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Nuclear Operating Company

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July 23, 2003
NOC-AE-03001568
10CFR50

U. S. Nuclear Regulatory Commission
Attention: Document Control Desk
One White Flint North
11555 Rockville Pike
Rockville, MD 20852

South Texas Project
Unit 1
Docket No. STN 50-498
Revised Summary of ASME Code Calculations Performed for
Repair of Bottom Mounted Instrumentation Penetrations

Reference: Letter from S. E. Thomas to NRC Document Control Desk dated July 2, 2003, "Summary of ASME Code Calculations Performed for Repair of Bottom Mounted Instrumentation Penetrations" (NOC-AE-03001555)

STP repaired two bottom mounted instrumentation (BMI) leaking penetrations with a "half-nozzle" design that relocated the pressure boundary to the outside of the reactor vessel. The repair is in accordance with the ASME Code as required by 10CFR50.55a.

To facilitate the NRC staff's review of the BMI repair, STPNOC provided the referenced summary of the ASME Code required analyses performed for the repair/replacement activity. Attachment 1 to this submittal revises the summary for the BMI guide tube-to-nozzle weld connection (Attachment 1 to the reference letter) and Attachment 2 to this submittal revises the summary for the BMI nozzle original J-groove weld residual stress analysis (Attachment 3 to the reference letter) in response to questions from the NRC staff. Changes to the original submittals are identified by change bars in the margin. A copy of the finite element model used in the analyses is also attached.

Please call me at (361) 972-7162 if you have any questions.

S. E. Thomas
Manager,
Plant Design Engineering

Awh

Attachments:

1. Revised BMI Guide Tube and BMI Nozzle Weld Analysis Summary
2. Revised BMI Nozzle Original J-Groove Weld Residual Stress Analysis Summary
3. BMI Finite Element Model

A047

cc:
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BMI Guide Tube and BMI Nozzle Weld Analysis Summary

Revised ASME Stress and Fatigue Analysis
BMI GUIDE TUBE-TO-NOZZLE SOCKET WELD CONNECTION
Summary of Framatome Proprietary Calculation 32-5028839-00

Purpose

The half-nozzle repair of BMI penetrations #1 and #46 on the South Texas Project Unit 1 reactor pressure vessel included a new weld to connect the stainless steel guide tubes to the new half nozzle. The connection consists of a socket weld as shown on the attached figure. The BMI guide tube is 1.0-inch outside diameter, specially manufactured tubing. Since the guide tubing is smaller than 1" nominal diameter tubing, ASME Code allows it to be designed as ASME Code Class 2 piping. ASME Code Class 2 does not require a fatigue analysis. However, STP is treating the guide tube the same as the reactor vessel and conservatively chose to perform the fatigue analysis for the thermal cycles. This document summarizes Framatome proprietary calculation 32-5028839-00, STP BMI Nozzle to Tube Connection Analysis and Qualification. Framatome performed the safety analysis of the weld connection in accordance with ASME Code Criteria of Section III, Article NB – 3220 (Stress Limits). The calculation demonstrates that the weld connection meets the ASME code requirements for design, test, and faulted conditions and for repetitive (fatigue) loading.

Scope

South Texas Project Unit 1 reactor vessel bottom head contains 58 BMI nozzles. The nozzles are aligned vertically and are located at various radial distances from the vertical centerline of the hemisphere. Based on the distance from the center of the hemispherical head, the length between the bottom head and the insulation varies. This distance has a significant effect on thermal and structural analysis.

Three BMI nozzle conditions were modeled and analyzed. Calculated models conservatively assume the worst location of the nozzle with respect to bottom head-to-insulation length. Verification of the BMI nozzle coupling necessitated the creation of 2D axi-symmetric finite element model and stress analyses of the BMI nozzle repair configurations. Although the repair configuration is only applicable to nozzles 1 and 46, the calculation performs bounding analysis to envelop other nozzles.

Methodology

The general methodology of model development and stress analysis consists of:

1. Building of two-dimensional model containing a portion of the BMI nozzle in the connection region. The model incorporates the geometry of the replacement BMI nozzle, the guide tube and new weld. Appropriate materials and boundary conditions were applied to the model. Two finite element models consist of thermal and structural elements, respectively, to support the thermal and structural analysis.

2. Applying the design pressure and temperature to the structural model and obtaining the deformation and stresses in the model.

3. Applying the thermal loads and run steady state thermal finite element analysis.

4. Applying the corresponding mechanical load (pressure) and thermal load (temperature distribution calculated in step 3) on the structural finite element model and run structural finite element analysis.

5. Perform ASME Code stress evaluation to demonstrate that failure does not occur due to application of design loads or due to repetitive loading.

6. Applying a Fatigue Strength Reduction Factor 4.0 to all analyzed areas (pipe and the nozzle weld).

The welded connection location with respect to the insulation varies depending on the nozzle radial location with respect to the center of the head. A socket weld located below the insulation (hypothetical case) will experience smaller thermal transients and minimum thermal stresses. A socket weld located between the insulation and the bottom head will experience larger thermal transients during heatup/cooldown cycles and correspondingly larger thermal stresses.

This calculation performs three analyses:

1. Nozzle with the weld closest to the insulation, but below the insulation (Model A).
2. Nozzle with the weld closest to the insulation, but above the insulation (Model B).
3. The furthest away nozzle: this connection is the closest to the head and is expected to have the highest temperature. (Model C)

Finite Element Model (FEM)

The FEM consists of 8279 nodes and 2544 elements. PLANE82 (2-D 8-node Structural Element) element was used in structural analysis. This element was converted to PLANE77 (2-D 8-node Thermal Element) for thermal analysis. The "mapped" meshing procedure was mostly applied to the model.

Thermal Loads

The possible nozzle configurations were enveloped by three models:

Analysis A:	The weld is **below** the insulation and very close to the insulation.
Analysis B:	The weld is **above** the insulation and very close to the insulation.
Analysis C:	The weld is **above** the insulation and very close to the head.

The thickness of insulation is neglected.

The surface of the BMI nozzle above the insulation exposed to ambient temperature was assumed completely insulated and a 0.0 BTU/hr-in^2-F heat transfer coefficient was applied from the bottom head to the insulation. A heat transfer coefficient of 0.0 BTU/hr-ft^2-F was applied on the inner surface of BMI nozzle assuming conservatively no flow condition inside the nozzle. The model, therefore, assumed only conduction heat transfer in the nozzle between the bottom head and the insulation. The outside surface of the BMI nozzle below the insulation is exposed to forced air convection; therefore 0.31 BTU/hr-in^2-F heat transfer coefficient was applied. The small gap between the BMI replacement nozzle ID and guide tube was modeled as "temperature coupling" representing the original configuration.

Each of the two BMI guide tube nozzle joints are at least 16" from the reactor vessel bottom head. There is no continuous flow through the guide tubes; therefore, the guide tube to the nozzle joint does not experience the same thermal cycles as the reactor shell. Consequently, the thermal transients that the reactor vessel is exposed to with respect to small temperature variation are excluded from this analysis. In addition, the pressure transients with small variation are excluded from this analysis because the pressure stress variation will be insignificant since the guide tube and the nozzle are thicker than what is required for the pressure load. Only transients with significant temperature or pressure variation such as plant heatup and cooldown, primary side hydrostatic test, primary side leak test, inadvertent depressurization, etc. are considered in this analysis. These transient loads were approximated by 1670 cycles with maximum applied pressure 2371 psia and temperature range from 120°F to 570.8°F. Temperatures of 120°F and 570.8°F were applied at the end of nozzle connected to RPVBH. A temperature of 70°F was applied on the bottom portion of the remaining pipe in the FEM Model.

For Design Condition analysis a uniform temperature of 650°F was applied.

Mechanical Loads

The connection between BMI nozzle and remaining pipe was exposed to external loads caused by seismic accelerations and operating pressure. Operating pressure creates the Cap Load, which is also applied to the FEM model. The pressure was applied to inner surfaces of the nozzle and remaining pipe. The Cap Load was applied on the bottom portion of the remaining guide tube in the FEM model.

Results

The fatigue cumulative usage factor (CUF) calculated in accordance with NB-3200 is 0.03 for the fillet weld between the guide tube and the nozzle and 0.24 for the guide tube. The CUF is negligible compared to the ASME Code allowable value of 1.0.

Revised BMI Nozzle Original J-Groove Weld Residual Stress Analysis Summary

Revised BMI Nozzle Stress Analysis
Summary of Dominion Proprietary Calculation C-3714-00-1

Purpose

The STP Bottom Mounted Instrumentation (BMI) nozzles are attached at the inside of the reactor vessel bottom head by a partial penetration J-groove weld. This document summarizes Dominion proprietary calculation C-3714-00-1, STP BMI Nozzle Stress Analysis. Dominion performs the calculation to document the results of finite element stress analyses of the BMI nozzle penetrations in the reactor vessel bottom head. In this analysis, a number of nozzle geometries spanning the range of penetration angles in the South Texas Project head are investigated.

Assumptions

The following modeling assumptions were used for the BMI nozzle modeling described in this calculation:

1. The range of clearance fits for the STP BMI nozzles may be calculated to be 0.5 to 2.5 mils radial. For the analysis, a 1.0 mil radial clearance fit was used.

2. Based on experimental stress-strain data and certified mill test report data for the materials, the room-temperature and 600°F elastic limit values were used in association with the elastic-perfectly plastic hardening laws.

The elastic limit values for the base materials (head shell and cladding), which undergo small strains during the analysis, are based on the 0.2% offset yield strength for the material. The elastic limit values for the weld materials, which undergo large strains during the analysis, are based on an average of the reported yield and tensile strengths.

3. Based on elevated temperature property data for Alloy 600, the 600°F yield strength value used in defining the multi-linear isotropic hardening curve for the nozzle material is 87.7% of the input room temperature value.

4. After the weld butter step is performed in the model but before the nozzle or J-groove welds are introduced, a stress relief pass at 1,100°F is performed by applying a uniform temperature to the model. The yield strength of the head, butter, and stainless cladding have been selected such that stresses in the low alloy steel material relax to 25 ksi or lower, while the other materials relax to 30 ksi.

5. For the J-groove weld simulation, two passes of welding were performed: an inner pass and an outer pass. The model geometry was designed such that each weld pass is approximately the same volume.

6. The model geometries for each of the BMI nozzle cases were based on nominal as-designed dimensions.

Methodology

ANSYS finite element analyses were performed using a model developed for commercial customers and described in a 1994 EPRI TR-103696 report on the subject of PWSCC of Alloy 600 components in PWR primary system service. The finite element model has been improved and refined since it was described in EPRI Report.

Finite Element Mesh

The model geometry used in this calculation makes use of approximately four times the mesh refinement in the J-groove weld areas relative to that shown in EPRI TR-103696 report. Additionally, the current model uses greater mesh refinement in other areas such as the nozzle, where five elements are used through the nozzle wall. Greater axial refinement through the head shell region above the J-groove weld was also used.

Material Properties

While the material properties used for the nozzle material continue to make use of multi-linear isotropic hardening, the material properties for the weld and weld buttering, head shell, and stainless steel cladding are now modeled using elastic-perfectly plastic hardening laws. This assumption gives more realistic stresses in the portions of the model where a high degree of plastic strain occurs at elevated temperatures, such as within the J-groove welds. The elastic limit for the weld materials is based on an average of the yield and tensile strengths.

As discussed in further detail below, this analysis included steps for weld depositing the butter and stress relieving the head and butter prior to the J-groove welding steps. In order to accurately model the stress relaxation in the butter region due to time at elevated temperature, the elastic limit for the Alloy 182 and head shell materials at temperatures near 1,100°F are reduced by a greater amount than in EPRI TR-103696 analyses.

Weld Butter Deposition and Thermal Stress Relief

Because the analyses performed in EPRI TR-103696 report were primarily concerned with calculating nozzle stresses, the J-groove butter and head shell region near the J-groove weld prep were assumed to be stress-free at the start of performing the J-groove weld. In order to more accurately determine the stresses in the J-groove weld buttering and head shell region near the J-groove weld, the current analysis model simulates the butter weld deposition process and the 1,100°F thermal stress relief of the head shell and butter. The butter weld deposition process is simulated using a single pass; i.e., the entire butter region is deposited at once. After completion of the butter deposition, the entire model is uniformly raised to 1,100°F. As noted above, the elastic limit material properties of the head shell and butter at 1,100°F are reduced relative to those used in EPRI TR-103696 report in order to simulate the stress relaxation caused by a multiple hour stress relief at 1,100°F.

Analytical Results Summary

The summary shows the maximum hoop and axial stresses at the ID of the nozzle, at the "uphill" (closest to the top of the head) and "downhill" circumferential planes, as well as "above" the weld (axial portion of the nozzle including the weld region and extending through the head shell) and "below" the weld (axial portion of the nozzle extending into the RPV). The maximum hoop stresses in the BMI nozzles are in the vicinity of the J-groove weld, and are in excess of the corresponding axial stresses, suggesting that PWSCC cracking should be axially oriented. The results also show that operating plus residual stresses are influenced by penetration angle, with higher angles generally leading to higher maximum hoop and axial stresses. Examining the above cases, the maximum ID hoop and axial stresses tend to occur at the downhill side of the nozzle.

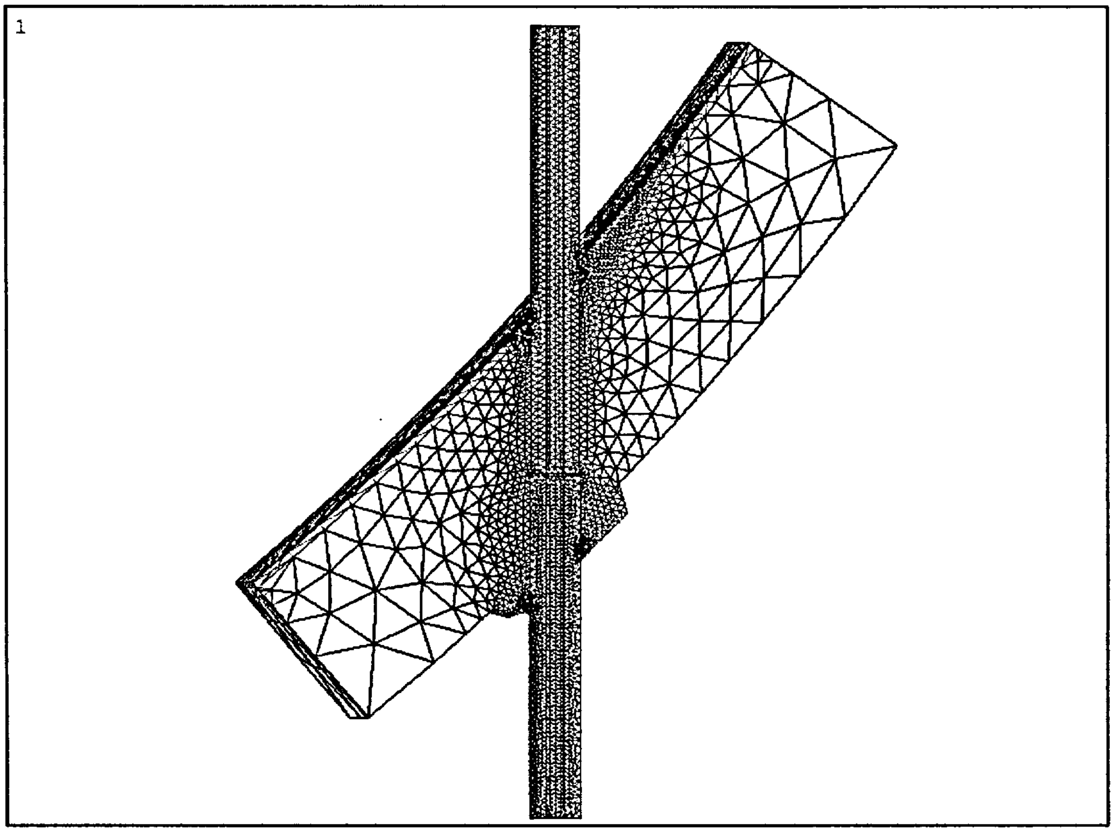
Analysis Cases and Selected Results

Nozzle Angle	Yield Strength (ksi)	Max Downhill ID Hoop Stress (ksi)	Max Uphill ID Hoop Stress (ksi)	Max Downhill ID Axial Stress (ksi)	Max Uphill ID Axial Stress (ksi)
5.5°	49.7	54.6	55.0	36.4	31.3
17.7°	49.7	55.3	54.9	43.7	33.1
35.7°	49.7	60.0	53.4	50.7	37.2
48.6°	49.7	66.2	55.0	49.1	40.1

It should be noted that the stresses reported in the above table are for the nozzle ID surface and are used to evaluate the likelihood and orientation of ID initiated PWSCC. Furthermore, it is noted that the absolute peak stresses in the nozzle tend to be located closer to the interface between the nozzle OD and the weld. The calculated values for the peak hoop stress in the STP BMI nozzles are as high as 75 to 100 ksi. While these values are substantially higher than the nominal yield strength, the Von Mises equivalent stresses at the locations of peak hoop stress have been verified to be consistent with the stress-strain curves input to the ANSYS model for the nozzle material.

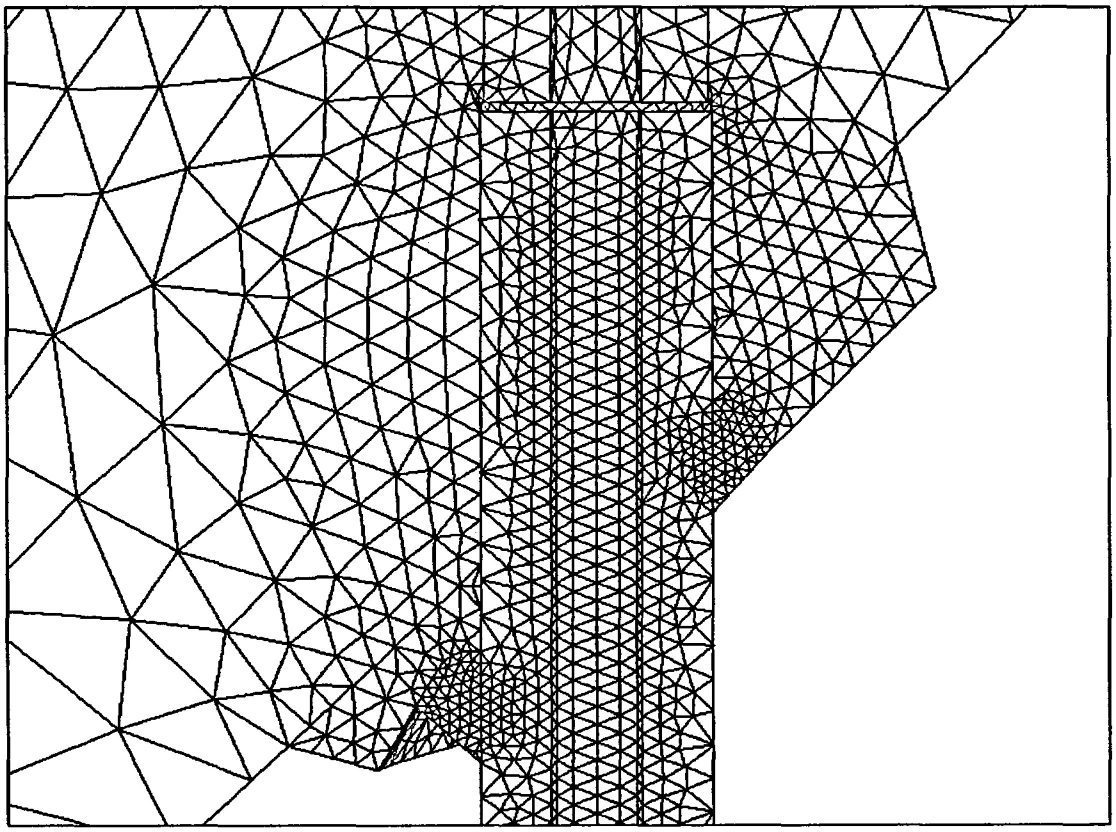
BMI Finite Element Model

STP BMI CONNECTION ANALYSIS AND QUALIFICATION
0105-0100187WN
(FANP 32-5028841)



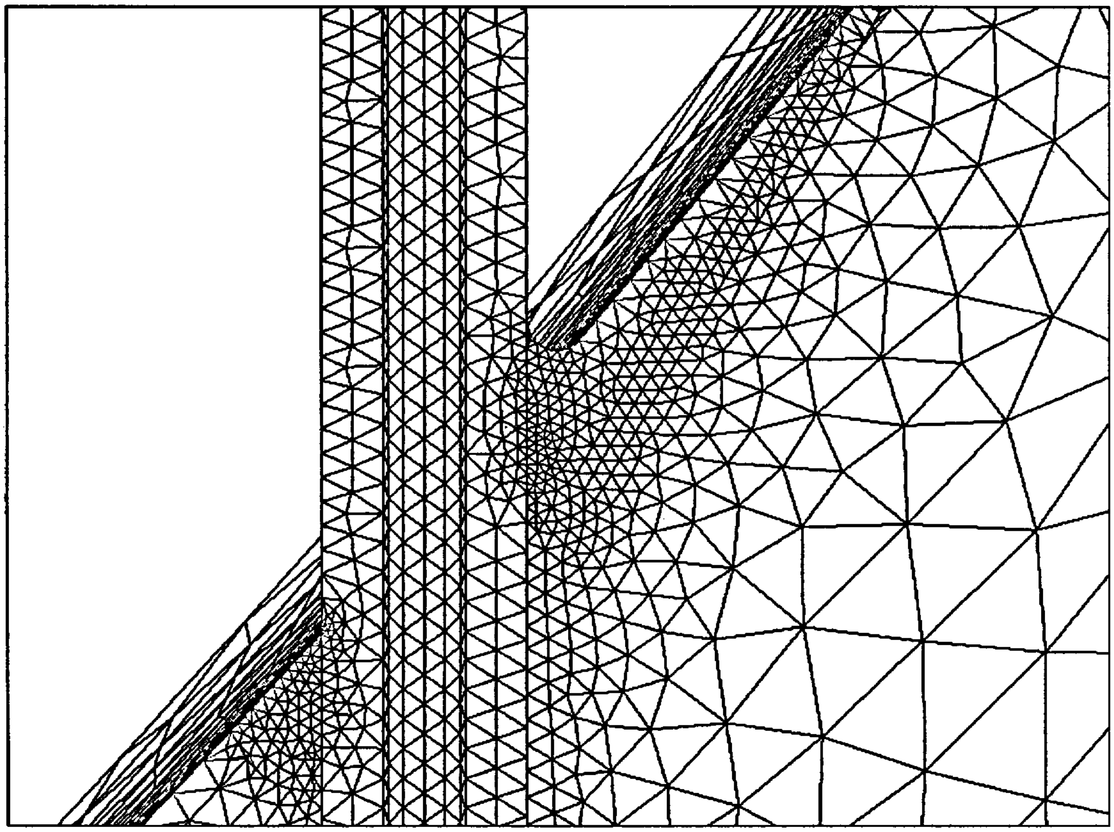
Finite element model showing mesh

STP BMI CONNECTION ANALYSIS AND QUALIFICATION
0105-0100187WN
(FANP 32-5028841)



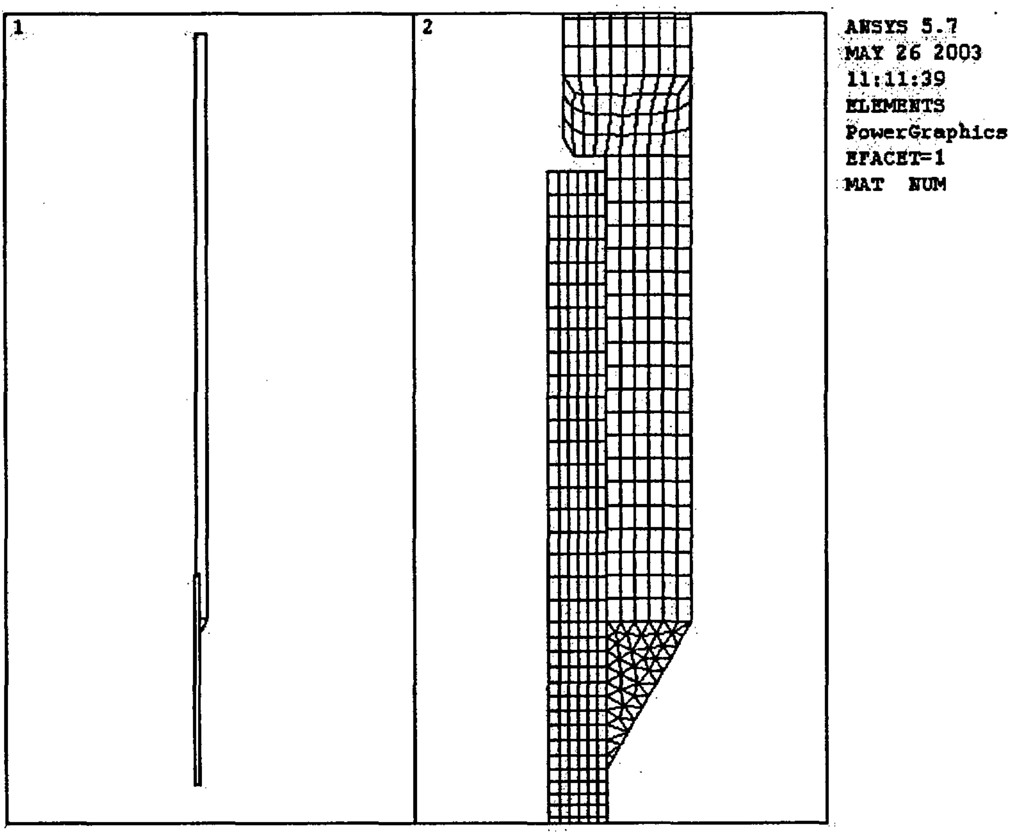
Finite element model showing mesh in the repair weld area

STP BMI CONNECTION ANALYSIS AND QUALIFICATION
0105-0100187WN
(FANP 32-5028841)



Finite element model in the existing weld area

STP BMI NOZZLE TO GUIDE TUBE CONNECTION ANALYSIS AND QUALIFICATION
0105-0100203WN
(FANP 32-5028839)



FEM Model of the Weld