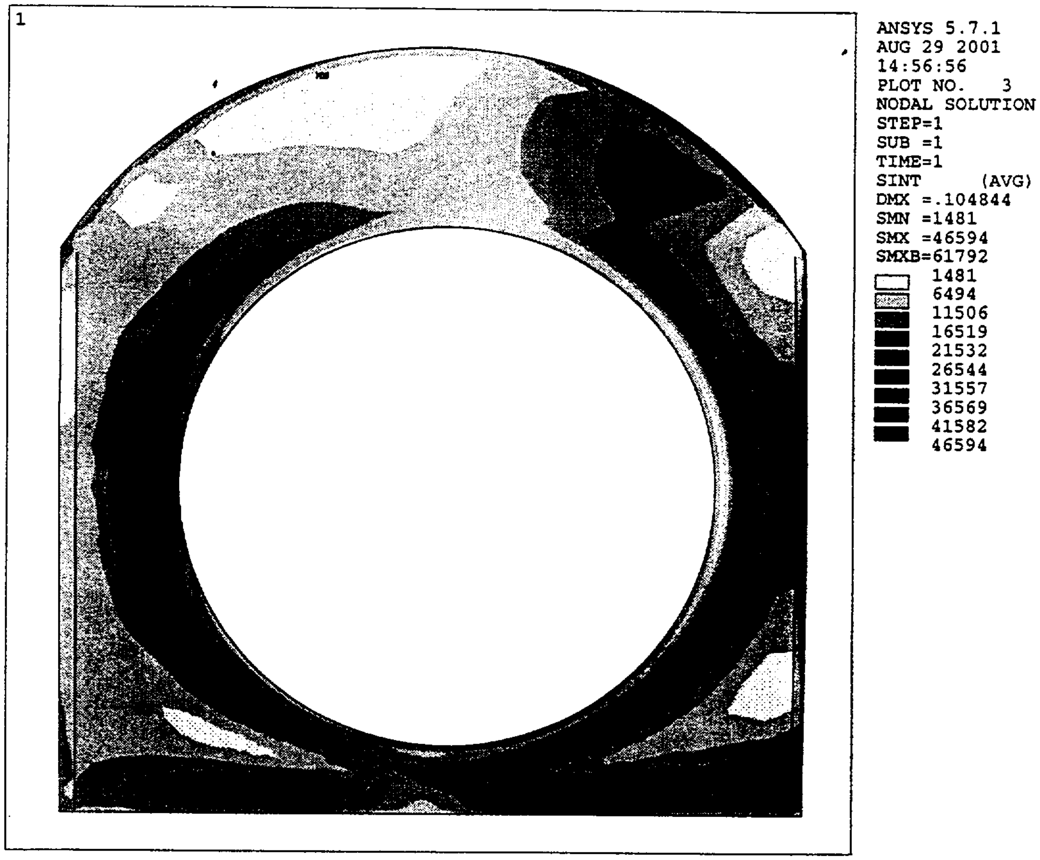

Figure 6. Stress Results in the Reinforcing Pad (Viewed from Outside the Tank)

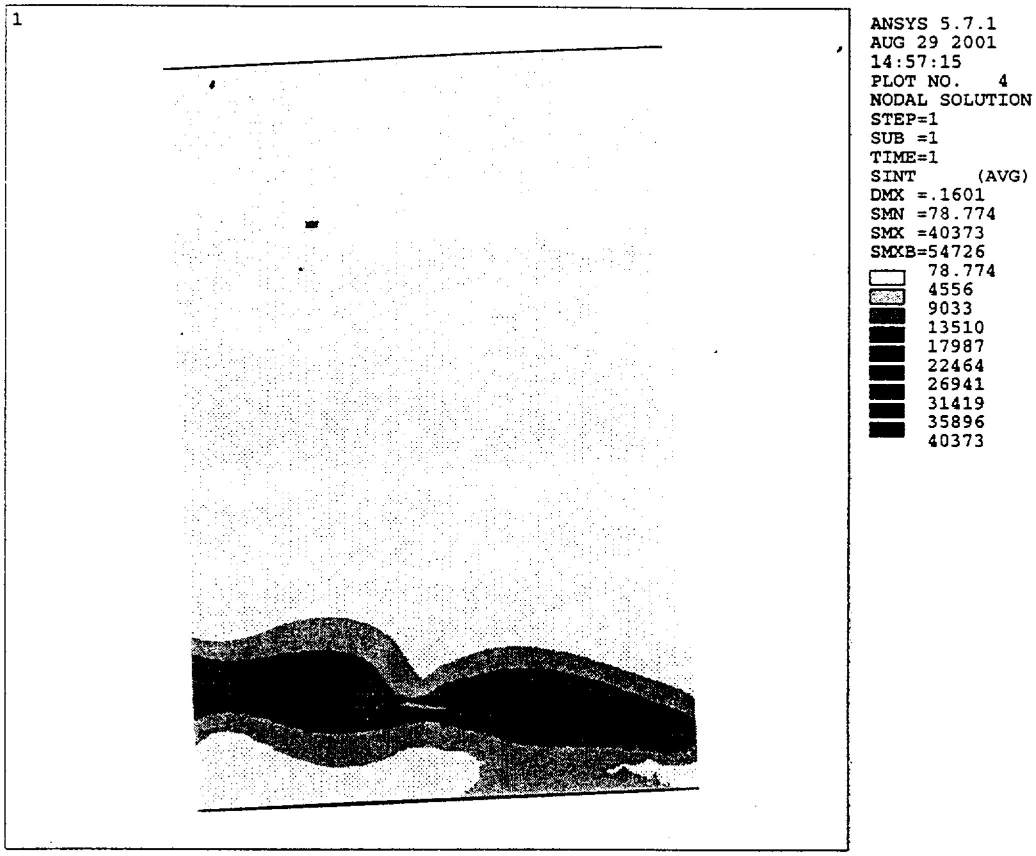

Figure 7. Stress Results in The Nozzle (View from Outside the Tank, Below the Nozzle, Looking Up)

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References

1. ANSYS Finite Element Analysis Computer Program, Version 5.7.1 installed on a Sun Microsystems 280R server running the Solaris 8 operating system. The ANSYS installation verification is documented in QA-57-1.
2. PSE&G Detail Specification No. 70-7148, including Addendum 1, dated 1/8/74.
3. 1974 ASME Code, Section III, Division 1, Subsection NC.
4. PSE&G drawing numbers 147766, 147770 and 147771.
5. PSE&G piping calculation number 267249B, "Safety Injection", Revision 3, dated 1/3/94, Attachment 2, page 2 of 8.
6. Computer output file 108-249-03-1.