ENCLOSURE

Evaluation of the Pressurizer Surge Line
for Stratified Flow Conditions
(Response to NRC Bulletin 88-11)

San Onofre Nuclear Generating Station Units 2 and 3

EXECUTIVE SUMMARY

Thermal stratification in the pressurizer surge line in pressurized water reactor power plants has been observed in the past. The stratification phenomenon can be explained by the difference in density between the pressurizer water and the reactor coolant system hot leg water. Although the potential for stratification is small during normal plant operation, it becomes significant during insurge and outsurge transient events, which occur during plant heatup and cooldown and during other modes of operation. Thermal stratification can be characterized by top-to-bottom thermal gradients in the pipe wall resulting in thermal stresses and pipe motion. The stresses and deformations produced by thermal stratification were not considered in the original design of the plant, and they could impact the fatigue life of the piping, or cause damage to the attached pipe supports and other components.

Recognizing the significance of thermal stratification in the surge line, and the other associated issues, the Nuclear Regulatory Commission (NRC) issued Bulletin 88-11 requesting that all utilities establish and implement a program to demonstrate the structural integrity of the surge line in view of thermal stratification. The Bulletin required utilities to perform inspections, conduct bounding analysis to provide justification for continued operation (JCO), collect plant data on thermal stratification and update the original design of the surge line, on a plant specific basis, to include the effect of thermal stratification. Collective effort in responding to some of these requests was allowed by the Bulletin, provided that similarity in design and operation is demonstrated.

In accordance with the requirements of Bulletin 88-11, Southern California Edison (SCE) has performed the requested inspection of the surge line, and the results were satisfactory. Also, SCE SONGS Units 2 and 3 surge lines were included in the collective effort by the Combustion Engineering Owners Group (CEOG). Two reports resulted from this collective effort documenting the data collection and reduction, structural and fatigue analysis of all surge lines (of the participating utilities) and shakedown analysis. These reports were used to meet the JCO and the bounding analysis requirements for SONGS Units 2 and 3. Furthermore, in accordance with the requirements of the NRC, SCE has performed a plant specific evaluation of the pressurizer surge lines including pipe supports and integral attachments, pressurizer surge nozzle, hot leg surge nozzles and the liquid sample line attached to the pressurizer surge line.

This report documents in detail the response of SCE to all the requirements of NRC Bulletin 88-11. These requirements are listed individually in Sections IV and V with SCE's response to each of these requests and the actions taken. The report also includes SCE's response to NRC staff recommendations provided in a Safety Evaluation Report. A summary of the scope of CEOG's reports on surge line thermal stratification is provided in Section V of this report. Section VII (Attachment A) of the report is dedicated to the plant specific evaluation performed by SCE in response to Item 1.d of Bulletin 88-11. A detailed description of the analysis results, system description and design input and analysis methodology is provided in Section VII.

Based on SCE's response to requirements of NRC Bulletin 88-11, it is concluded that all of these requirements are met for the licensed life of the plant.

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I. INTRODUCTION

The purpose of this report is to document the work performed by Southern California Edison (SCE) in response to the Nuclear Regulatory Commission (NRC) Bulletin 88-11 (Reference 1) which addresses pressurizer surge line flow stratification. The report documents the analyses performed and actions taken by SCE to ensure that Units 2 and 3 at San Onofre Nuclear Generating Station (SONGS) meet all the requirements of Bulletin 88-11.

Bulletin 88-11 was issued by the NRC on December 20, 1988 to address the issue of thermal stratification in the pressurizer surge line. The Bulletin requested that utilities establish and implement a program to confirm the structural integrity of the pressurizer surge line in pressurized water reactors (PWRs) under the effects of thermal stratification. It also requested that utilities inform the staff of the actions taken to resolve all the concerns associated with this issue.

An evaluation of the pressurizer surge line under stratified flow conditions was performed by Combustion Engineering (CE) for the Combustion Engineering Owners Group (CEOG) in response to Bulletin 88-11 concerns. This evaluation was documented in Report CEN-387-P, Revisions 0 and 1, which applies to all CEOG surge lines (References 5 and 6). The report responds generically to the NRC concerns for SONGS Units 2 and 3, and it was demonstrated by CE in this report that the structural integrity of all pressurizer surge lines in CE designed plants is maintained for the 40-year service life of the plant as requested by NRC Bulletin 88-11. Revision 1 of the CEOG report was reviewed and accepted by the NRC in a Safety Evaluation Report (Reference 15).

In addition to generic work performed for the CEOG (documented in References 5 and 6), SCE took actions to provide plant specific assurance of the structural integrity of SONGS Units 2 and 3 pressurizer surge lines including the impact of the additional fatigue and stresses caused by surge line thermal stratification. This report summarized the actions taken and the plant-specific analytical evaluations performed by SCE. These evaluations include, in addition to the pressurizer surge line, all components impacted by surge line thermal stratification. Attachment A of this report (included in Section VII) provides the details of the analysis results, the analysis methodology, system description and design input for the surge line and all other impacted components. The scope of the analysis includes structural and fatigue evaluations, effect of thermal striping and a recent ASME Code update as required by Bulletin 88-11.

I.1 BACKGROUND

As shown in Figure I-1, the Reactor Coolant System (RCS) at SONGS Units 2 and 3 consists of two loops connecting the reactor vessel to the steam generators. The system also includes a pressurizer, a surge line connecting the pressurizer and the RCS hot leg, pressurizer safety valves and a relief tank (quench tank). The pressurizer contains water and steam at saturated conditions, with the water-steam interface varying according to plant conditions. The steam bubble in the pressurizer acts as a cushion against sudden changes in RCS pressure. A system of electric heaters and water spray nozzles provide pressure control in the pressurizer.

Thermal stratification in the pressurizer surge line results from the difference in density between the hotter pressurizer water and the cooler RCS hot leg water. The hotter and less dense pressurizer water tends to float on top of the cooler and more dense RCS hot leg water as shown schematically in Figure I-2a. The potential for stratification in the surge line at power is relatively small since the difference between the pressurizer temperature and the RCS hot leg temperature, ΔT_{sys}, is small (less than 50°F at SONGS). As explained in detail in Section 5.1 of Attachment A of this report, the potential for stratification decreases as ΔT_{sys} decreases since Richardson number is proportional to ΔT_{sys}.

However, the potential for stratification increases considerably during plant heatup and cooldown where the temperature difference between the pressurizer and the hot leg (ΔT_{sys}) typically exceeds 300°F. Large values of ΔT_{sys} result in considerable difference in the density between the pressurizer water and the RCS water. Thus, the insurge (flow from the hot leg to the pressurizer) and outsurge (flow from the pressurizer to the hot leg) events occurring during plant heatup and cooldown could produce stratified flow conditions in the surge line. Quantitative assessment of the potential for thermal stratification is discussed in Section 5 of Attachment A in this report (Attachment A, Analysis Summary Report, is included in Section VII of this report).

Thermal stratification in the pressurizer surge line results mainly in the following effects that were not considered in the original design of the plant:

- Global thermal bending stress affecting the surge line, pipe supports and surge nozzles,

- Potential reduction in fatigue life of the plant due to global bending stress and local (peak) stress resulting from stratification and thermal striping in the pipe (see Figure I-2b).

A more detailed description of the above effects can be found in Attachment A along with an evaluation of their impact.

Concerns identified with thermal stratification in the pressurizer surge line were initiated by Safety Event Report (SER) number 25-87 issued by the Institute of Nuclear Power Operations (INPO) in September 1987. The report included examples of observed stratification effects in some PWR plants. These effects were in the form of excessive pipe top-to-bottom temperature differential and pipe motion. These concerns were addressed by NRC Bulletin 88-11 which requires utilities to resolve the issue of surge line thermal stratification on a plant-specific basis. In the following sections of this report, a detailed description of the requirements of Bulletin 88-11 is given along with the actions taken by SCE in response.

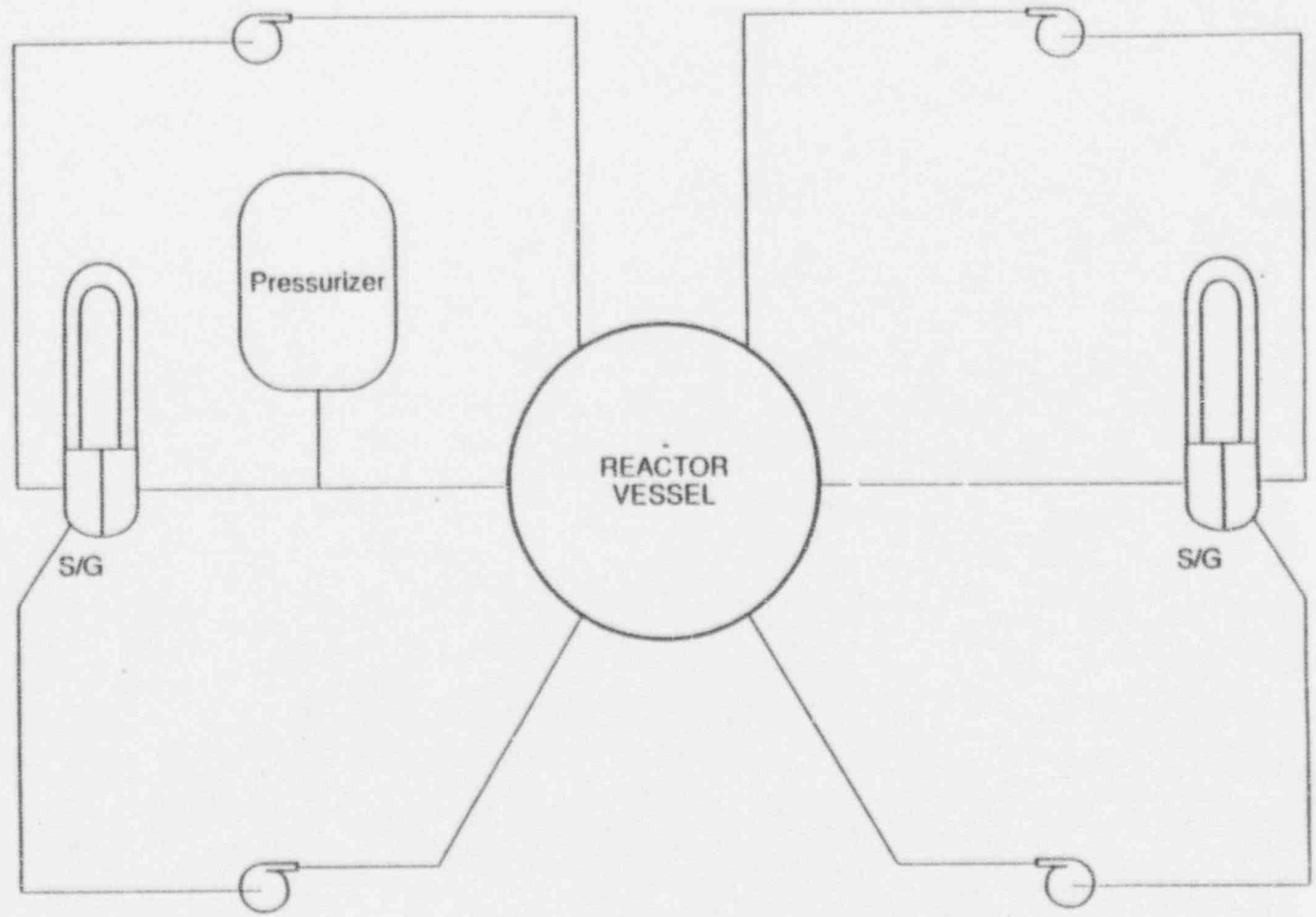

Figure I-1 Schematic of the Reactor Coolant System at SONGS 2 and 3

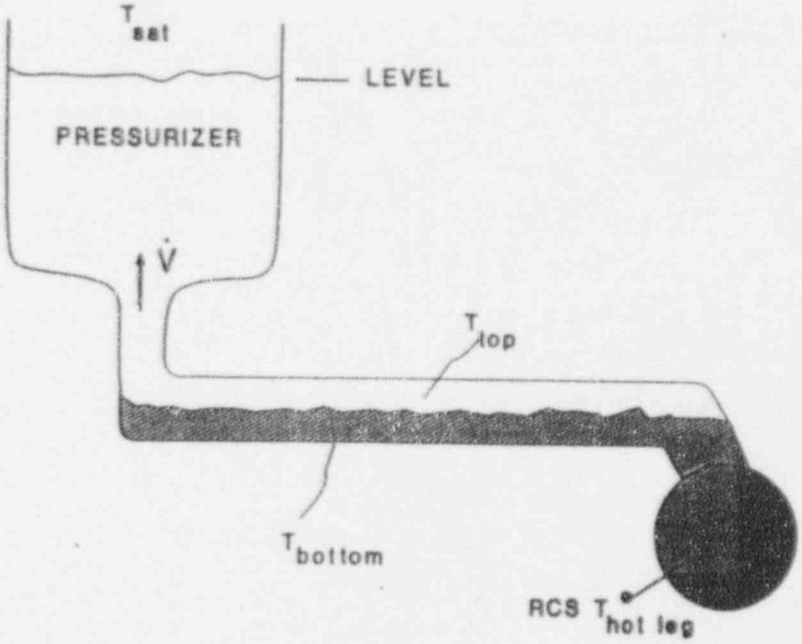

Figure I-2a Schematic of Stratified Flow in the Surge Line

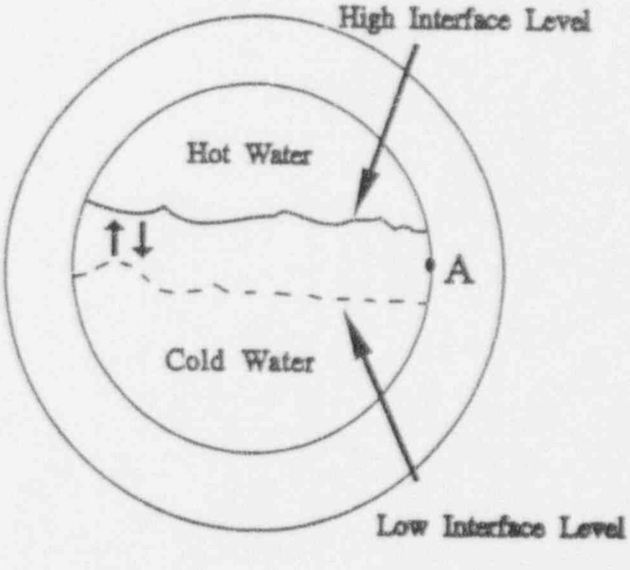

Figure I-2b Schematic of Thermal Striping in the Surge Line

II. SUMMARY OF RESULTS

In response to the requirements of NRC Bulletin 88-11, SCE has performed inspections and a plant specific evaluation of the pressurizer surge line at SONGS Units 2 and 3. The results of the evaluation and the inspection of the surge line demonstrate that all requirements of Bulletin 88-11 are satisfactorily met. Results of the analysis show that all the requirements of the ASME Code are satisfactorily met for the following components for the life of the plant:

- The surge line and its supports,
- The RCS hot leg surge nozzle,
- The pressurizer surge nozzle, and
- The liquid sample line

The results of the plant specific evaluation are in agreement with the results of CEOG Report CEN-387-P, Revisions 0 and 1 which concluded that all CE designed surge lines, including SONGS 2 and 3, meet all the applicable ASME Code requirements for the service life of 40 years. Detailed results of the ASME Code evaluation of the surge line and all impacted components can be found in Attachment A (Section VII) of this report.

Furthermore, all other actions and NRC requests and recommendations specified in Bulletin 88-11 have been completed as detailed in Sections IV and V of this report.

III. NRC SAFETY EVALUATION OF COMBUSTION ENGINEERING OWNERS GROUP (CEOG) REPORT CEN-387-P, REVISION 1

The NRC staff and its consultant, Brookhaven National Laboratory (BNL), have completed the review of the CEOG report CEN-387-P, "Pressurizer Surge Line Flow Stratification." The NRC concluded that the CEOG analysis adequately demonstrates that the bounding pressurizer surge line and surge nozzles meet all applicable American Society of Mechanical Engineers (ASME) Code stress and fatigue requirements for the 40-year design life of the facility considering the phenomena of thermal stratification and thermal striping.

NRC Bulletin 88-11 required licensees to update their stress and fatigue analyses to ensure compliance with applicable ASME Code requirements. The CEOG report can be used to update plant specific Code stress reports. NRC's SER requires SCE to verify the applicability of the CEOG bounding analysis in CEN-387-P, Revision 1, to SONGS Units 2 and 3. In addition, the SER requires confirmation that all actions required by Bulletin 88-11, including the updating of the plant specific stress and fatigue analyses, have been completed.

It should be noted that the NRC's safety evaluation (Reference 15) states that due to the fact that the elastic-plastic analysis was necessary in performing the pressurizer surge line stress evaluation, the NRC concurs with BNL's recommendation for performing enhanced inservice inspections to provide additional confidence in the structural integrity of the surge lines. Therefore, the NRC recommends that SCE perform a volumetric examination of critical elbow components as part of the future ASME Section XI inservice examinations. Examinations of elbow bodies, as well as welds, should be performed to ensure that the most highly stressed areas have not sustained damage. These additional examinations are staff recommendations only. However, it is requested that SCE inform the NRC of its intentions regarding the implementation of these staff recommendations.

III.1 SCE's Response to SER Recommendations

Current ASME Code Section XI inspection requirements for Class I piping (Table IWB 2500) covers only welds. The ASME Section XI Task Group on ISI optimization is presently chartered to establish recommendations for surge

line inspections, including welds and base metal. Progress has been delayed, with the concurrence of the NRC, for the NRC to complete review of the surge line analyses by the three vendor owner groups. Future inspection criteria for the surge lines can best be developed through the CEOG in cooperation with the ASME Task Group.

Therefore, performance of base metal volumetric examination will be evaluated to present Section XI requirements including future ISI programs on surge line inspection when the ASME Section XI criteria are modified by ongoing Code efforts. Until then, current Section XI inspections will continue. It should be noted that CEOG member utilities are currently active in the Task Group on ISI optimization and in the interim member utilities will cooperate with the ASME in developing future ISI requirements.

IV. NRC BULLETIN 88-11 REQUIREMENTS

IV.1 Actions Requested

Since thermal stratification was not addressed in the original design of the pressurizer surge line, the effects of this phenomenon were not included in the design basis analysis of any CE designed plant. Actions were already underway by the Utility Owner's Groups to address this phenomenon when, in December 1988, the NRC issued Bulletin 88-11 which requested that specific actions be taken by the utilities to address the issues associated with thermal stratification. A summary of these requested actions follows:

1. For all licensees of operating PWRs:

A. <u>Action 1.a</u>

Perform a visual inspection walkdown (ASME Section XI, VT-3) at the first available cold shutdown after the receipt of the bulletin which exceeds 7 days. This inspection should determine any gross discernable distress or structural damage in the entire pressurizer surge line, including piping, pipe supports, pipe whip restraints and anchor bolts.

B. <u>Action 1.b</u>

Perform a plant specific or generic bounding analysis to demonstrate that the surge line meets applicable design codes and other Final Safety Analysis Report (FSAR) and regulatory commitments for the licensed life of the plant. The analysis is requested within four months for the plants in operation over 10 years and within 1 year for plants in operation less than 10 years. If the analysis does not demonstrate compliance with these requirements, submit a justification for continues operation (JCO) and implement Actions 1.c and 1.d below.

C. <u>Action 1.c</u>

Obtain data on thermal stratification, thermal striping, and surge line deflections either by plant specific monitoring or through collective efforts among plants with a similar surge line design. If the collective effort option is selected, the licensee should demonstrate similarity in geometry and operation.

D. Action 1.d

Perform detailed stress and fatigue analysis of the surge line to ensure compliance with applicable ASME Code requirements, incorporating any observations from 1.a above. The analysis should be based on the applicable plant specific or referenced data, and should be completed no later than 2 years after the receipt of the bulletin. If the detailed analysis is unable to show compliance, submit a JCO and description of corrective actions for effecting long term resolution.

2. For all applicants for PWR Operating Licenses:

   This action is not applicable to SONGS.

3. Addressees are requested to generate records to document the development and implementation of the program requested by Items 1 or 2, as well as any subsequent corrective actions, and maintain these records in accordance with 10CFR part 50, Appendix B and plant procedures.

IV.2 Reporting Requirements

1. Addressees shall report to the NRC any discernable distress and damage observed in Action 1.a along with corrective actions taken or plans and schedules for repair before restart of the unit.

2. Addressees who cannot meet the schedule described in Items 1 or 2 of Actions Requested are required to submit to the NRC within 60 days of receipt of the bulletin an alternative schedule with justification for the requested schedule.

3. Addressees shall submit a letter within 30 days after the completion of these actions which notifies the NRC that the actions requested in Items 1.b, 1.d or 2 of Actions Requested have been performed and that the results are available for inspection. The letter shall include the justification for continued operation, if appropriate, a description of the analytical approaches used, and a summary of the results.

V. SCE RESPONSE TO NRC BULLETIN 88-11 ACTIONS

A. Action 1.a: Perform visual inspection

The Bulletin requires that a visual inspection be performed in accordance with ASME Section XI, VT-3 at the first available cold shutdown that exceeds seven days. Inspection performance and results are described below.

Inspection Performance

ASME Section XI, VT-3 requires that:

- Visual examination shall be conducted to determine the general mechanical and structural conditions of the components and their supports, such as the presence of loose parts, debris, or abnormal corrosion products, wear, erosion, corrosion and the loss of integrity at bolted or welded connections.
- Visual inspection may require as applicable to determine structural integrity, the mechanical measurement of clearances, detection of physical displacement, structural adequacy of supporting elements, connections between load carrying structural members and tightness of bolting.
- For component supports and component interiors, the visual inspection may be performed remotely with or without optical aids to verify the structural integrity of the component.

This inspection was accomplished in accordance with SCE approved CE visual examination procedure for preservice and inservice inspections, Reference 7. In this procedure, VT-3 examination standards are identified per the ASME Code requirements. Any relevant conditions which need to be recorded will be on the inspection form.

Inspection Results

The inspection was done by a level II examiner on January 22,1989 for Unit 2, and on April 18 and 19,1990 for Unit 3. The results of the visual inspection showed that there is no discernable stress or structural damage to the pipe and pipe supports. The results of the inspection were satisfactory.

B. **Action 1.b:** Bounding Evaluation

Action 1.b of Bulletin 88-11 requests that a bounding analysis be performed which demonstrates acceptability for the licensed life of the plant. In SCE's initial response to NRCB 88-11 (Reference 3), SCE stated that it would provide the NRC with the results of our plant specific analysis required by the bulletin. This letter also informed the NRC that SCE was participating in a CEOG program that would provide a generic bounding analysis upon which SCE's plant specific analysis would be based. CEOG submitted this analysis, CEN-387-P, Revision 0, dated July, 1989 (Reference 5), and the Revision 1 version, dated December 1991 (Reference 6).

CEOG Response to Action 1.b

In July 1989, CEOG submitted a report (Revision 0 of the CEN-387-P), which contained a bounding generic analysis performed using generic loading conditions and plant specific surge line data. This report documented the results obtained for a pressurizer surge line flow stratification evaluation. This evaluation addressed the impact of surge line thermal stratification and thermal striping as reported by INPO SER 25-87 and NRCB 88-11. The results of this evaluation demonstrate that the structural integrity of all CEOG pressurizer surge lines is maintained for their forty year design life as required by Bulletin 88-11.

The CEOG program consisted of collecting and reducing data (outside pipe wall temperature and displacements), developing thermal hydraulic models, defining new generic thermal load definitions, performing a stress and fatigue analysis and determining the fatigue life of the surge line. Based on measured outside wall temperatures, conservative thermal hydraulic models were developed for the thermal striping, stress and fatigue evaluations in a manner that was consistent with the test data.

The data noted above, was temperature data collected from SONGS Unit 3 (August 1988) surge line. SCE collected temperature data with surface mounted thermocouples during heatup. In addition, SCE recorded temperature data during the drawing of the steam bubble.

As a result of the analysis performed on the surge lines of the participating utilities, all of the surge lines exceeded the 3Sm elastic stress limit of Equation 12 of the ASME Code, Section III, Subsection 3650 (Sm is the allowable stress intensity). An elastic-plastic analysis was performed on the most highly stressed surge line to demonstrate that all surge lines shakedown, i.e., progressive distortion will not occur. Although the ASME Code stress limits were exceeded, shakedown was proven to occur and the fatigue usage factor is less than 1.0. All CEOG surge lines have a fatigue usage factor less than 1.0, and hence a fatigue life greater than 40 years.

Revision 0 of the report was divided into seven sections of analytical evaluations. The first two were associated with the data collection and reduction. This task consisted of a study of the pressurizer and reactor coolant system and the selection of thermocouple locations. Data was then collected and reduced to a manageable format. Transients, temperature ranges and generic loadings were then determined from the data and specific design conditions.

The third area of study concentrated on thermal hydraulic models. The purpose of this evaluation was to obtain an understanding of the relationship between the surface mounted thermocouples and the fluid conditions inside the surge line piping. The purpose of this task was to develop thermal hydraulic models that would conservatively calculate the pipe wall temperature distributions consistent with test data. In this task, the generic nature of the thermal loadings on the CEOG member surge lines was addressed as well as the correlations between the collected data and plant operations. Generic thermal load definitions were also developed.

The fourth evaluation consisted of structural analyses for the purpose of demonstrating shakedown, after some initial plastic deformation has occurred, and that progressive distortion does not occur throughout the operating life of the plant. An elastic-plastic analysis of the bounding surge line piping was performed to investigate its behavior with respect to thermal ratcheting, and to provide the strain range for the fatigue evaluation of the piping elbows, i.e., the piping component most severely affected by stratified flow loadings.

The fifth section of the analysis addressed the issue of thermal striping. This analysis used a one-dimensional heat transfer and structural finite element model to investigate the thermal stresses due to the oscillations at the hot-cold interface during stratified flow.

The sixth and seventh sections of the report address the cyclic fatigue life of the surge line for all transients including thermal stratification and thermal striping. This involved modeling of the surge lines to include supports and then applying all generic loadings.

The results and conclusions of the CEOG report are applicable to SONGS. Therefore, thermal loading characteristics are generic for all of the CEOG participants. In addition, the largest temperature difference between the pressurizer and the RCS for all CE-designed plants participating in the program (system ΔT) was around 320 to 340°F based on plant heatup conditions. This limiting system ΔT was then applied to all plants configuration.

The NRC reviewed this revision 0 of the report and issued a letter in August 1990 with a number of questions and concerns. Based on the NRC concerns the CEOG approved the third task in October 1990 to resolve NRC concerns. During April 1990, surge line cooldown data were collected at SONGS and other CEOG plant and analyzed. Subsequently, meetings and phone conversations were held with the NRC, and consequently CEOG issued Revision 1 of the report to resolve the NRC questions. Revision 1 of the report was reviewed by the NRC staff and its consultant, Brookhaven National Laboratory, and staff concluded that: "the CEOG analysis adequately demonstrates that the bounding surge line and nozzles meet ASME Code stress and fatigue requirements for the 40-year design life of the facility considering the phenomenon of thermal stratification and thermal striping." This NRC staff evaluation was documented in a letter from the NRC to H. B. Ray of SCE (Reference 15).

Therefore, all ASME Code requirements were met and shakedown was demonstrated. To confirm that the intent of the Code requirements have been met, an ASME Code Inquiry has been submitted, and the response was favorable. All CEOG surge lines have a fatigue usage factor of less than 1.0 and hence a fatigue life of greater than 40 years. This analysis included the phenomena of thermal stratification and thermal striping in the fatigue and stress evaluations. For SONGS, it is confirmed that all specific surge line support capabilities are within the range assumed in this analysis.

C. Action 1.c: Plant Monitoring

Requested Action 1.c of NRCB 88-11 states that utilities may obtain surge line monitoring data either by plant specific monitoring or through a collective effort. If the latter option is selected, similarity in geometry and operation should be demonstrated. CEOG, in a combined effort with SCE, obtained plant specific data through monitoring of the surge line at SONGS Unit 3.

The pressurizer surge lines at SONGS Units 2 and 3 are approximately seventy-nine feet long. Each line is made up of a 12 inch schedule 160 pipe that runs primarily horizontal, attaching vertically to the bottom of the pressurizer and the top of the RCS hot leg. Detailed description of the surge line geometry, support configuration and material properties can be found in Attachment A of this report.

Pipe wall temperature monitoring was performed on the SONGS Unit 3 surge line. Two surface mounted thermocouples (T/C) were positioned at the top (0°) and bottom (180°) of the surge line piping at location 1 (see Figure 4.9 of Attachment A). Locations 2, 3, 4, and 5 were fitted with bands of six thermocouples that were 60° apart starting from the top (0°). Location 6 had two thermocouples, one on the east and one on the west side of the pipe. The T/C's used were Omega Type K with Type K wiring. The wiring was run outside of containment to the plant computer, a GOULD 32/9780. All thermocouple data were recorded at two minute intervals by the plant computer. A more detailed description of the pipe wall temperature monitoring and a summary of the results can be found in Section 4 of Attachment A.

Plant parameters were also collected at two minute intervals. These included the following:

- Cold leg temperature,
- Surge line temperature,
- Pressurizer pressure and level, and
- Reactor coolant pump status.

During heatup, data recording commenced prior to drawing the bubble in the pressurizer, and continued until the plant was at normal operating temperature and pressure. During cooldown, data were collected at 100% power and continued until the bubble in the pressurizer was collapsed. The plant

computer produced a hard copy of the recorded data. This data was entered on to floppy computer disks and plotted.

The data described above was used in CEOG analysis and is included in their acceptability report for Items 1.b and 1.d.

D. **Action 1.d:** Update Stress and Fatigue Reports

CEOG issued Revision 1 of Report CEN-387-P in response to additional NRC questions about Revision 0 of the same report. Revision 1 also serves as a part of SCE response to Action 1.d.

This Revision 1 effort was divided into eight tasks. The first task was data collection during plant heatup and cooldown (noted above). This consisted of a study to determine what plant data relevant to the issue of surge line flow stratification could be collected.

The second task was to reduce the plant data and generate time versus temperature plots. This task also involved determining which plant events resulted in surge line thermal transients. In this task, the generic nature of the thermal loadings on the CEOG member surge lines was addressed as well as the correlations between the collected data and plant operations.

The third task concentrated on thermal hydraulic modeling. The purpose of this evaluation was to obtain an understanding of the relationship between the temperature measured by the surface mounted thermocouples and the fluid conditions inside the surge line piping. This study determined how to conservatively calculate the pipe wall temperature distribution using thermal hydraulic models.

The fourth task was to develop revised thermal transients for the pressurizer surge line in view of thermal stratification. Generic thermal load definitions were developed for use in both the structural and striping analyses.

The fifth analysis addressed the issue of thermal striping. This analysis used a one dimensional heat transfer and structural finite element model to investigate the thermal stresses due to the oscillations at the hot-cold interface during stratified flow.

The sixth evaluation consisted of a structural analysis of the surge line. The first step in the evaluation was to model all CEOG surge lines. An elastic piping analysis of each surge line using the revised surge line thermal transients was then performed. The second step was to perform an elastic-plastic analysis for the bounding surge line (bounding was based on the results of the elastic analysis).

The seventh task was performed to evaluate the cyclic fatigue life of the surge line for all transients including thermal stratification, thermal striping and Operating Basis Earthquake (OBE) seismic loading. This involved applying the results from the fifth and sixth evaluations to each plant surge line. All load states were included and the fatigue analysis was performed in accordance with the ASME Code cycle combination methodology.

The eighth task was performed to determine the effect on both the pressurizer surge nozzle and the RCS hot leg surge nozzle. This nozzle evaluation was performed per the requirements of the applicable ASME Code.

In addition to the CEOG evaluation of the surge line, SCE performed a <u>plant specific</u> evaluation of SONGS Units 2 and 3. A summary description of this plant specific evaluation including analysis results, analysis methodology, system description and design input is documented in Attachment A (Section VII) of this report.

As part of the plant specific analysis, design specifications for the surge line, pressurizer surge nozzles, and RCS hot leg surge nozzle are being updated to include the new plant design load cycles from thermal stratification. This effort is being performed by the CEOG in behalf of SCE.

Additional NRC Requests

<u>Response to Request No. 2:</u>

This item requests information from all applicants for PWR Operating Licenses and is therefore not applicable since SONGS has its operating license.

<u>Response to Request No. 3:</u>

This item requests addressees to generate records to document the development and implementation of the program requested by Items 1 and 2.

SCE has compiled records to document the development and implementation of the program requested by Actions 1.a, 1.b, 1.c, and 1.d, as well as any subsequent corrective actions. These records are maintained in accordance with 10 CFR Part 50, Appendix B and the plant procedures.

V.1 SCE Response to Reporting Requirements

1. This item requires the addressees to report to the NRC any discernable distress and damage observed during the walkdown requested in Action 1.a along with corrective actions.

   SCE has completed the inspection of the pressurizer surge lines and the results were satisfactory. These inspections were performed on January 22, 1989 for unit 2 and April 18, 1990 for Unit 3. There was no evidence of bowing damage, structural distress damage or visible degradation.

   All supports appeared to be intact, and no wear or fretting of the pressurizer surge line was noted at support locations.

2. This item requires the addressees who cannot meet the schedule described in Items 1 and 2 of Actions requested to submit to the NRC within 60 days of receipt of the bulletin and alternative schedule with justification for the requested schedule.

   This item was addressed initially in Revision 0 of the CEOG report (Reference 5). This report addresses all of the NRC concerns as discussed at the September 1990, May 1991, and September 1991 meetings between the CEOG and the NRC.

3. This item requires the addressees to submit a letter within 30 days after the completion of the action items 1.b, 1.d, or 2 to notify the NRC that the results are available for inspection.

On March 8, 1989, via a letter to the NRC (Reference 8), SCE informed the NRC of its participation in the CEOG program ("Reduction and Analysis of Pressurizer Surge Line Data Collected from CEOG Plants") and stated that it would provide the NRC with the results of SONGS 2 and 3 plant specific analysis required by NRCB 88-11 by February 4, 1991. By Reference 9, the NRC acknowledged that it would be acceptable for SCE to work through the CEOG to address the issues discussed in Bulletin 88-11. On March 1, 1991 SCE submitted another letter (Reference 10) to the NRC to confirm that the

original due date of February 4, 1991, was superseded by the September 5, 1990 meeting (documented in Reference 11), and the new schedule for completing our plant specific analysis is December 30, 1991.

On May 7 and 8, 1991, the NRC staff audited the CEOG progress (Reference 12). The audit identified additional items that ABB/Combustion Engineering needs to resolve. A second meeting between the NRC and the CEOG was held on September 18 and 19, 1991. This meeting resolved many of the NRC staff's concerns (Reference 13). In this meeting, the NRC agreed to a link between the plant specific analysis due date and the issuance of a favorable NRC Safety Evaluation Report (SER) for the CEOG bounding analysis. In addition, the NRC acknowledged that a Justification for Continued Operation (JCO) is not required from the utilities if the CEOG analysis report is issued before December 31, 1991. Therefore, SCE submitted a letter to the NRC (Reference 14) stating that our report will be submitted to the NRC within either 90 days after the issuance of a favorable SER, or by September 1, 1992, whichever is later.

With the submittal of the CEOG analysis which includes a description of the analytical approaches and a summary of the results, and this report, the action in Item 3 above is completed.

VI. LIST OF REFERENCES AND FIGURES

VI.1 REFERENCES

1. NRC Bulletin No. 88-11, Pressurizer Surge Line Thermal Stratification, dated December 20, 1988.

2. SCE Calculation No. N-0220-027, Revision 0, Subject: SONGS Unit 2&3 Maximum Pressurizer and RCS Hot Leg Temperature Differential During Heatup.

3. Letter from F.R. Nandy (SCE) to Document Control Desk (NRC) dated March 8, 1989, Subject: Pressurizer Surge Line Thermal Stratification.

4. SCE letter to CE dated November 22,1991.

5. Combustion Engineering Owners Group (CEOG) report CEN-387-P, Revision 0, Pressurizer Surge Line Thermal Stratification Evaluation, July 1989.

6. Combustion Engineering Owners Group (CEOG) report CEN-387-P, Revision 1, Pressurizer Surge Line Thermal Stratification Evaluation, December 1991.

7. CE Visual Examination Procedure for Preservice and Inservice Inspection, SO23-ESS-066.

8. Letter from F. R. Nandy (SCE) to Document Control Desk (NRC) dated March 8,1989; Subject: Response to NRC Bulletin 88-11.

9. Letter from L. W. Kokajko (NRC) to Messrs. Harold B. Ray (SCE) and G. D. Cotton (SDG&E) dated July 25, 1990;"Evaluation of Combustion Engineering Owners Group Bounding Analysis."

10. Letter from F. R. Nandy (SCE) to Document Control Desk (NRC), dated March 1,1991; Subject: NRC Bulletin, Pressurizer Surge Line Thermal Stratification, SONGS Units 2&3.

11. Letter from Edward C. Sterling (CEOG) to J. T. Larkins (NRC) dated October 24, 1990, "Evaluation of Combustion Engineering Owners Group Bounding Analysis Regarding NRC Bulletin 88-11."

12. Letter from L. E. Kokajko (NRC) to Messrs. H. B. Ray (SCE) and G. D. Cotton (SDG&E), dated September 13, 1991,"Pressurizer Surge Line Thermal Stratification, Bulletin 88-11."

VI.1 REFERENCES - cont.

13. Letter from P. J. Hijeck (CEOG) to CEOG Analysis Subcommittee Members dated September 30, 1991,"NRC/CEOG Pressurizer Surge Line Stratification meeting of September 18 & 19, 1991 (CEOG Task 662)."

14. Letter from R. M. Rosenblum (SCE) to Document Control Desk (NRC) dated December 17, 1991; NRCB 88-11 Plant Specific Analysis Submittal Schedule.

15. Letter from Mel B. Fields (NRC) to Harold Ray (SCE) dated August 2, 1993. Subject: Safety Evaluation for CEOG Report CEN-387-P, Revision 1, "Pressurizer Surge Line Thermal Stratification Evaluation," (Bulletin 88-11).

VI.2 LIST OF FIGURES

1. Figure I-1 Schematic of the Reactor Coolant System at SONGS 2 and 3.

2. Figure I-2a Schematic of Stratified Flow in the Surge Line.

3. Figure I-2b Schematic of Thermal Striping in the Surge Line.

VII.1 ANALYSIS SUMMARY REPORT

THERMAL STRATIFICATION IN THE PRESSURIZER SURGE LINE

SAN ONOFRE NUCLEAR GENERATING STATION

UNITS 2 AND 3

ATTACHMENT A - TABLE OF CONTENTS

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1 PURPOSE

Item 'd' of Bulletin 88-11 requires plant specific update of the pressurizer surge line stress and fatigue analyses to ensure compliance with the (ASME) Code requirements. Accordingly, the pressurizer surge lines at SCE's SONGS Units 2 and 3 were reanalyzed to include the effect of thermal stratification. This effort comprises the tasks described in Sections 1.1 through 1.5.

It should be noted that in addition to the plant specific evaluation summarized in this attachment, a generic bounding evaluation was issued by CEOG. This report was reviewed and approved by the NRC, as explained in Section V of this report. The purpose of plant specific analysis required by the bulletin is to build upon the CEOG work, and to demonstrate the SONGS Units 2 and 3 are bounded by the results included in the CEOG report.

1.1 Pressurizer Surge Line Structural and Fatigue Analysis

The purpose of this task is to perform an analysis per ASME Code, Section NB-3650 on the pressurizer surge line including the effect of thermal stratification. The purpose of the structural analysis step of this task is to generate the response of the surge line to unit thermal and mechanical loads. This response was obtained in terms of forces and moments at different locations. The thermal loads represent both stratified and non-stratified conditions. The results of the structural analysis are used in a subsequent ASME Code evaluation to ensure compliance with the Code under the updated design bases including thermal stratification. In this evaluation, applicable Code equations stresses are to be calculated and compared with the corresponding allowables. Fatigue usage factors were calculated based on the design transients, listed in Section 4, for the service life of the plant.

In addition to generating the data necessary for the Code evaluation, the structural analysis of the surge line is also used to calculate the following:

(a) Reaction loads at the pressurizer and hot leg surge nozzles.

(b) Rigid support loads and displacements at all support locations. These results are generated for use in the pipe support evaluation.

(c) Calculate the thermal movement at the liquid sample line branch connection, which is used to update the sample line structural analysis.

Calculation of support loads and thermal movement is conservatively based on the most severe stratified flow conditions, from past operation.

1.2 Surge Nozzles

The surge nozzles at the RCS hot leg side and the pressurizer side of the surge line are impacted by thermal stratification, and require re-evaluation. Structural and fatigue evaluations were performed on both nozzles to ensure compliance with the Code requirements.

1.3 Integral Attachments

Each of the pressurizer surge line at SONGS Units 2 and 3 has one rigid support, four snubbers and two spring hangers as shown in Figure 4.2. The rigid support has two rectangular lugs welded to the surge line. Similarly, each snubber is attached to the surge line by means of a dummy pipe. Two dummy pipes are horizontal and the other two are vertical. The purpose of this analysis task is to perform a fatigue evaluation on the rectangular lug and the bounding dummy pipe.

1.4 Liquid Sample Line

Each of the pressurizer surge line at SONGS Units 2 and 3 has one sample branch line as shown in Figure 4.2. One of the purposes of the structural analysis of the surge line (Section 1.1) is to produce updated thermal movement at the liquid sample line branch connection under stratified flow conditions in the surge line. The purpose of this task is to re-analyze the liquid sample line using the calculated thermal movement to ensure compliance with the Code requirements when stratified flow conditions exist in the surge line. Conservatively, the evaluation is based on the most severe thermal stratification conditions.

1.5 Pipe Support Evaluation

The purpose of this task is to perform a pipe support re-evaluation in view of thermal stratification in the pressurizer surge line (see the pipe support configuration in Figure 4.2). This evaluation uses updated thermal loads and displacements based on the results of the structural analysis of the surge line (see Section 1.1 above) including the most severe thermal stratification condition.

2 RESULTS/CONCLUSIONS

Structural and fatigue analyses of the pressurizer surge line were performed per the ASME Code to evaluate the effect of thermal stratification on the pressurizer surge line, the RCS hot leg surge nozzle, the pressurizer surge nozzle, and the surge line integral attachments. The evaluation includes the effects of thermal striping. Thermal stress ratchet analysis was performed per the ASME Code when required. Results also include an evaluation of the pressurizer surge line support loads and displacements. Furthermore, a re-analysis of the liquid sample line was performed since it is affected by thermal stratification in the surge line. A summary of these results is given in Sections 2.1 through 2.4

2.1 Pressurizer Surge Line Piping and Integral Attachments

Structural and fatigue analysis of the pressurizer surge line were performed per the ASME Code to include the effect of thermal stratification. Results of the analysis are summarized in Tables 2.1 and 2.2. These tables summarize the results of the stress and fatigue evaluations at different piping locations (see Figure 4.2 for node point definition). Specifically, a total of 18 piping locations, identified by the ANSYS node point numbers shown in Figure 4.2, were evaluated per NB-3600 rules. The evaluation was performed on the inside and outside surfaces at each ANSYS piping node point location.

The stress limit of equation (10) of ASME Code, Subsection NB-3653 was exceeded at ten of the 18 locations shown in Figure 2.1 on the inside diameter of the pipe. Simplified elastic-plastic analysis rules were invoked at these ten locations, and Code Equations 12 and 13 stresses were evaluated. Also, a K_e penalty factor was used in the fatigue analysis as required by the Code. Furthermore, a thermal stress ratchet was performed in accordance with NB-3653.7 requirements (see Section 2.1.3).

Similarly, Equation (10) stress limit was exceeded at 12 outside diameter locations. Simplified elastic-plastic analysis rules were invoked for 8 of these 12 locations, and Code Equations 12 and 13 stresses were evaluated. Also, a K_e penalty factor was used in the fatigue analysis as required by the Code. Furthermore, a thermal stress ratchet was performed in accordance with NB-3653.7 requirements (see Section 2.2.3). The remaining 4 locations that did not meet the simplified elastic-plastic requirements met the Code requirements for shakedown. The Combustion Engineering Owners Group (CEOG) evaluation of the pressurizer surge line (Reference 3) has demonstrated shakedown for all surge line locations. Analysis results, however, show that the 4 locations that did not meet the simplified elastic-plastic requirements are bounded by the Reference 3 evaluation. Accordingly, it is concluded that the shakedown analysis of Reference 3 is bounding.

Table 2.1 Stress and Fatigue Evaluation[1],[2] - Inside Diameter

Location on the surge line	Eq (10)/ S_m	Eq (12)/ S_m	Eq (13)/ S_m	Fatigue usage factor
Node point: 3	3.00	1.98	1.33	0.536
4	3.88	2.82	1.49	0.981
12	3.99	2.84	1.39	0.787
14	3.85	2.85	1.41	0.815
22	3.78	2.80	1.40	0.705
23	2.00	1.10	0.96	0.371
28	1.91	0.98	1.10	0.453
29	3.37	2.23	1.35	0.438
37	3.31	2.17	2.17	0.438
38	1.61	0.75	1.08	0.440
44	1.61	0.76	1.02	0.340
46	2.80	1.87	1.39	0.422
54	3.18	2.07	1.39	0.431
57	3.19	2.09	1.39	0.433
65	3.06	1.98	1.37	0.429
67	3.07	1.89	1.90	0.993
68	2.15	1.13	1.49	0.697
69	2.29	1.24	1.44	0.536

Notes: (1) See Figure 4.2 for node point definition
(2) See Section 5.3.1 of this attachment for details of stress limits and applicable ASME Code criteria

Table 2.2 Stress and Fatigue Evaluation[1],[2] - Outside Diameter

Location on the surge line	Eq (10)/ S_m	Eq (12)/ S_m	Eq (13)/ S_m	Fatigue usage factor
Node point: 3	3.50	2.49	1.39	0.096
4	4.59	3.55	1.58	0.401
12	4.72	3.58	1.46	0.247
14	4.55	3.59	1.48	0.271
22	4.46	3.53	1.47	0.191
23	2.27	1.39	0.96	0.003
28	2.16	1.23	1.15	0.005
29	3.94	2.80	1.40	0.018
37	3.87	2.73	1.46	0.015
38	1.79	0.94	1.12	0.004
44	1.79	0.96	0.96	0.002
46	3.22	2.35	1.46	0.004
54	3.71	2.61	1.46	0.007
57	3.72	2.64	1.46	0.009
65	3.56	2.50	1.42	0.008
67	3.38	2.16	1.96	0.089
68	2.48	1.42	1.56	0.024
69	2.69	1.57	1.53	0.015

Notes: (1) See Figure 4.2 for node point definition
(2) See Section 5.3.1 of this attachment for details of stress limits and applicable ASME Code criteria. Section 5.3.1 also addresses the cases where Equation 12 limit is exceeded

2.1.3 Thermal Stress Ratchet

In accordance with the rules of ASME Code, Subsection NB-3653.7, thermal stress ratchet check was performed at locations where Code Equation (10) stress limit is exceeded. Similarly, the rules of NB-3222.5 require a thermal stress ratchet check to be performed. The methodology of the this check is summarized in Section 5 of this summary report.

Results of the thermal ratchet check indicate that all ASME Code requirements are satisfied.

2.1.4 Thermal Striping

Thermal striping analysis was performed, and the fatigue usage factor due to thermal striping was shown to be less than 0.01. It occurs at the hot/cold fluid interface at the middle of the pipe, while the accumulated usage factor due to all other loadings occurs at either the top or the bottom of the pipe. Therefore, the thermal striping fatigue usage factor was not included in the usage factor calculations. It should be noted, however, that the fatigue usage factor of 1.0 is met at all locations even when the thermal striping is included.

Description of the methodology of thermal striping fatigue analysis can be found in Section 5 of this attachment.

2.2 Surge Nozzles

The pressurizer surge nozzle and the RCS hot leg surge nozzle were evaluated per Subsection NB-3200 of the ASME Code (Design by Analysis). Results are summarized in Tables 2.3 and 2.4.

Table 2.3 Summary of Pressurizer Surge Nozzle Evaluation

	Maximum $(P_L+P_B+Q)/S_m$	Maximum(1) $(P_L+P_B+Q)/S_m$	Fatigue Usage Factor
Nozzle Inside Diameter	3.15	1.00	0.252
Nozzle Outside Diameter	3.01	1.00	0.009

Notes: (1) Excluding thermal bending.

Table 2.4 Summary of Hot Leg Nozzle Evaluation

	Maximum $(P_L+P_B+Q)/S_m$	Maximum(1) $(P_L+P_B+Q)/S_m$	Fatigue Usage Factor
Nozzle Inside Diameter	3.28	1.01	0.767
Nozzle Outside Diameter	3.43	1.01	0.062

Notes: (1) Excluding thermal bending.

It should be noted that in Tables 2.3 and 2.4 the limit on $(P_L+P_B+Q)/S_m$ is 3.0 per NB-3222.2. However, as shown in Subsection NB-3228.5 of the ASME Code, this limit can be exceeded provided that:

(a) $(P_L+P_B+Q)/S_m$, excluding thermal bending, is lass than 3.0
(b) A penalty factor, K_e, is applied to the alternating stress, S_a, in the fatigue analysis, and
(c) The fatigue usage factor is less than 1.0.

Details of the applicable criteria can be found Section 5.3.1 of this attachment.

Accordingly, it is concluded that the requirements of NB-3200 are met.

2.3 Integral Attachments - Section 2.3

Each surge line at SONGS Units 2 and 3 has five integral attachments, as shown in Figure 4.2. These attachments include rectangular lugs at the rigid support (node point 38), and dummy pipes at all snubber locations (node points 26, 28, 38 and 44). The effect of thermal stratification is greater on horizontal dummy pipes since they are subjected to greater thermal gradients during stratified flow conditions in the surge line. Therefore, a horizontal dummy pipe was conservatively selected for analysis. Integral attachments were evaluated per Subsection NB-3650 in combination with Code Cases N-122-1 and N-391-1. The methodology of this evaluation is described in Section 5.3.4 of this attachment. Tables 2.5 and 2.6 summarize the results obtained for the integral attachments on the inside and outside diameters of the pipe, respectively.

Table 2.5 Integral Attachments Evaluation(1) - Inside Diameter

	Maximum Eq 10 Stress Ratio	Maximum Eq 12 Stress Ratio	Maximum Eq 13 Stress Ratio	Fatigue Usage
Rectangular lug(2)	2.25	0.75	1.28	0.740
Dummy pipe(3)	4.15	0.76	1.37	0.562

Notes: (1) See Section 5.3.1 of this attachment for details of the application of Code Cases N-122-1 and N-391-1
(2) Code Case N-122-1 used
(3) Code Case N-391-1 used

Table 2.6 Integral Attachments Evaluation(1) - Outside Diameter

	Maximum Eq 10 Stress Ratio	Maximum Eq 12 Stress Ratio	Maximum Eq 13 Stress Ratio	Fatigue Usage
Rectangular lug(2)	2.46	0.94	1.32	0.055
Dummy pipe(3)	4.33	0.96	1.39	0.064

Notes: (1) See Section 5.3.1 of this attachment for details of the application of Code Cases N-122-1 and N-391-1
(2) Code Case N-122-1 used
(3) Code Case N-391-1 used

2.3 Liquid Sample Line Structural Analysis

The maximum displacement at the pressurizer liquid sample branch connection was calculated for a maximum recorded system temperature differential (ΔT_{sys} = 386°F) per reference 16. This evaluation is similar to the existing evaluation of the branch line, except that the thermal displacements at the branch line connection include the effect of thermal stratification in the surge line.

The structural analysis of the liquid sample line was performed for SONGS Units 2 and 3 under the thermal stratification conditions described above. Results of the analysis show that all ASME Code requirements are met. Pipe supports were evaluated for the new loads, and were found adequate under the new loads.

2.4 Pipe Support Loads

As shown in Figure 4.2, each pressurizer surge line at SONGS has one rigid support, four snubbers and two spring hangers. The Rigid support load and displacements at all snubber and spring hanger locations were calculated under maximum thermal stratification conditions in the surge line. The rigid support was evaluated, and was found capable of sustaining the new faulted load. Similarly, the displacements at all snubber and spring hanger locations are within range, and no resetting is required.

3 ASSUMPTIONS

1. Thermal stratification, in the horizontal part of the pressurizer surge line, is constant in the axial direction of the pipe. This assumption is conservative, since an axially varying stratification profile results in lower bending of the pipe, and consequently lower stresses.

2. Thermal stratification does not occur in the vertical runs of the pressurizer surge line, or the nozzle at both ends of the line. The difference in density between hot water and cold water should not produce a hot side and a cold side in a vertical pipe. This assumption is supported by test data recorded during plant heat up, which show that thermal stratification does not occur at location number 6 of the surge line which lies on the vertical run of the surge line below the pressurizer.

3. Thermal anchor movement of the RCS hot leg is proportional to the temperature rise above 70°F. The reactor cooling loop is basically allowed to expand without restriction; therefore, the displacement due to temperature rise would be proportional to the magnitude of this rise.

4. The ratio of the pipe wall ΔT to the system ΔT ($\Delta T_{WALL}/\Delta T_{SYS}$) where

   ΔT_{SYS} = difference between pressurizer temperature and RCS hot leg temperature,
   ΔT_{WALL} = pipe wall top-to-bottom temperature differential,

   was calculated corresponding to the maximum value of ΔT_{WALL} of 308.51°F recorded at Unit-3 on 8/9/88 (Reference 17). This calculated ratio(=0.95), however, was assumed constant for all values ΔT_{WALL}, i.e., it is assumed that ΔT_{WALL} can be obtained from ΔT_{SYS} at any given time by multiplying by a factor of 0.95 for all values of ΔT_{SYS}. This assumption represents a good approximation for the ratio $\Delta T_{WALL}/\Delta T_{SYS}$ based on the available test results and the record of ΔT_{SYS}.

5. The hot/cold fluid interface is assumed to be at middle of the pipe cross section. This interface level should generate the highest bending (secondary) stress in the pipe that results in a conservative fatigue usage factor.

3 ASSUMPTIONS - cont.

6. The fatigue usage factor due to thermal striping is calculated independently, and is not added to the total usage factor. This is based on the fact that the maximum bending stress occurs at the top and the bottom of the pipe when the fluid hot/cold interface is in the middle of the pipe. However, the stress due to striping occurs in the pipe wall at the hot/cold interface not at the top or the bottom.

7. Only part of the sample line, from the branch connection to the three-way support at elevation 40'-10", is analyzed. This segment of the line includes at least three supports in each direction. Limiting the analysis to this part of the line is considered acceptable since the only difference between the current analysis and the previous analysis is the change in thermal movement at the branch connection. The impact of this difference on the line beyond the analyzed segment is negligible.

4 DESIGN INPUT

4.1 Geometry and General Description of Analyzed Components

4.1.1 Surge Line Description

Figure 4.1 shows a schematic of the arrangement of the reactor vessel, steam generator, reactor coolant system (RCS) piping, the pressurizer and the pressurizer surge line at SONGS 2 and 3. The pressurizer surge lines at SONGS Units 2 and 3 can be described briefly as follows:

Pipe Size & Schedule : 12" sch 160 (outside diameter = 12.75", wall thickness = 1.312")

Pipe Material : SA-376 Gr TP-316

Design Temperature : 700°F

Operating Temperature: 653°F

Design Pressure : 2485 psig

Operating Pressure : 2235 psig

4.1.2 Surge Line Integral Attachments

Each of the pressurizer surge lines at SONGS Units 2 and 3 are supported by one rigid support, four snubbers and two spring hangers as shown in Figure 4.2. Figures 4.3 and 4.4 show the details of the rigid support rectangular lugs (at node point 38) and the dummy pipe used at snubber locations (node points 26, 28, 38 and 44). Thermal and mechanical properties were obtained from the ASME material properties tables (ASME Code, Section III, Division I, Appendix I).

4.1.3 Surge Nozzles

Each of the pressurizer surge lines at SONGS Units 2 and 3 is connected by two surge nozzles to the pressurizer at one end and the RCS hot leg at the other end. Figures 4.5 and 4.6 show the details of the RCS hot leg surge nozzle, and the pressurizer surge nozzle, respectively. Thermal and mechanical properties were obtained from the ASME material properties tables (ASME Code, Section III, Division I, Appendix I).

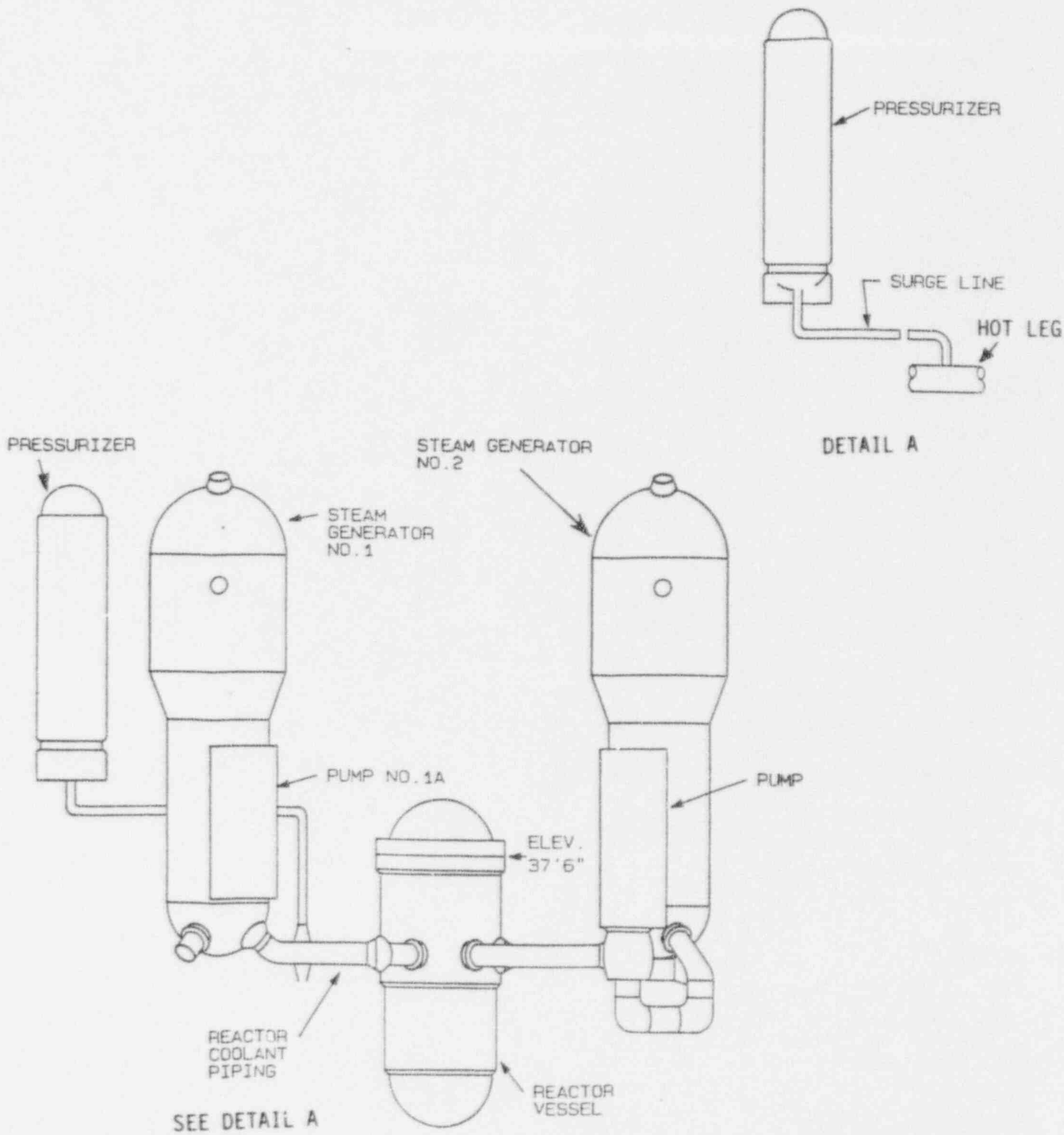


Figure 4.1 Reactor Coolant System Arrangement at SONGS 2 and 3

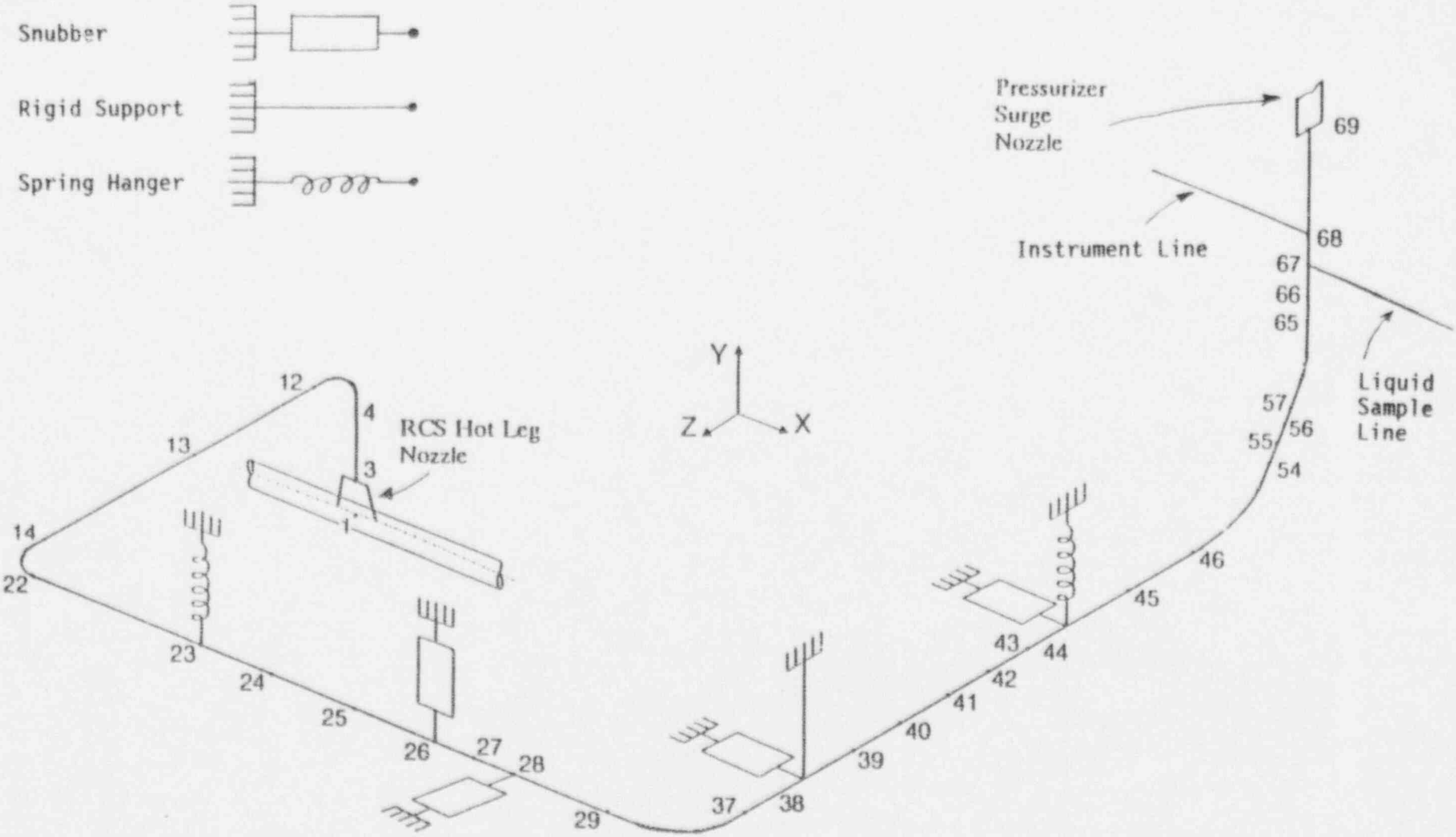


Figure 4.2 Isometric Drawing of the Pressurizer Surge Line Showing Pipe Supports and Finite Element Model Node Numbers

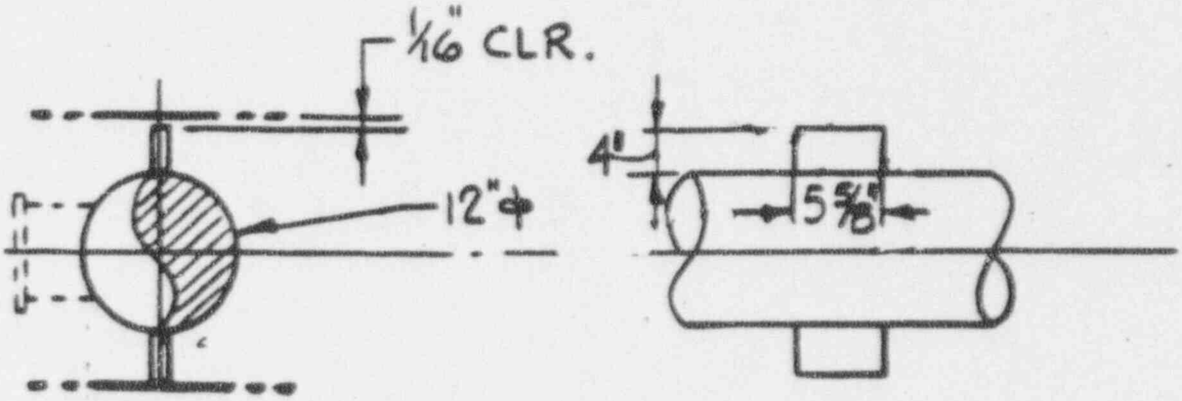
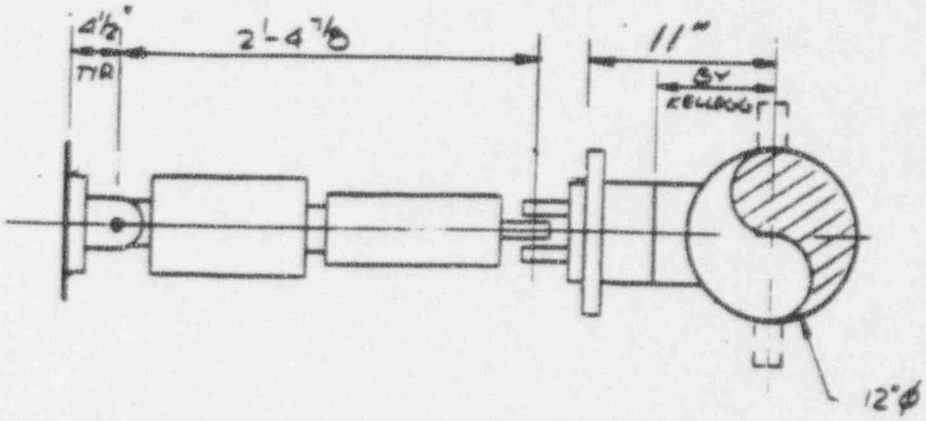


Figure 4.3 Rigid Support Rectangular Lug

(Node Point 38)



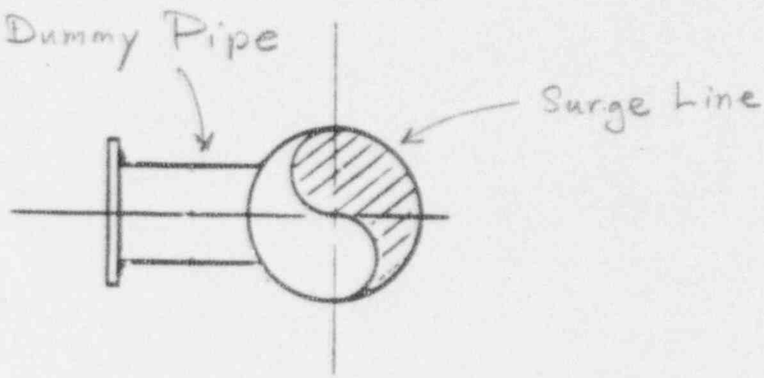


Figure 4.4 Dummy Pipe at Snubber Locations

(Node points 26, 28, 38 and 44)

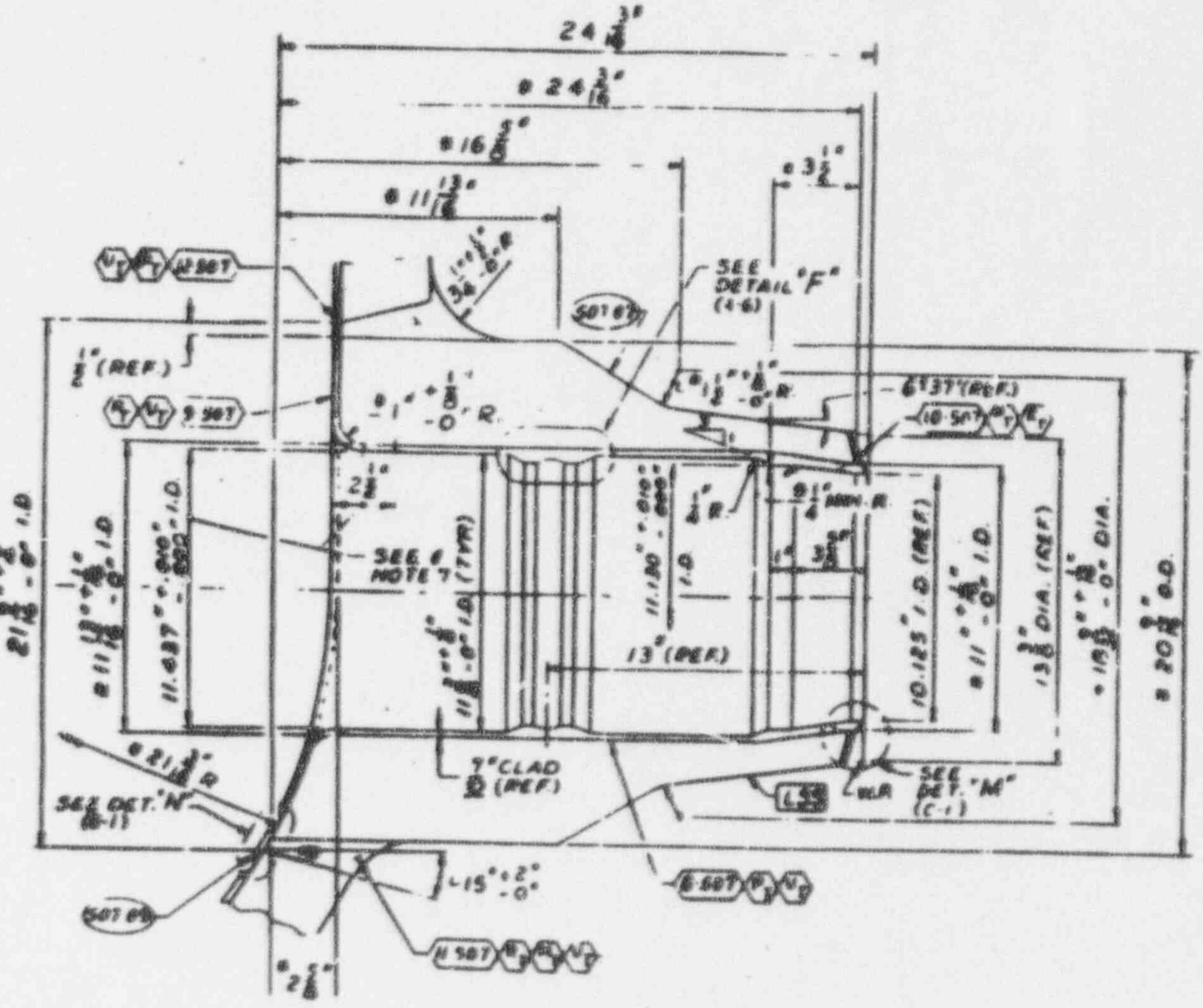


Figure 4.5 RCS Hot Leg Surge Nozzle Details (Reference 10)
(Node Point 3)

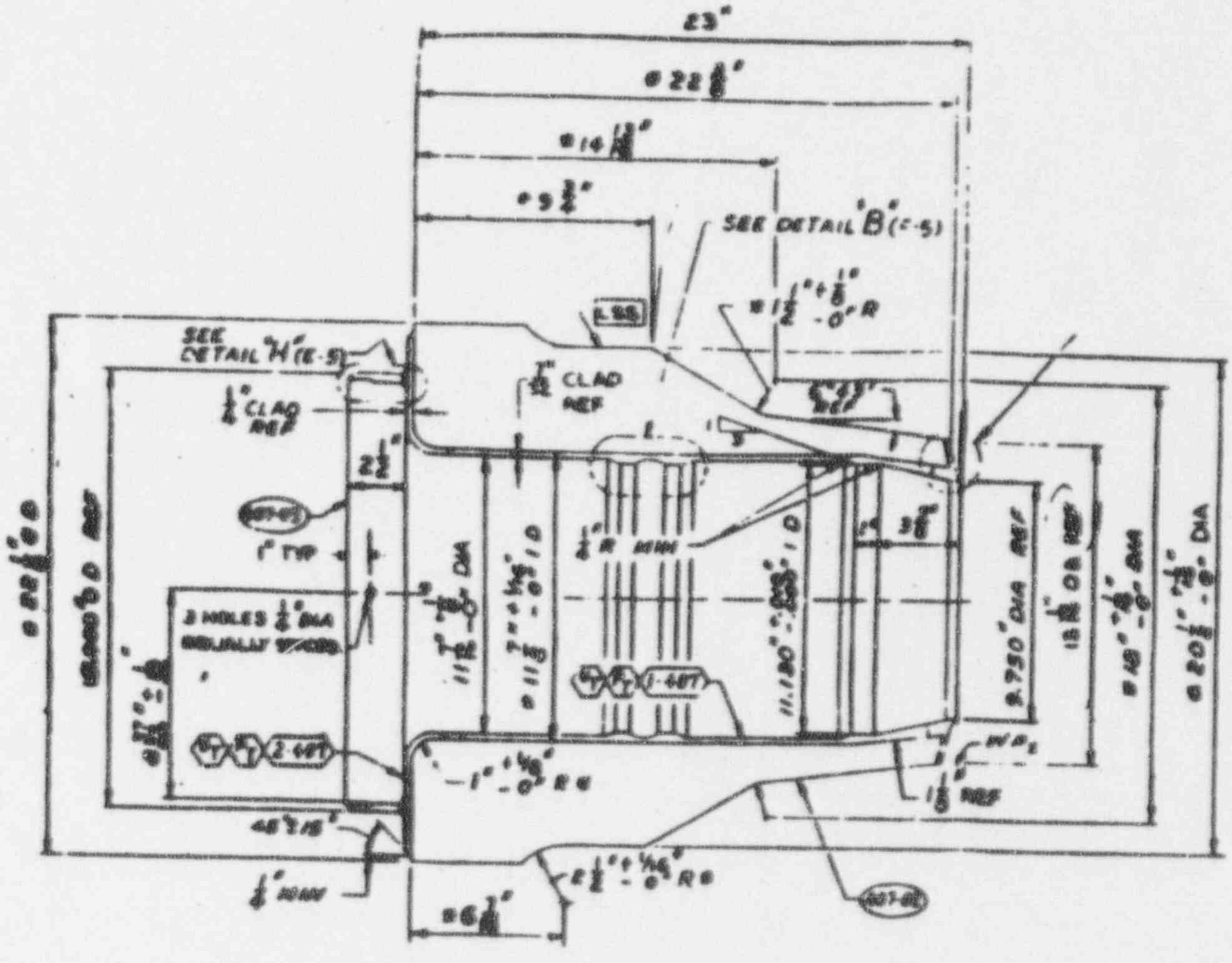


Figure 4.6 Pressurizer Surge Nozzle Details (Reference 11)

(Node Point 69)

4.2 Material Properties

The material properties used in the analysis are: Young's modulus (E), Poisson's ratio (ν), thermal conductivity (k), coefficient of thermal expansion (α) and heat capacity . These properties were obtained from Appendix I of the ASME Code (Reference 6).

4.3 Design Transients and Past Operation System ΔT

4.3.1 Design Transients

Design basis transients for SONGS Units 2 and 3 are tabulated in Tables 4.1 through 4.5. These transients can be divided into the following:

(a) Normal Transients

Normal transients are listed in Table 4.1. In this table, the first column identifies each transient by an ID number ranging from 1a to 18. The second column gives a brief description of the transient and the fourth column gives the number of occurrences over the life of the plant. The third column gives the absolute maximum pressure during the transient. The last column gives the temperature profile in terms of the reactor coolant system (RCS) temperature (T_{RCS}), the pressurizer temperature (T_{PRZ}), and the system temperature differential ΔT_{SYS}, which is defined as the temperature difference between the pressurizer and the RCS.

It should be noted that some transients in Table 4.1 are classified as "No Stratification" transients. Other transients are considered to have a potential for thermal stratification in the surge line.

(b) Upset Transients

Upset transients are listed in Table 4.2, which has the same arrangement as Table 4.1. These transients were included in the thermal stratification analysis of the surge line.

(c) Test Conditions

Table 4.3 lists the test transients for the life of the plant. These transients are divided into 10 hydro tests at 3125 psia pressure and 200 leak tests at the normal operating pressure of 2250 psia. Test conditions are included in the fatigue analysis.

(d) Operating Basis Earthquake (OBE) Transients

OBE seismic transients are listed in Table 4.4. These transients are included in the fatigue analysis of the surge line.

(e) Full Flow Water Slug

Additional transients, defined as full water slug, are listed in Table 4.5. These transients are included in the fatigue analysis.

Heat transfer coefficients during slug flow transient are given in Table 4.6 (events 3, 4, 5, 6 and 7 in Table 4.1).

Table 4.1 Design Basis Transients - Normal

Event	Operation	Press. (psia)	No.of Occurrences.	Rate (°F/hr)	Temperatures (°F)		
					T_{RCS}	T_{PRZ}	ΔT_{SYS}
1a	Steady state uniform	2250	2000000	0.	653	653	0[1]
1b	Steady state strat.	2250	2000000	0.	621	653	32
2a	Unload	2250	15000	-14.4	621-593	653	32-60
2b	Load	2250	15000	14.4	593-621	653	60-32
3a	Turbine Step (inc.)[2]	2250	4120	0.	564	653	89
3b	Turbine Step (dec.)[2]	2250	4120	0.	564	653	89
4a	Turbine Ramp (inc.)[2]	2250	17040	0.	573	653	80
4b	Turbine Ramp (dec.)[2]	2250	17040	0.	573	653	80
5	Planned[2]	2250	9400	0.	573	653	80
6	Unplanned[2]	2250	200	0.	564	653	89
7	Below power[2]	2250	4580	0.	564	653	89
8a	Heatup low[3]	410	75	100.0	100	440	340
8b	Heatup high[3]	2250	75	100.0	313	653	340
8c	Heatup low[3]	410	375	100.0	190	440	250
8d	Heatup low[3]	410	400	100.0	240	440	200
8e	Heatup low[3]	410	500	100.0	290	440	150
8f	Heatup high[3]	2250	375	100.0	403	653	250
8g	Heatup high[3]	2250	400	100.0	453	653	200
8h	Heatup high[3]	2250	500	100.0	503	653	150
9a	Cooldown high[3]	2250	75	-100.0	313	653	340
9b	Cooldown low[3]	410	75	-100.0	100	440	340

(1) No stratification.

(2) See Table 4.6 for the heat transfer coefficients during these events.

(3) ΔT_{sys} in the table represents maximum system ΔT.

Table 4.1 Design Basis Transients - Normal -- cont.

Event	Operation	Press. (psia)	No.of Occur- rences.	Rate (°F/hr)	Temperatures (°F)		
					T_{RCS}	T_{PRZ}	ΔT_{SYS}
9c	Cooldown high(3)	2250	375	-100.0	403	653	250
9d	Cooldown high(3)	2250	400	-100.0	453	653	200
9e	Cooldown high(3)	2250	500	-100.0	503	653	150
9f	Cooldown low(3)	410	375	-100.0	190	440	250
9g	Cooldown low(3)	410	400	-100.0	240	440	200
9h	Cooldown low(3)	410	500	-100.0	290	440	150
10a	Heatup hot standby(3)	2250	87710	100.0	563	653	90
10b	Cooldown hot standby(3)	2250	87710	-100.0	563	653	90
11	Start heatup(3)	15	500	100.0	100	100	0(1)
12	Pressure low(3)	410	500	100.0	100	440	0(1)
13	Heatup no strat.(3)	410	500	100.0	313	653	0(1)
14	Pressure high(3)	2250	500	100.0	313	653	0(1)
15	Cooldown no strat.(3)	2250	500	-100.0	313	653	0(1)
16	Cooldown delta P(3)	410	500	-100.0	230	440	0(1)
17	Cooldown uniform(3)	15	500	-100.0	100	100	0(1)
18	Shutdown	15	500	0	70	70	0(1)

(1) No stratification.

(2) See Table 4.6 for the heat transfer coefficients during these events.

(3) ΔT_{sys} in the table represents maximum system ΔT.

Table 4.2 Design Basis Transients - Upset

Event	Operation	Press. (psia)	No.of Occurrences.	Rate (°F/hr)	Temperatures (°F)		
					T_{RCS}	T_{PRZ}	ΔT_{SYS}
1	Heat removal	2250	70	0.	621	653	32
2	Decay heat	2250	95	0.	621	653	32
3	Decay RCS	2250-410	30	-50/-44	621-403	653-403	32-0
4	Reactor An[1]	2000-2450	40	0.	564	653	89
5	Inc RCS In[2]	2250	30	0.	621	653	32
6	Inc RCS Out[3]	2250	5	0.	621	653	32

[1] <u>Reactor An</u> stands for Reactivity and Power Distribution Anomalies which is broken into 10 occurrences of uncontrolled CEA withdrawal from subcritical or low power, 10 occurrences of uncontrolled CEA withdrawal at power and 20 occurrences of control rod misoperation, system malfunction, RCPS inadvertent operation or operator error.

[2] <u>Inc RCS In</u> stands for an Increase in Reactor Coolant System Inventory such as when there is a loss of component cooling water to the letdown heat exchanger or when there is a CVCS malfunction that increases RCS inventory.

[3] <u>Inc RCS Out</u> stands for a Decrease in Reactor Coolant System Inventory such as during a sample line break or failure of other small lines that carry coolant outside containment.

Table 4.3 Design Basis Transient - Test

Event	Operation	Press. (psia)	No.of Occurrences.	Rate (°F/hr)	Temperatures (°F)		
					T_{RCS}	T_{PRZ}	ΔT_{SYS}
1	Hydro	3125	10	±100.0	70-400-70	70-400-70	0
2	Leak	2250	200	±100.0	70-400-70	70-400-70	0

Table 4.4 Design Basis Transient - OBE Seismic

Event	Operation	Press. (psia)	No.of Occurrences.	Rate (°F/hr)	Temperatures (°F)		
					T_{RCS}	T_{PRZ}	ΔT_{SYS}
1	OBE Seismic	2250	1440	0	621	653	0(1)

(1) No stratification.

Table 4.5 Design Basis Transient - Full Flow Water Slug

Event	Operation	Press. (psia)	No.of Occurrences.	Rate (°F/hr)	Temperatures (°F)		
					T_{RCS}	T_{PRZ}	ΔT_{SYS}
1	Upset	2250	100	Step	563	653	90
2	Heatup/cooldown	2250	500	Step	563	653	90

Table 4.6 Heat Transfer Coefficients for Slug Flow Events

Event	Heat Transfer Coefficient (BTU/hr ft^2 °F)	
	Top	Bottom
3a	4613	2
3b	2	4613
4a	4631	2
4b	2	4631
5	1391	2
6	2	11080
7	183	2

4.3.2 Past Operation System ΔT

In addition to the design transients given in Section 4.3.1, a review of past operation of Units 2 and 3 was made to identify any system ΔT in excess of the values included in the design transients. Table 4.7 gives the highest system ΔT during Unit-2 heatups since 1983 based on Reference 16. Similarly, Table 4.8 gives the maximum heatup system ΔT for Unit-3. Extreme transients were included in the fatigue analysis in addition to the design transients.

Table 4.7 Unit-2 Maximum System ΔT

Outage Dates	Heatup Dates	Pressurizer Press. and Temperature(1)		RCS Temp. (°F)	System ΔT (°F)
		P (psia)	T (°F)		
11/14/83-12/20/83	12/13,14/83	2300	656	270	386(2)
06/20/84-07/25/84	07/24/84	2250	653	268	385(2)
01/13/84-02/16/84	02/10/84	2310	657	278	379(2)
03/15/86-06/12/86	05/31/86	2250	653	275	378(2)
10/20/84-04/17/85	04/03/85	2250	653	280	373(2)

Notes: (1) Saturation temperature corresponding to pressure (P).

(2) This value of system ΔT exceeds the value allowed by SCE Operating Instruction,"Plant Startup from Cold Shutdown to Hot Standby," which is 340°F (Reference 38). This limiting value of the system ΔT will not be exceeded in the future during normal operation of the plant (Reference 40).

Table 4.8 Unit-3 Maximum System ΔT

Outage Dates	Heatup Dates	Pressurizer Press. and Temperature[1]		RCS Temp. (°F)	System ΔT (°F)
		P (psia)	T (°F)		
01/16/88-01/26/88	01/21/88	2270	654	300	354[2]
01/03/87-03/12/87	03/01/87	2250	653	322	331
04/15/92-05/10/92	05/07/92	-	660	333	327
01/25/92-03/21/92	03/21/92	-	660	334	326
06/11/84-07/07/84	07/03/84	2270	654	330	324

Notes: (1) Saturation temperature corresponding to pressure (P).

(2) This value of system ΔT exceeds the value allowed by SCE Operating Instruction,"Plant Startup from Cold Shutdown to Hot Standby," which is 340°F (Reference 38). This limiting value of the system ΔT will not be exceeded in the future during normal operation of the plant (Reference 40).

4.4 Pipe Wall Temperature Measurements Survey

Heatup test data were collected at SONGS Unit-2 using surface mounted thermocouples (T/C). Figure 4.8 shows the locations of pipe surface temperature measurements (Reference 3). Two thermocouples were mounted at the top (0°) and bottom (180°) of the surge line at location 1. Locations 2, 3, 4 and 5 were fitted with bands of six thermocouples that were 60° apart starting from the top (0°). Location 6 had two thermocouples, one on the east and one on the west side of the pipe. Figure 4.9 shows the arrangement of the thermocouples on the pipe outside surface at the different locations. The thermocouples used were Omega Type K with Type K wiring. The wiring was run outside of containment to the plant computer, a GOULD 32/9780.

All thermocouple data were recorded at two minute intervals by the plant computer. The following plant parameters were also collected at two-minute intervals:

a) Cold leg temperature,
b) Surge line temperature,
c) Pressurizer pressure and level,
d) Reactor coolant pump status.

The plant computer produced a hard copy of the recorded data (Reference 17).

Figures 4.10 through 4.15 show typical plots of:

a) Pipe top (0°) temperature,
b) Pipe bottom (180°) temperature,
c) The difference between the top and bottom temperatures (delta T)

at locations 1 through 5, respectively as shown in Figure 4.8. These plots cover the period from 8/7/1988 to 8/14/1988 during heatup. Figure 4.16 shows the RCS cold leg temperature, the pressurizer temperature, and the system ΔT during the same period.

The system ΔT during heatup is larger than cooldown. Conservatively, the analysis was based on heatup system ΔT for both heatup and cooldown transients.

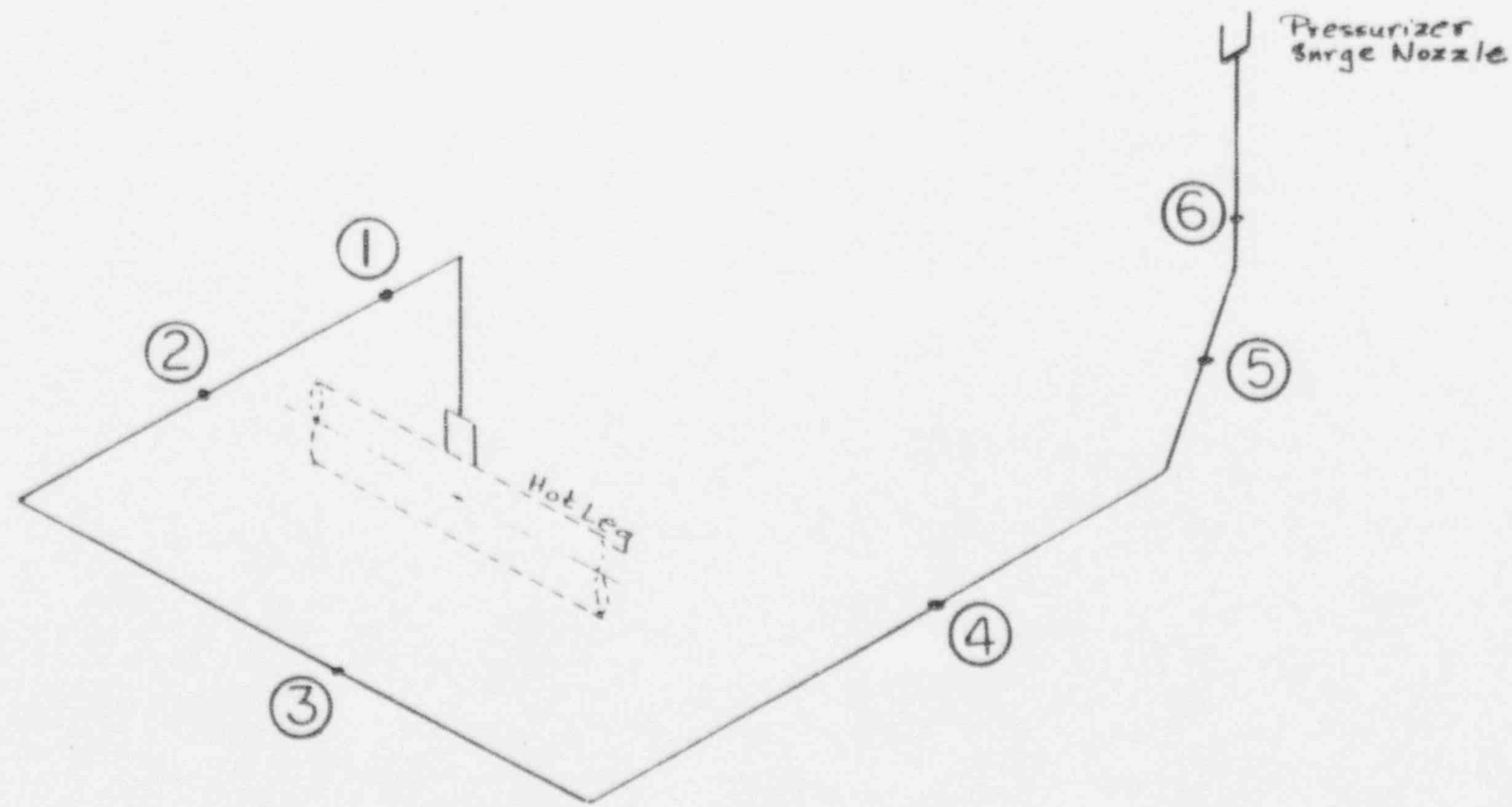
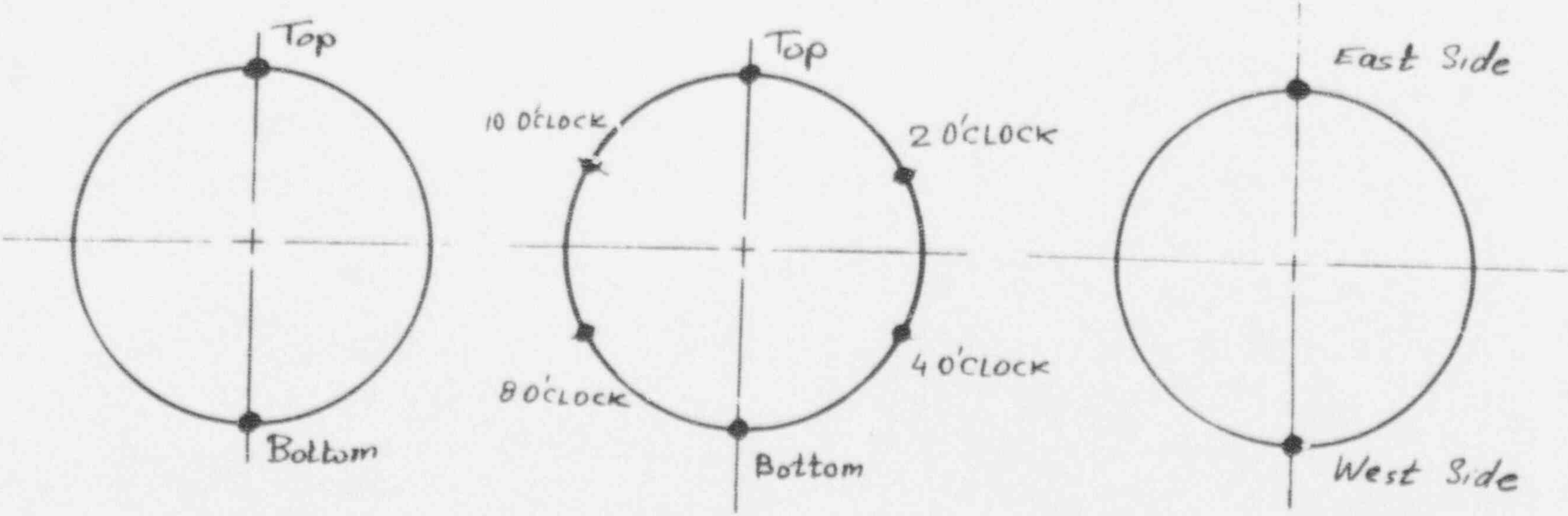


Figure 4.8 Location of Pipe Wall Temperature Measurements



Location 1 **Locations 2, 3, 4 and 5** **Location 6**

Figure 4.9 Thermocouple Installation Orientation on the Surge Line

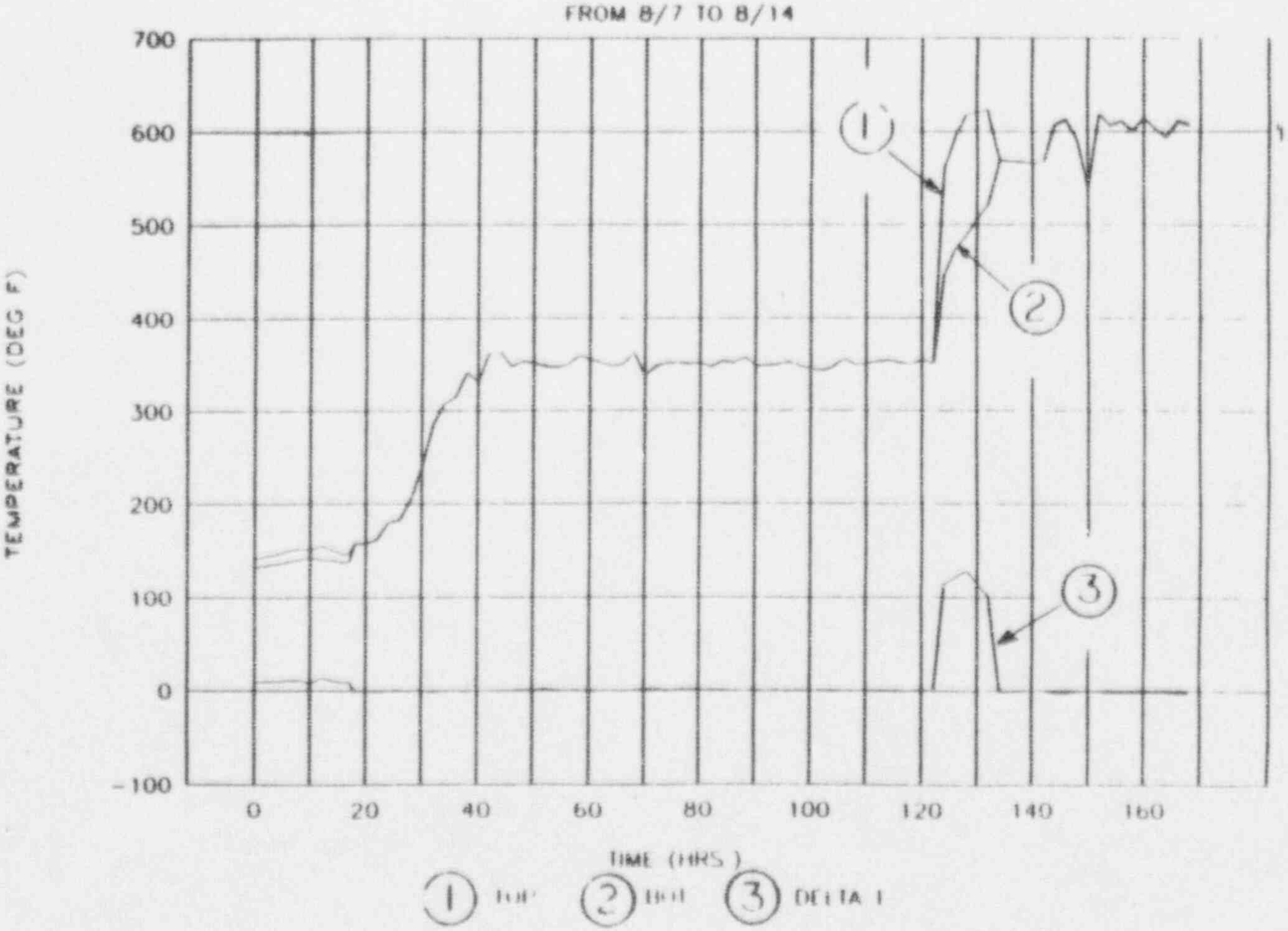


Figure 4.10 Top and Bottom Temperatures and Top-to-Bottom ΔT at Location (1)

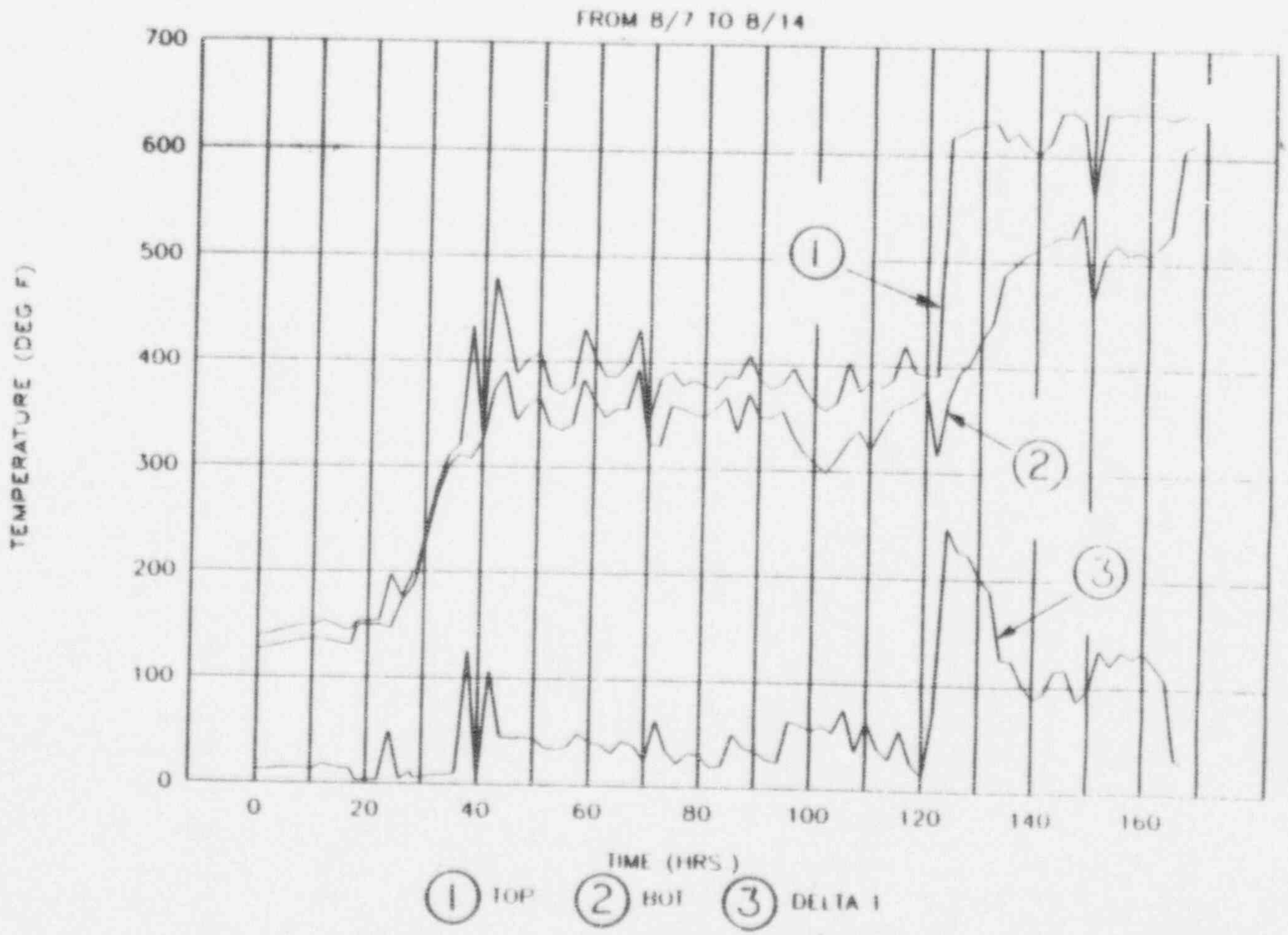


Figure 4.11 Top and Bottom Temperatures and Top-to-Bottom ΔT at Location (2)

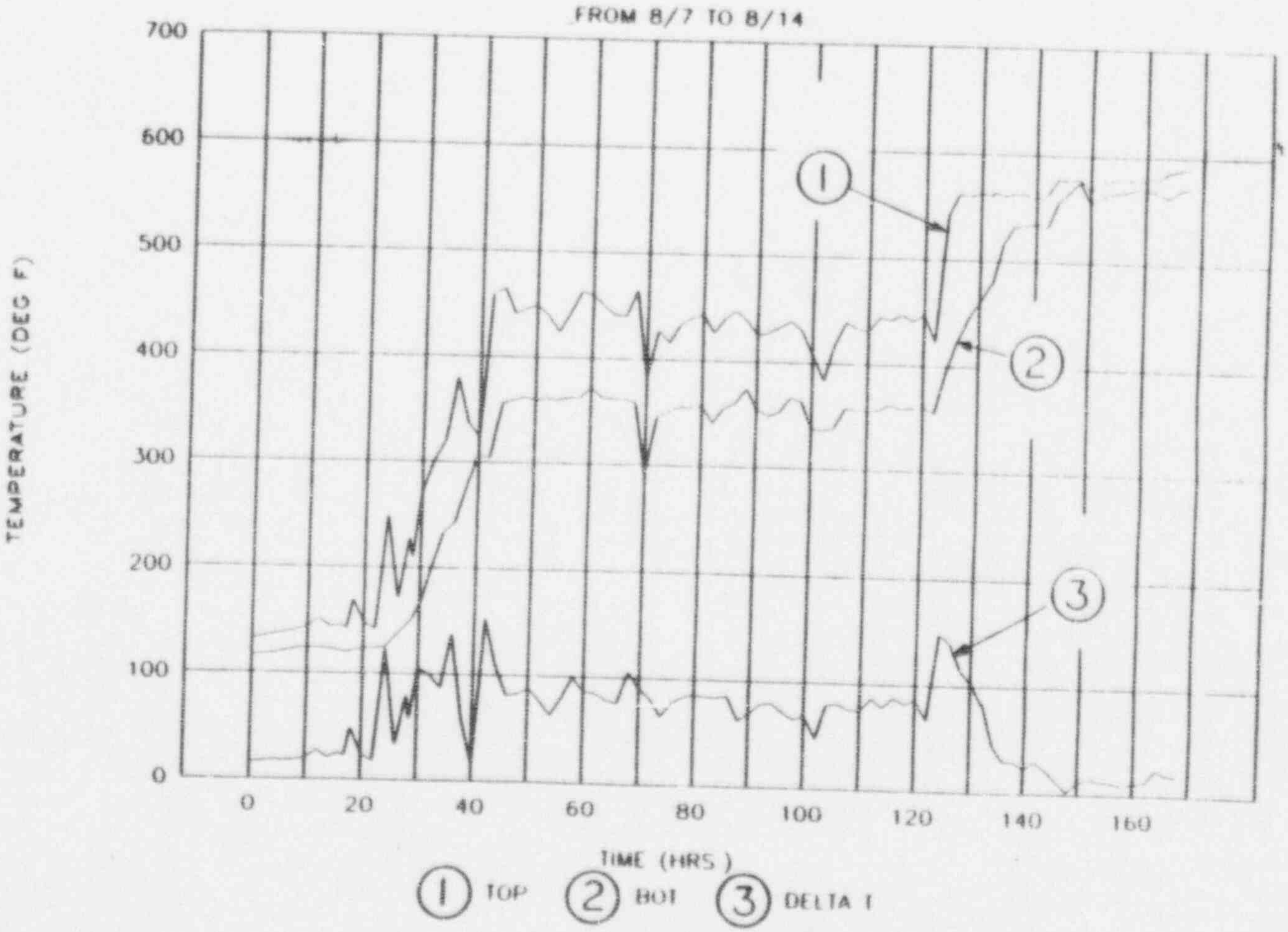


Figure 4.12 Top and Bottom Temperatures and Top-to-Bottom ΔT at Location (3)

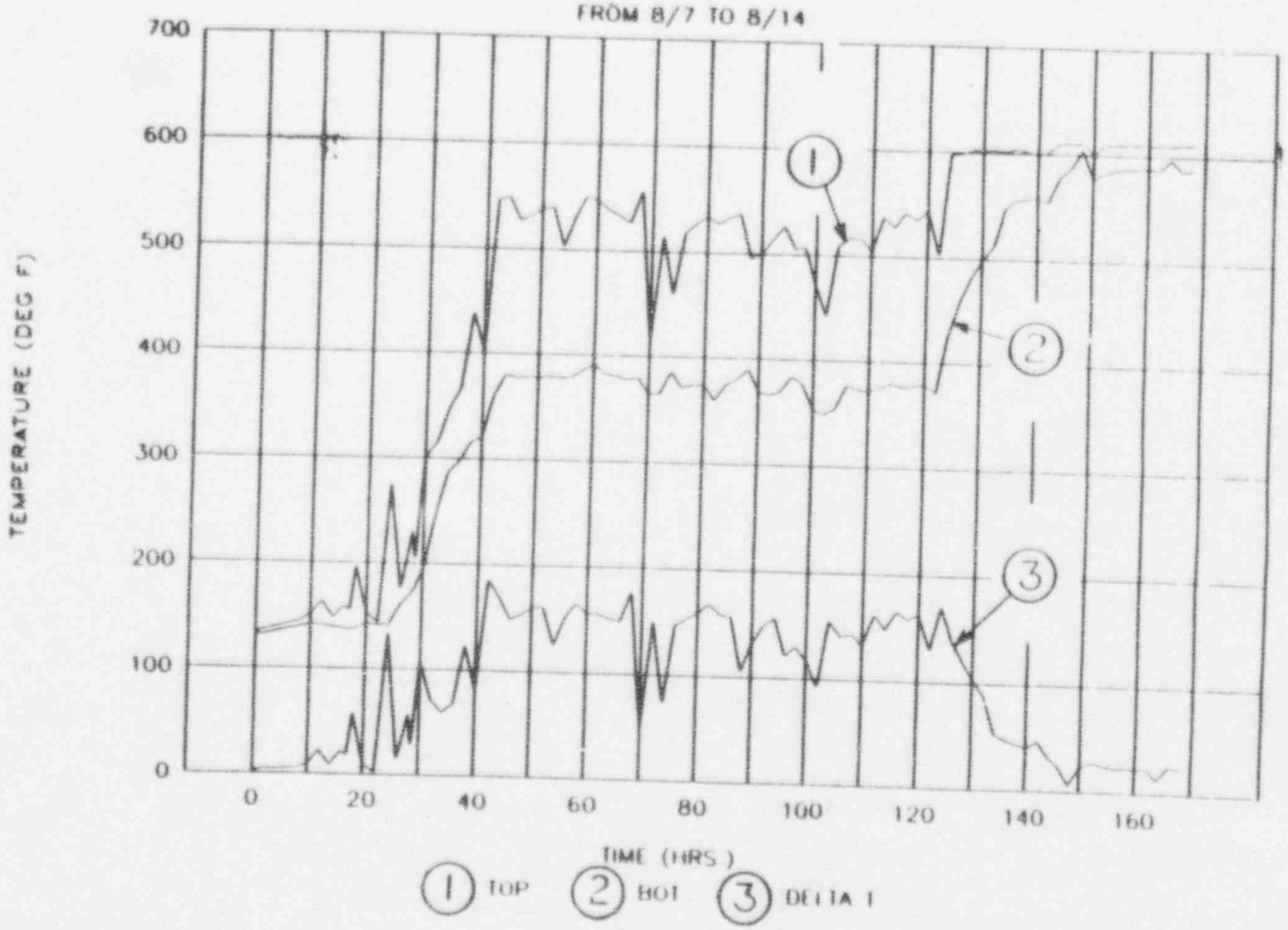


Figure 4.14 Top and Bottom Temperatures and Top-to-Bottom ΔT at Location (4)

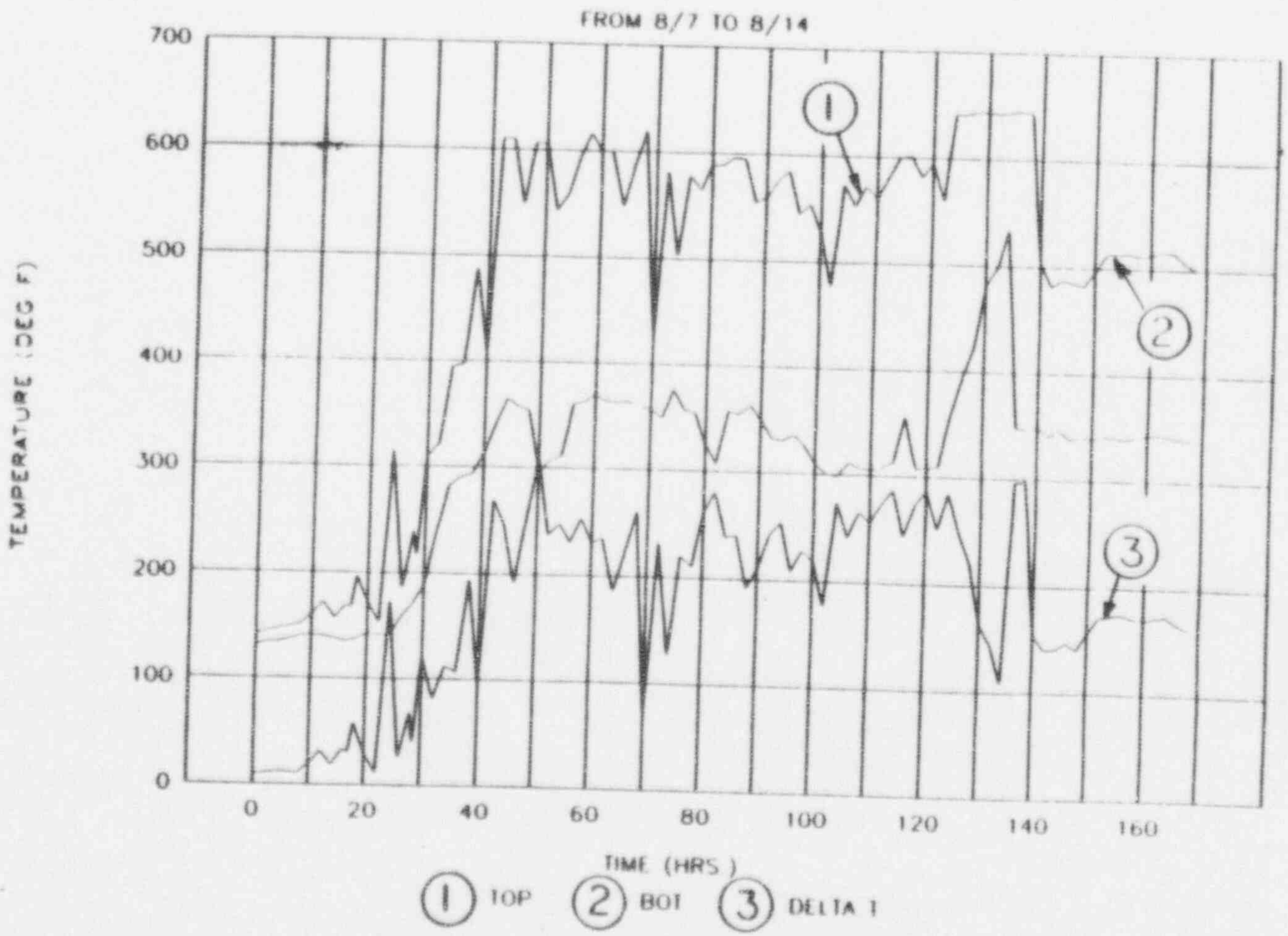


Figure 4.13 Top and Bottom Temperatures and Top-to-Bottom ΔT at Location (5)

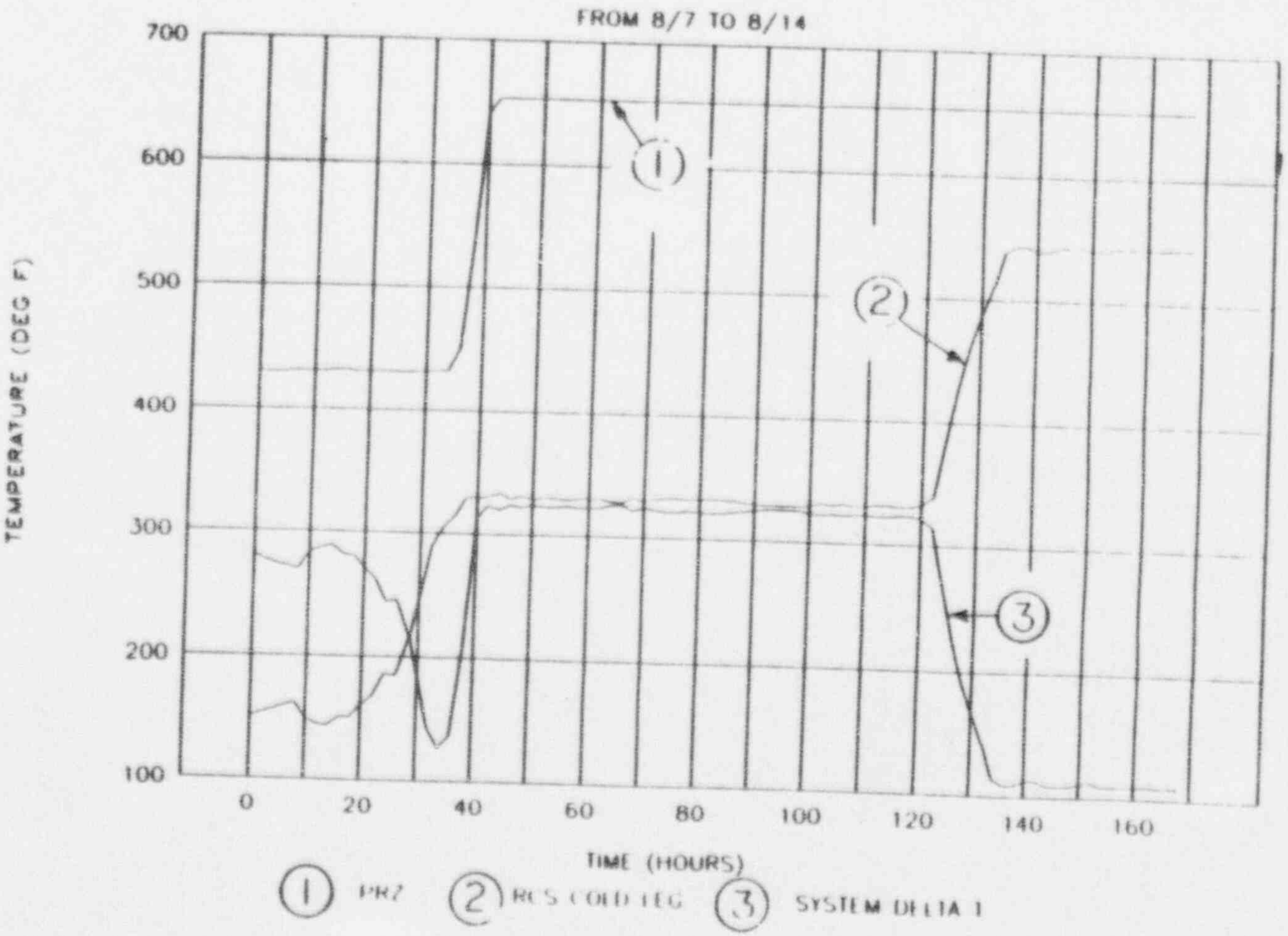


Figure 4.15 Cold Leg and Pressurizer Temperatures and System ΔT During Plant Heatup (from 8/7 to 8/14/1988, SONGS Unit-2)

4.5 Pressurizer Liquid Sample Line

The pressurizer liquid sample line was evaluated for stratified flow conditions in the pressurizer surge line. All loading of this line are the same as in the previous evaluation (original design report) except for the thermal movement at the branch point. The branch point thermal movements were calculated under thermal stratification conditions in the surge line.

5 METHODOLOGY

5.1 Introduction

Thermal stratification occurs when the temperature of a fluid, inside a horizontal pipe, varies from top to bottom resulting in temperature gradients in the pipe wall. This phenomenon often exists in the pressurizer surge line for the following reasons:

(a) The hotter pressurizer water has lower density than the colder RCS hot leg water. Thus, during insurges and outsurges, the hotter fluid tends to flow on top of the colder water,

(b) The flow rates during insurges and outsurges are, in most cases, relatively small. Small flow rates can result in thermal stratification (Reference 39).

Test data, recorded during plant heatup (Reference 17), confirm the occurrence of thermal stratification in the pressurizer surge line, and show that the top of the horizontal section of the pipe is at considerably higher temperature than the bottom.

5.2 Structural Analysis of the Pressurizer Surge Line

Structural analysis of the pressurizer surge line at SONGS 2 and 3 was performed. The finite element program ANSYS was used to calculate the resulting thermal stresses in the pipe, the rigid support loads, the pipe displacement, and the nozzle loads.

5.2.1 Calculation of the Temperature Profile in the Pipe

Stratified flow in the pipe generates temperature gradients in the pipe wall that change nonlinearly in the vertical direction, as shown by the test results (References 3 and 17) described in Section 4.4.

The actual temperature profile was based on the test data collected at SONGS Unit 3 in 1988 using surface mounted thermocouples at different locations of the pressurizer surge line, as explained in Section 4.4 of this summary report. The ratio of the system ΔT to the actual pipe wall ΔT was calculated at maximum top-to-bottom ΔT from the test data. This ratio was assumed constant for all values of ΔT_{SYS} (see Section 3 of this summary report).

Only linear temperature profiles can be modeled using ANSYS. The ratio between the linear temperature profile and the equivalent nonlinear pipe wall

temperature was calculated equal to 0.95. This ratio was based on equivalent pipe bending moment between two models: the first is a three-dimensional model with nonlinear temperature distribution, and the second is a straight pipe model with linear temperature distribution.

Both ratios calculated above were applied to the system ΔT to obtain the equivalent ΔT_{linear}. This ΔT_{linear} was used in the ANSYS model.

5.2.2 Thermal Stratification Analysis

An ANSYS model of the pressurizer surge line was generated using element type STIF20 for straight pipe segments, and STIF60 for curved pipe segments. The top-to-bottom temperature differential (ΔT_{linear}) was obtained from the system ΔT by applying the two ratios explained in Subsection 5.2.1 above. The system ΔT was based on the maximum past operation ΔT_{system} for Units 2 and 3. Only the horizontal section of the pipe was considered stratified.

The ANSYS finite element model of the pressurizer surge line is based on the geometry and support configuration shown in Figure 4.2. Figure 5.1 shows a computer plot of the finite element model including the ANSYS node numbers. A sample of the results obtained is shown in Figure 5.2, which shows the displaced configuration of the line due to thermal stratification.

Results of the surge line analysis were obtained in the form of nodal forces and moments, reaction force at the rigid support, and displacements at all locations of snubbers, spring hangers, and branch connections. Calculated forces and moments were used to calculate ASME Code stresses and demonstrate compliance with the Code requirements. Rigid support load was compared with design load, and displacements at the locations of snubbers and spring hangers were compared with allowable ranges.

5.2.3 Response of the Surge Line to Thermal and Mechanical Unit Loads

To simplify the analysis, unit loads based on the design loading conditions including thermal expansion, thermal stratification and nozzle movements were applied independently. Results from the unit loads were combined, after applying appropriate scaling factors, using the principle of superposition to calculate the results for the actual loads. In the structural analysis of the pipe, internal pressure was applied, and the elbow stiffness includes the effect of pressure in accordance with ASME Code Subsection NB-3650.

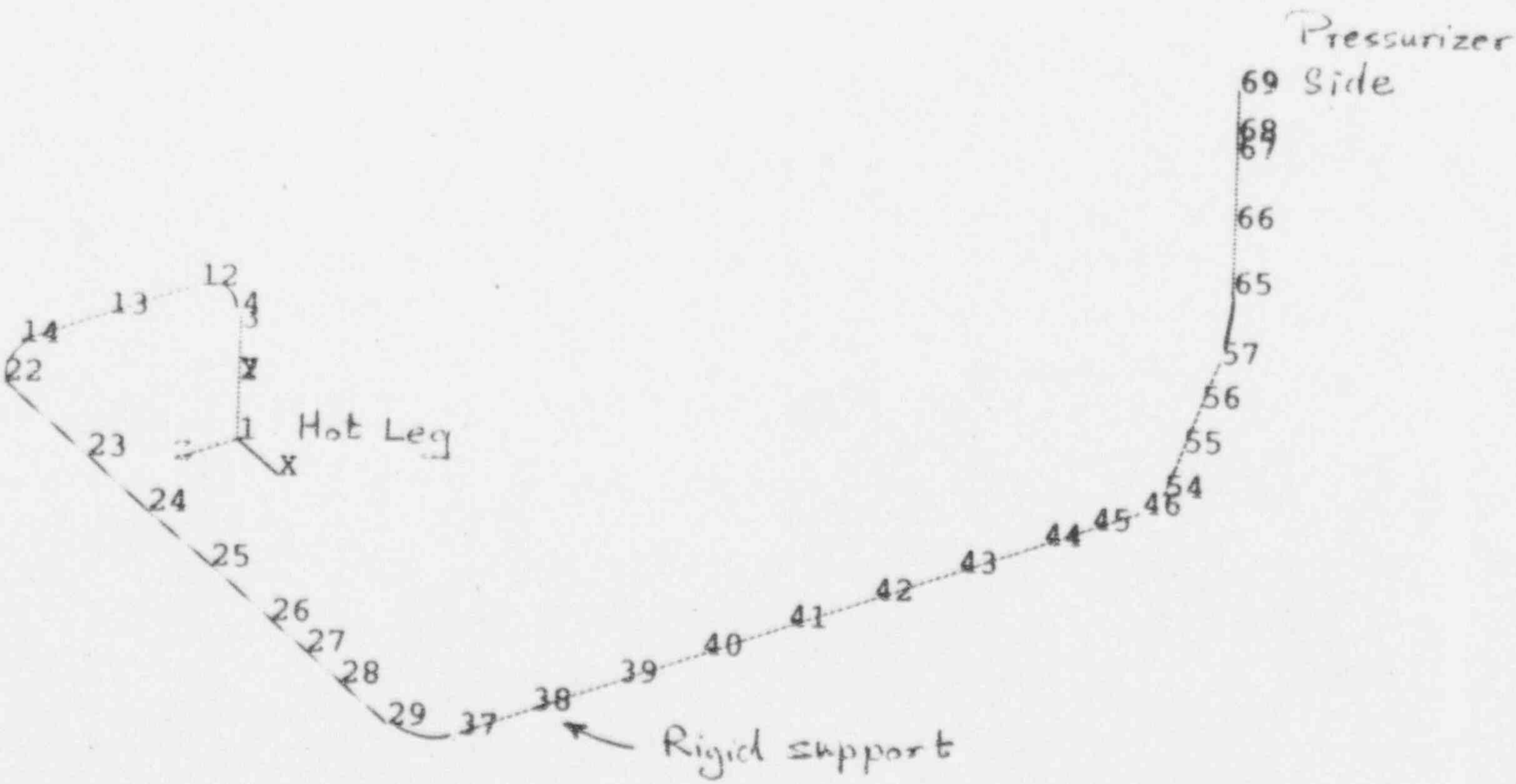


Figure 5.1 Computer Plot of the ANSYS Finite Element Model

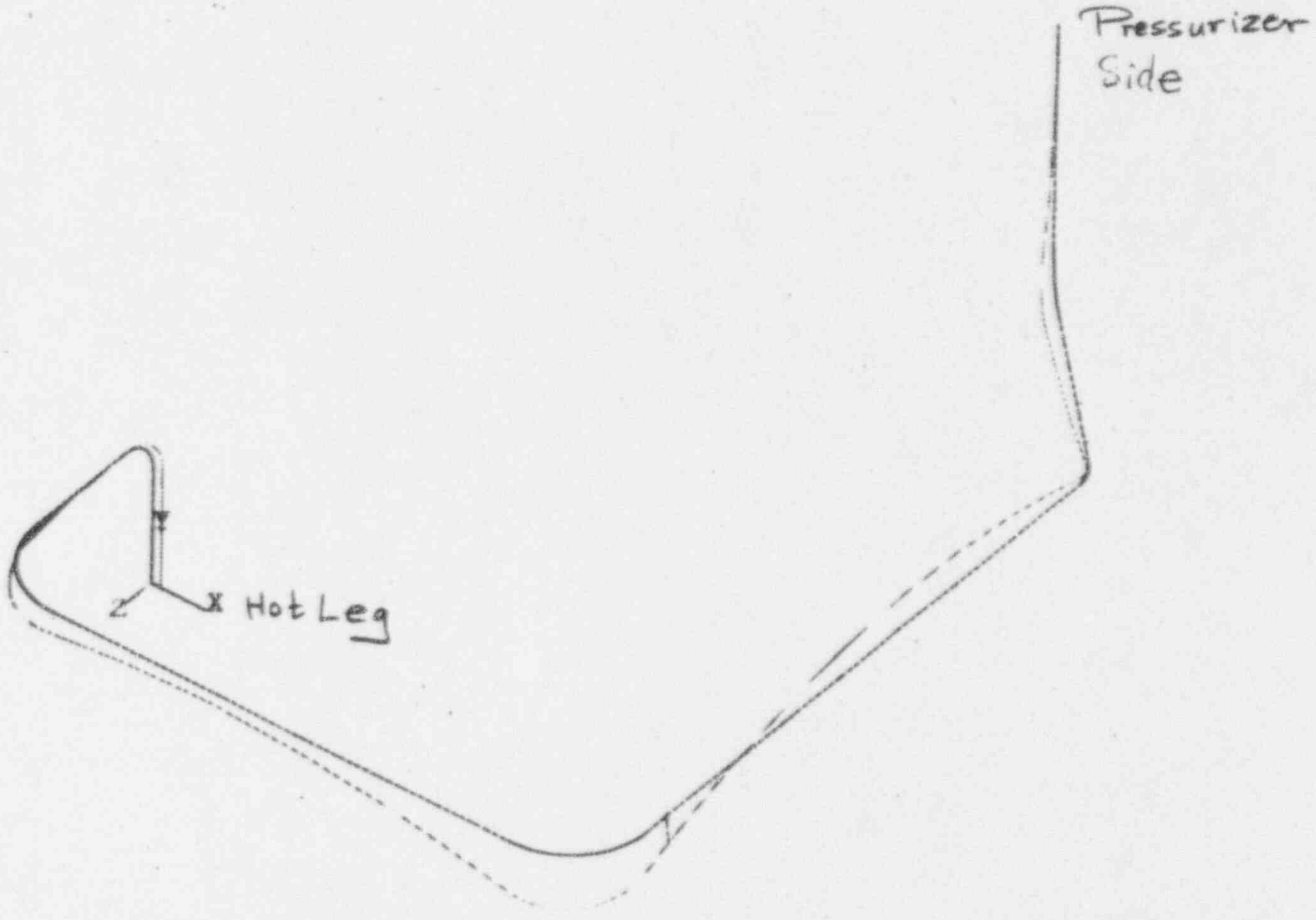


Figure 5.2 Computer Plot of the Stratified Surge Line Showing the Bowing Effect

The following unit loads were applied to the finite element model of the pressurizer surge line described in Section 5.2:

(a) RCS Hot Leg Surge Nozzle Movement

Anchor displacements applied at the hot leg end of the pressurizer surge line. These displacements represent the movement of the RCS hot leg surge nozzle due to thermal expansion.

(b) Pressurizer Surge Nozzle Movement

Anchor displacements applied at the pressurizer end. These displacements represent the movement of the pressurizer surge nozzle due to thermal expansion.

(c) Normal Thermal Expansion

Uniform temperature rise of 10°F, representing thermal expansion without stratification.

(d) Thermal Stratification

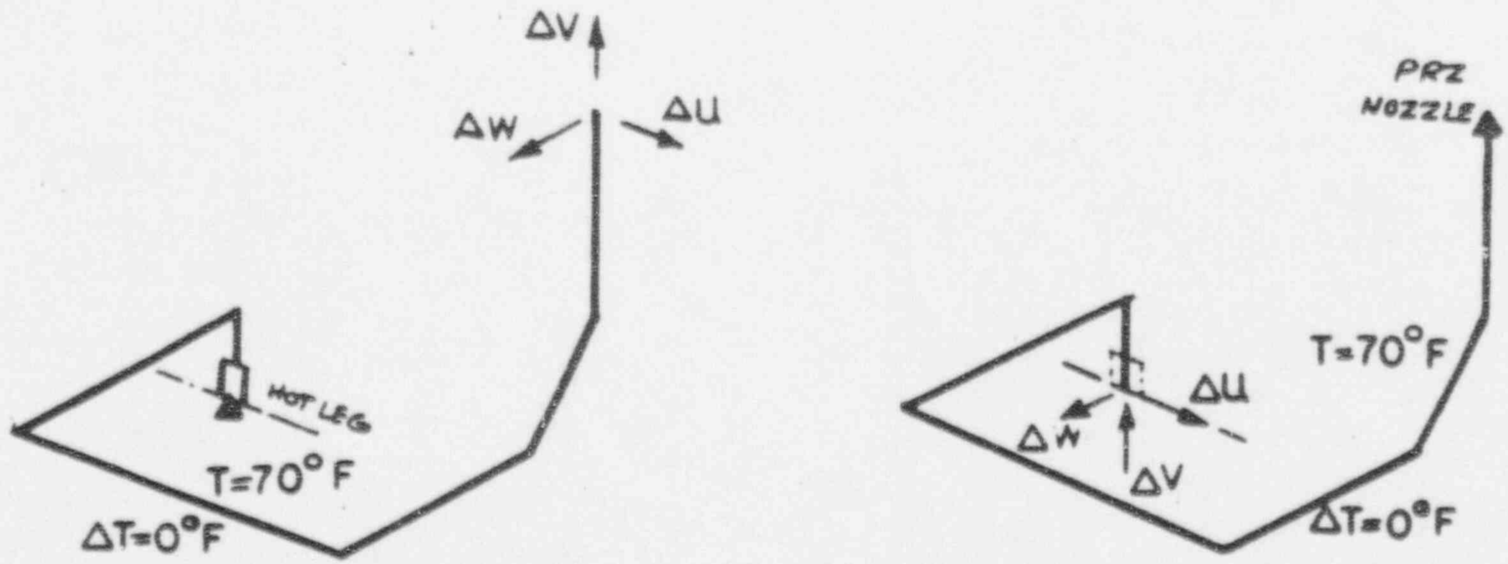
Top-to-bottom stratification of 10°F in the horizontal run of surge line, representing thermal stratification conditions.

The unit load cases described above are shown schematically in Figures 5.3 and 5.4.

5.2.4 Response of the Surge Nozzles to Unit Loads

The nozzles are connected to the vertical piping section and do not experience thermal stratification. However, they are impacted by the bending moments and forces induced by stratification in the horizontal sections of the pipe.

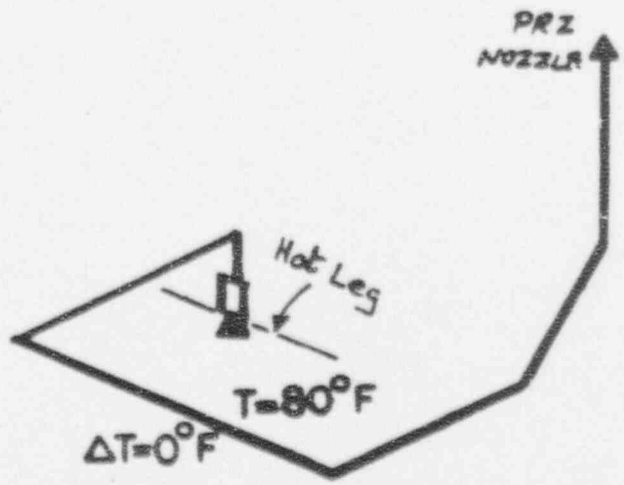
Unit thermal and mechanical loads were applied independently, and the results were multiplied by appropriate factors and combined to calculate the response to actual loads, based on the principle of superposition. The models were generated using ANSYS. These models are shown in Figures 5.5 and 5.8 for the RCS hot leg surge nozzle and the pressurizer surge nozzle, respectively. ANSYS thermal analysis two-dimensional element type STIF55, and the structural element type STIF42 were used to generate the models of the surge nozzles. Structural element type STIF25 was used when asymmetric loading was applied.



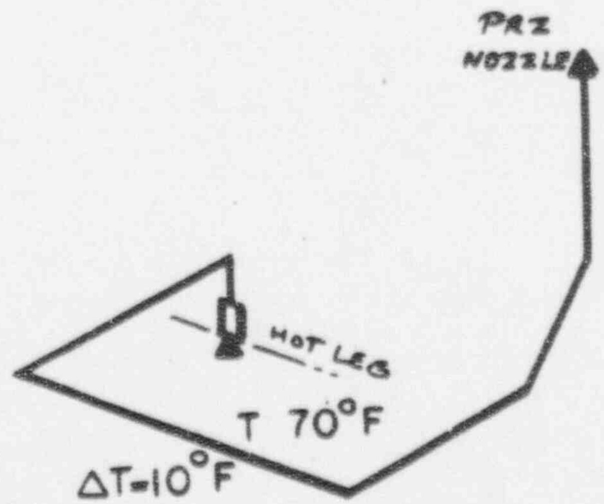
RCS Hot Leg Surge Nozzle Displacement

Pressurizer Surge Nozzle Displacement

Figure 5.3 Unit Load Cases for Fatigue Analysis - RCS and Pressurizer Surge Nozzle Displacements



Uniform Pipe Wall Temperature of 80°F
(10°F above reference temperature)



Thermal Gradient in the Pipe Wall
(top-to-bottom ΔT=10°F)

Figure 5.4 Unit Load Cases for Fatigue Analysis - Uniform and Stratified Flow Conditions

The unit load cases comprise the following:

(a) Unit Thermal Shock

Thermal transient analysis was performed to calculate the temper`ture time history due to a thermal shock on the inside surfacε of the pipe. Conservatively, the outside surface of the model was assumed to be adiabatic (perfectly insulated) with no heat transfer to the surroundings. Results of this computer run are stored on a data file generated by the thermal transient analysis.

A second run uses the data stored to calculate the time history of membrane, bending, peak, and total stresses due to the thermal gradients generated by the thermal shock. Sample results are shown in Figure 5.5, which shows the temperature time history at the inside and outside nodes of section 1330-01284 (see Figure 5.5). The corresponding stress components are shown in Figure 5.7.

(b) Internal Pressure

Each two-dimensional axisymmetric model was subjected to internal pressure of 2250 psi (operating pressure) on the inside surface of the pipe. Appropriate end load was applied on the end of the model representing the cap load.

(c) Unit Force Perpendicular to Pipe Axis

A unit shearing force was applied at the pipe side of the model perpendicular to the pipe axis.

(d) Unit Force in the Axial Direction of the Pipe

A unit force was applied on the side of the pipe in the direction of the pipe axis.

(e) Unit Bending Moment

A unit moment was applied at the pipe side of the nozzle model perpendicular to the nozzle axis . This moment has a bending effect on the nozzle.

(f) Unit Twisting Moment

A unit moment was applied at the pipe side of the nozzle model in the direction of the nozzle axis. This moment has a twisting (torsional) effect on the nozzle.

A similar analysis was performed on the pressurizer surge nozzle to calculate its unit load case, which are similar to the unit load cases of the RCS hot leg surge nozzle. Figure 5.8 shows a computer plot of the finite element model used for the pressurizer surge nozzle. This model includes the pressurizer head, the nozzle safe end and part of the surge line piping. The nozzle geometry is based on Figure 4.6. Sample results of the thermal analysis are shown in Figure 5.9, which shows the temperature time history response of the inside and outside nodes of section 1422-1419 (see Figure 5.8) to a thermal shock. The corresponding stress components are shown in Figure 5.10.

As in the case of the surge line, results of the unit load cases described above were combined by superposition in the fatigue analysis of the surge nozzle. A more detailed description of the fatigue analysis can be found in Section 5.3.

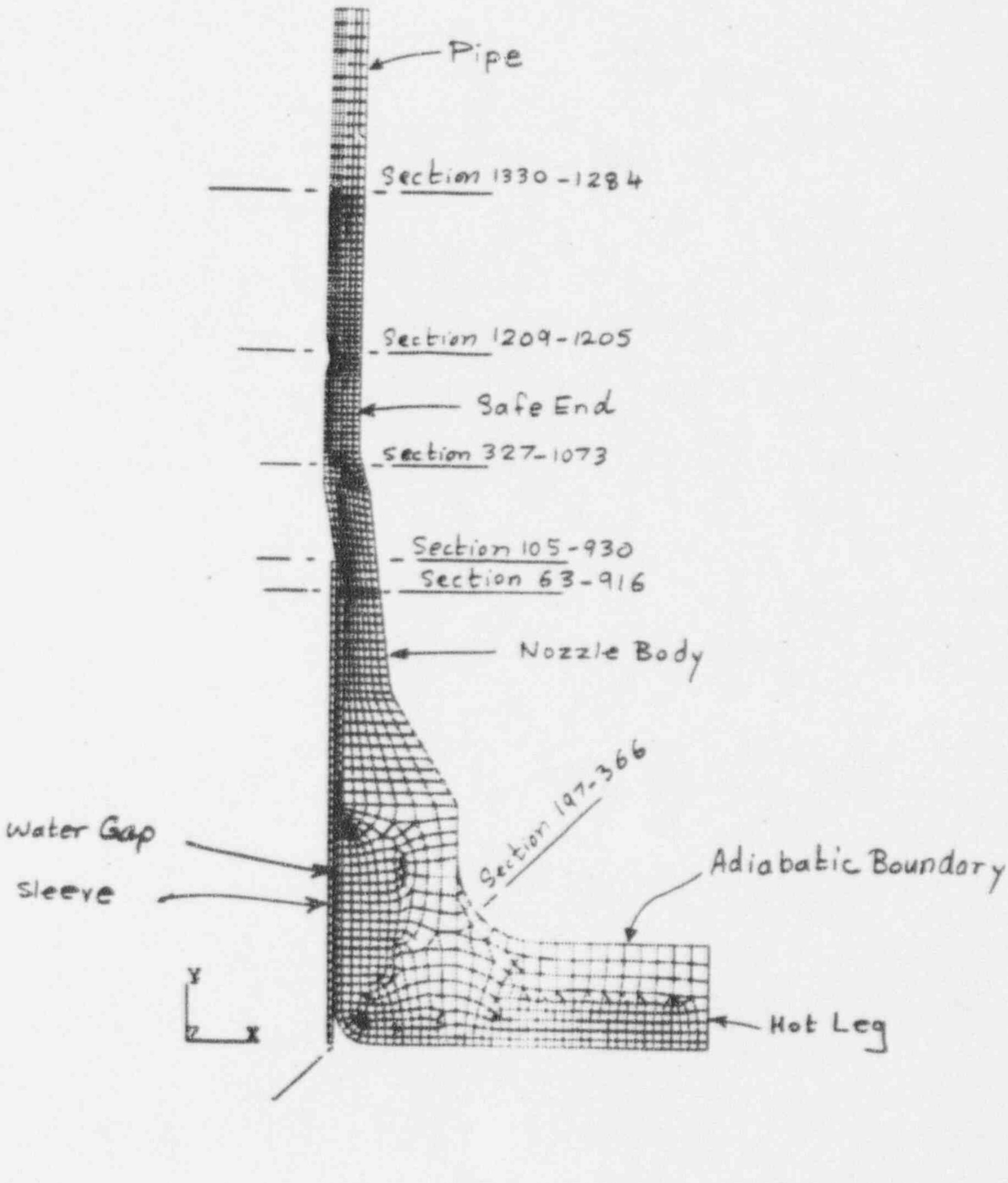


Figure 5.5 Finite Element Model of the Hot Leg Surge Nozzle

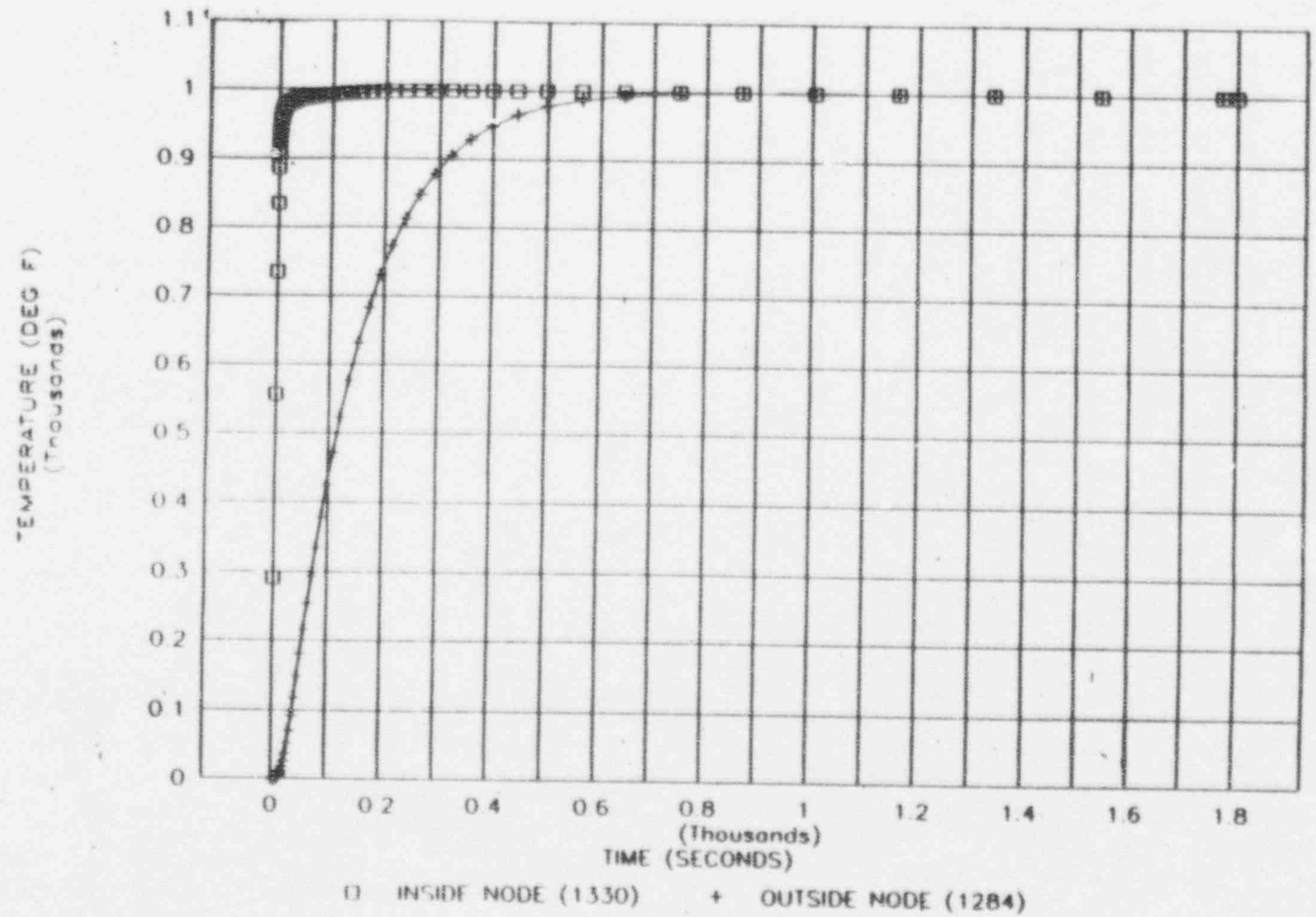


Figure 5.6 Temperature Time History on Section 1330-1284

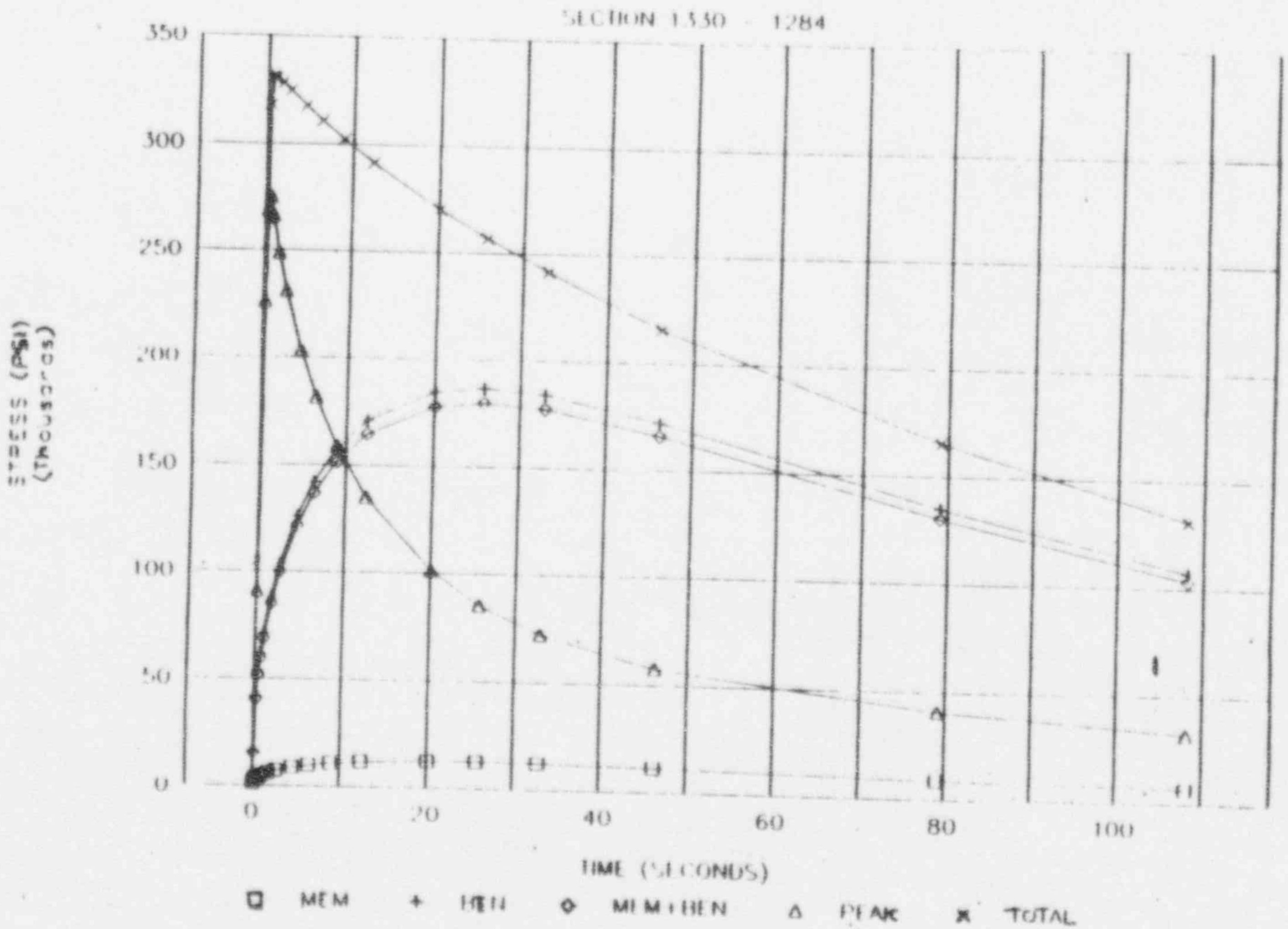


Figure 5.7 Stress Components Time History on Section 1330-1284

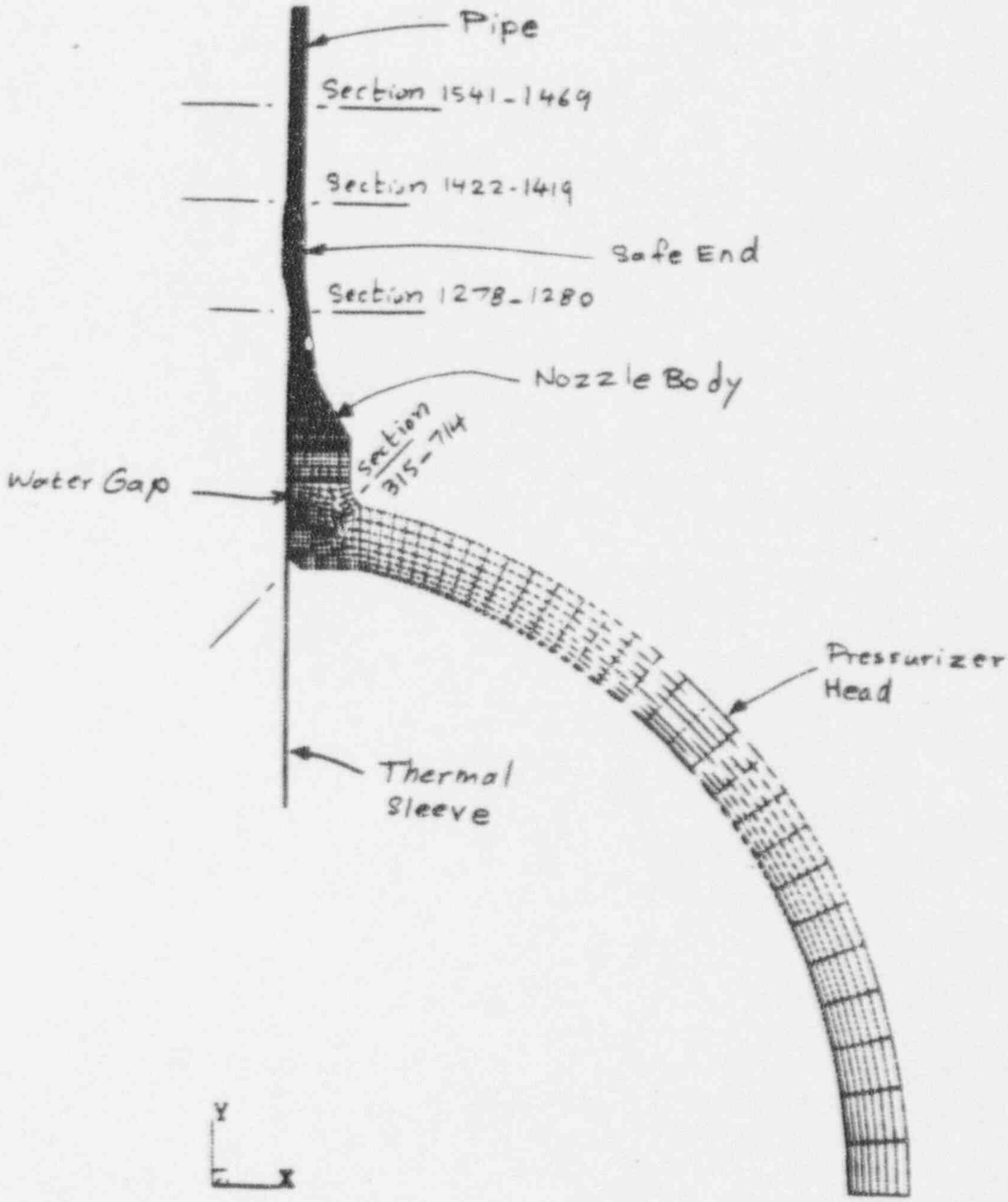


Figure 5.8 Finite Element Model of the Pressurizer Surge Nozzle

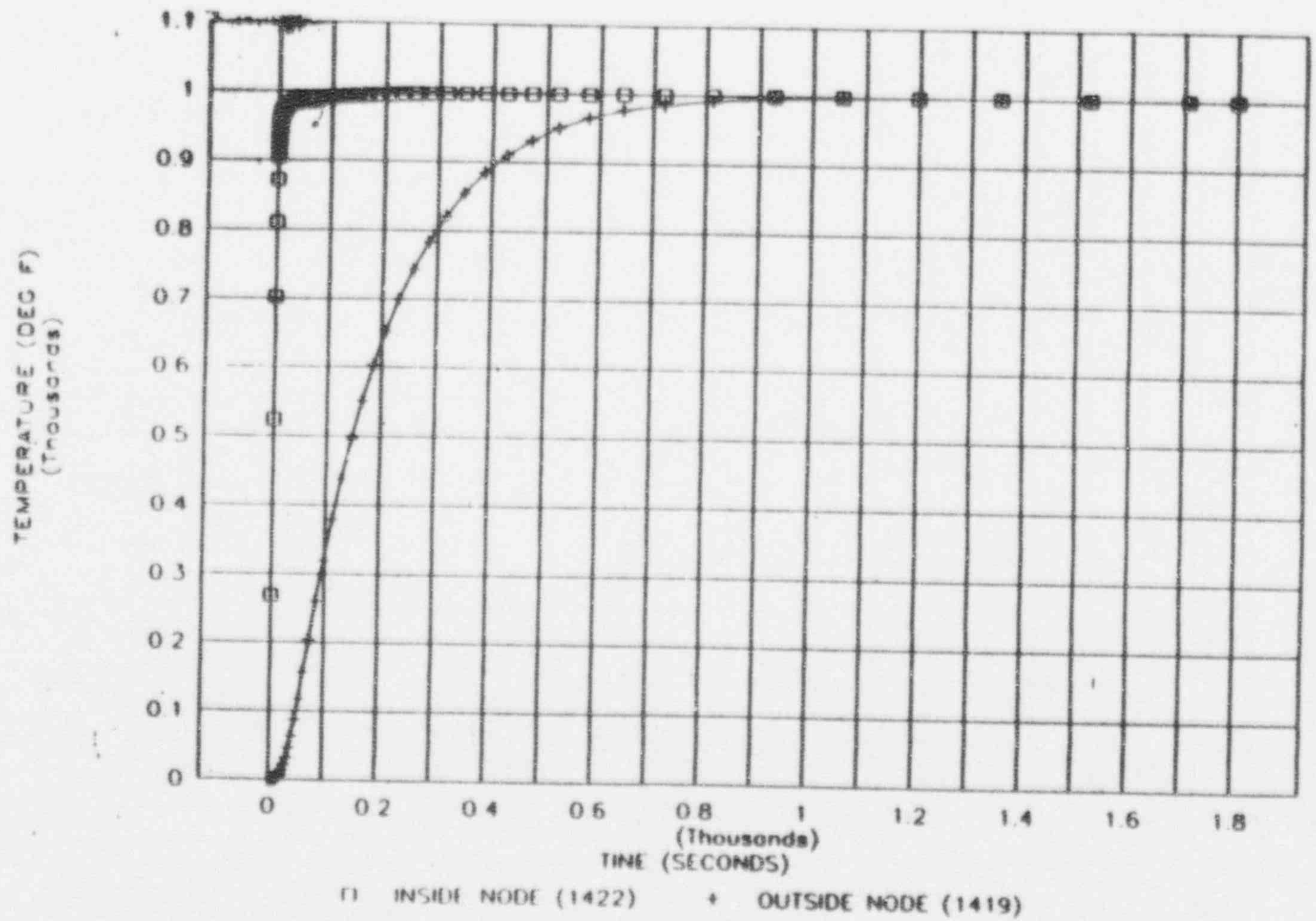


Figure 5.9 Temperature Time History on Section 1422-1419

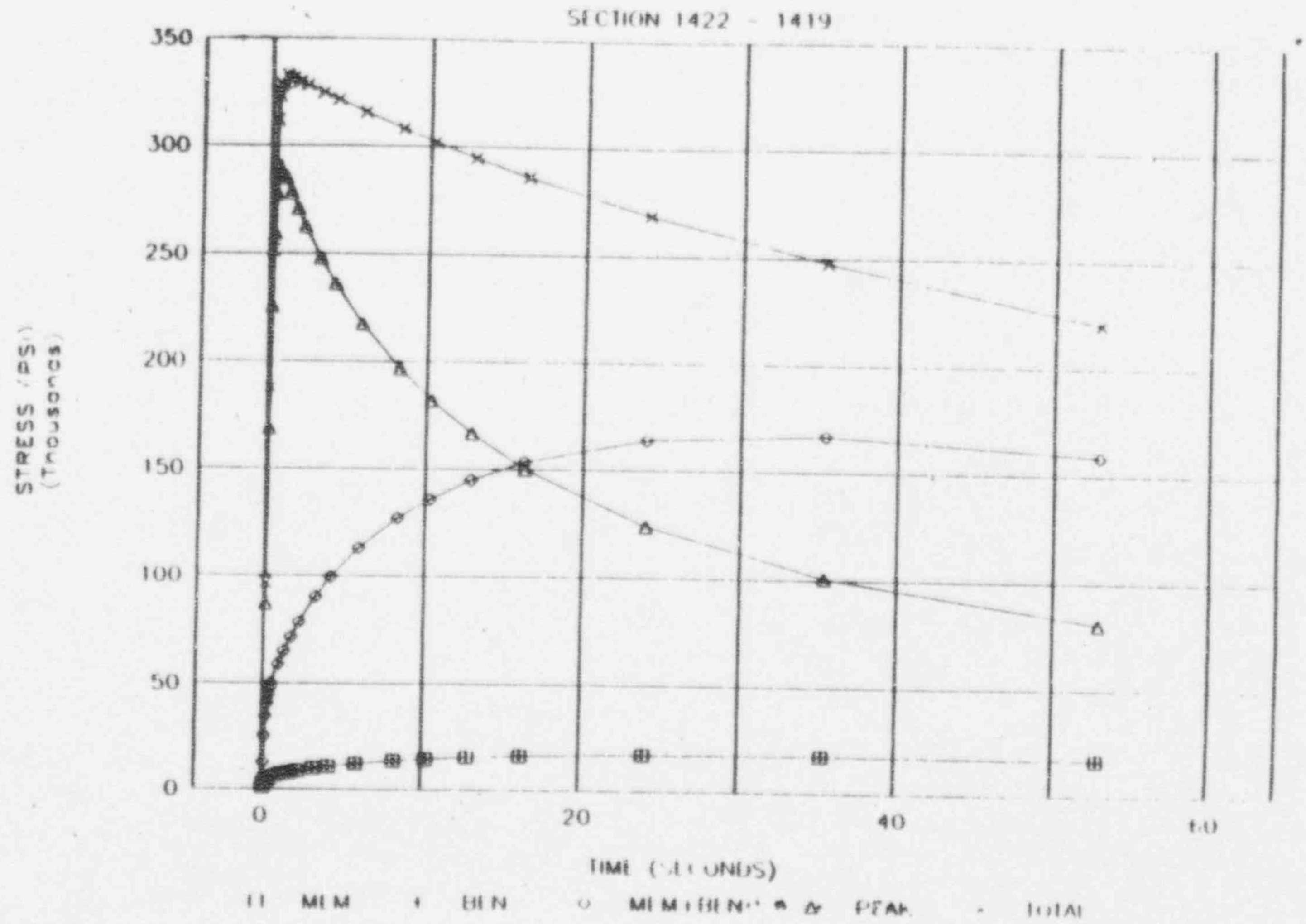


Figure 5.10 Stress Components Time History on Section 1422-1419

5.2.5 Integral Attachment Analysis

Snubbers are connected to the surge line by means of dummy pipes. Similarly, the rigid support load is transmitted by means of rectangular lugs, as shown in Section 4 of this attachment.

Unit thermal and mechanical loads were applied independently, and the results were multiplied by appropriate factors and combined to calculate the response to actual loads, based on the principle of superposition. The three-dimensional models were generated using ANSYS. Three-dimensional models of the rectangular lug and the dummy pipe were used due to the absence of axial symmetry and to capture the details of the welds. ANSYS thermal analysis three-dimensional element type STIF70, and the structural element type STIF45 were used to generate the models of the integral attachments. Figures 5.11 and 5.12 show a computer plot of the dummy pipe model, and figures 5.14 and 5.15 show a sample of the thermal analysis results obtained for the transient shown in Figure 5.13. Similarly, Figure 5.16 shows a computer plot of the rectangular lug model, and Figures 5.17 and 5.18 show a sample of the thermal analysis results obtained for the a thermal shock transient.

Critical sections were selected for stress calculations in each model based on material and geometric discontinuities.

The following unit thermal and mechanical loads were considered:

(a) Unit Thermal Shock

Thermal transient analysis was performed to calculate the temperature time history due to a thermal shock on the inside surface of the pipe. Conservatively, the outside surface of the model was assumed to be adiabatic (perfectly insulated) with no heat transfer to the surroundings. Results of this computer run are stored on a data file generated by the thermal transient analysis. A second run uses the data stored on FILE to calculate the time history of membrane, bending, peak, and total stresses due to the thermal gradients generated by the thermal shock.

(b) Internal Pressure

Each three-dimensional (solid) model was subjected to internal pressure (on the inside surface of the pipe). Appropriate end load was applied on the end of the model representing the cap load.

(c) Unit Force Perpendicular to Pipe Axis

A unit force was applied on the integral attachment, rigid support lug or snubber dummy stub, representing the actual operating loads.

(d) Unit Force in the Axial Direction of the Pipe

A unit force was applied on the end of the pipe in the direction of the pipe axis.

Figures 5.11 and 5.12 show two computer plots of the three-dimensional finite element model of the dummy pipe. Figure 5.11 also shows the critical sections, representing geometric discontinuities, selected for stress calculations. Figure 5.13 shows how the thermal shock was applied to the dummy stub model. Sample results of the thermal analysis are shown in Figure 5.14, which shows the temperature time history response of some inside nodes in the hot layer and cold layer to a thermal shock. Stress components acting on section 5-1883 (see Figure 5.11) are shown in Figure 5.15.

Similarly, Figure 5.16 shows a computer plot of the three-dimensional model used to generate the base load cases for the rigid support rectangular lug. The figure also shows the critical sections selected for the calculation of stress components. Sample results of the thermal analysis are shown in Figure 5.17, which shows the temperature time history response of the inside and outside nodes of section 717-362 (see Figure 5.16) to a thermal shock. Figure 5.18 shows the stress components time history acting on section 719-403.

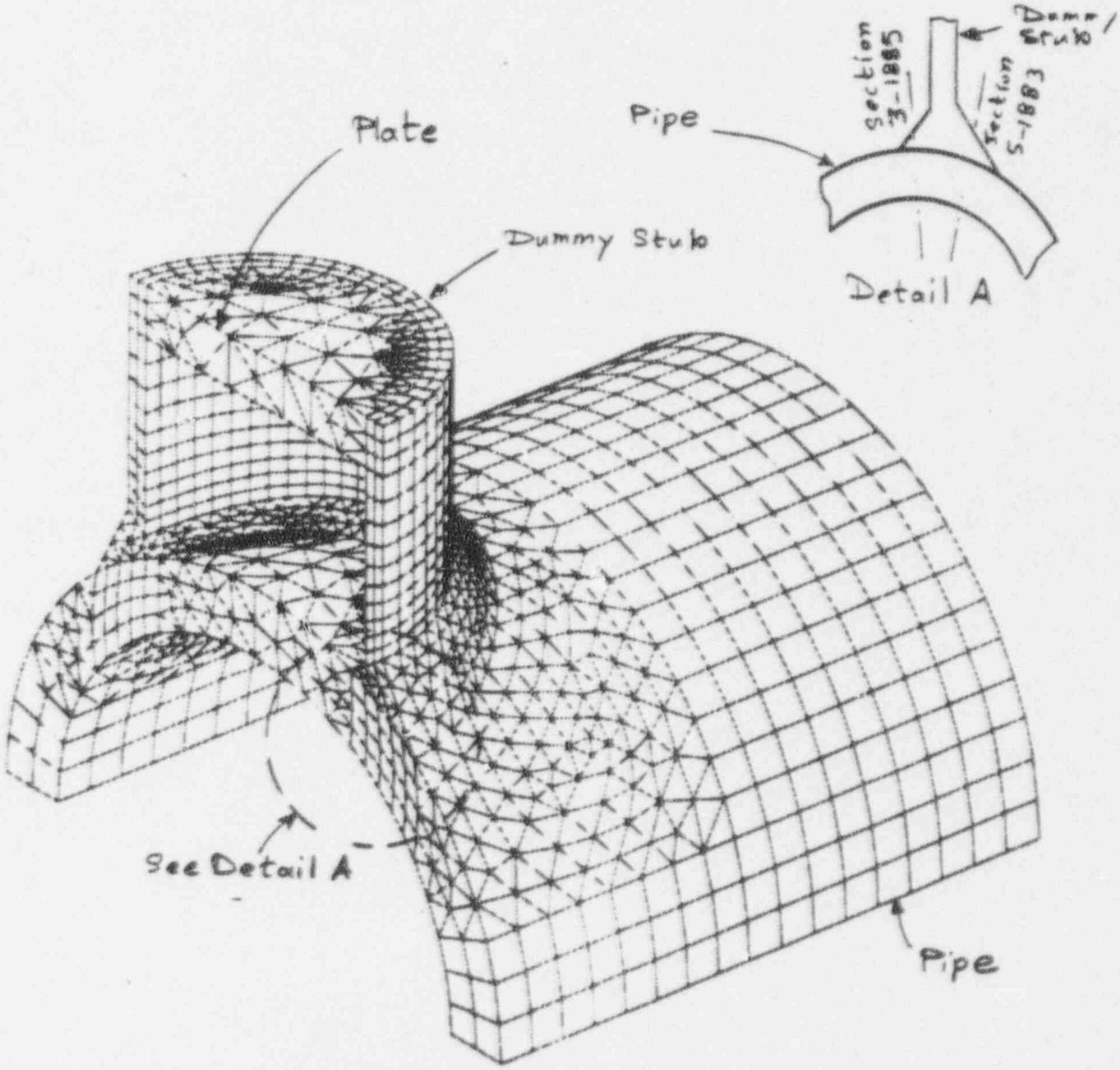


Figure 5.11 Finite Element Model of the Dummy Pipe Showing Sections Selected for Stress Calculations (Front View)

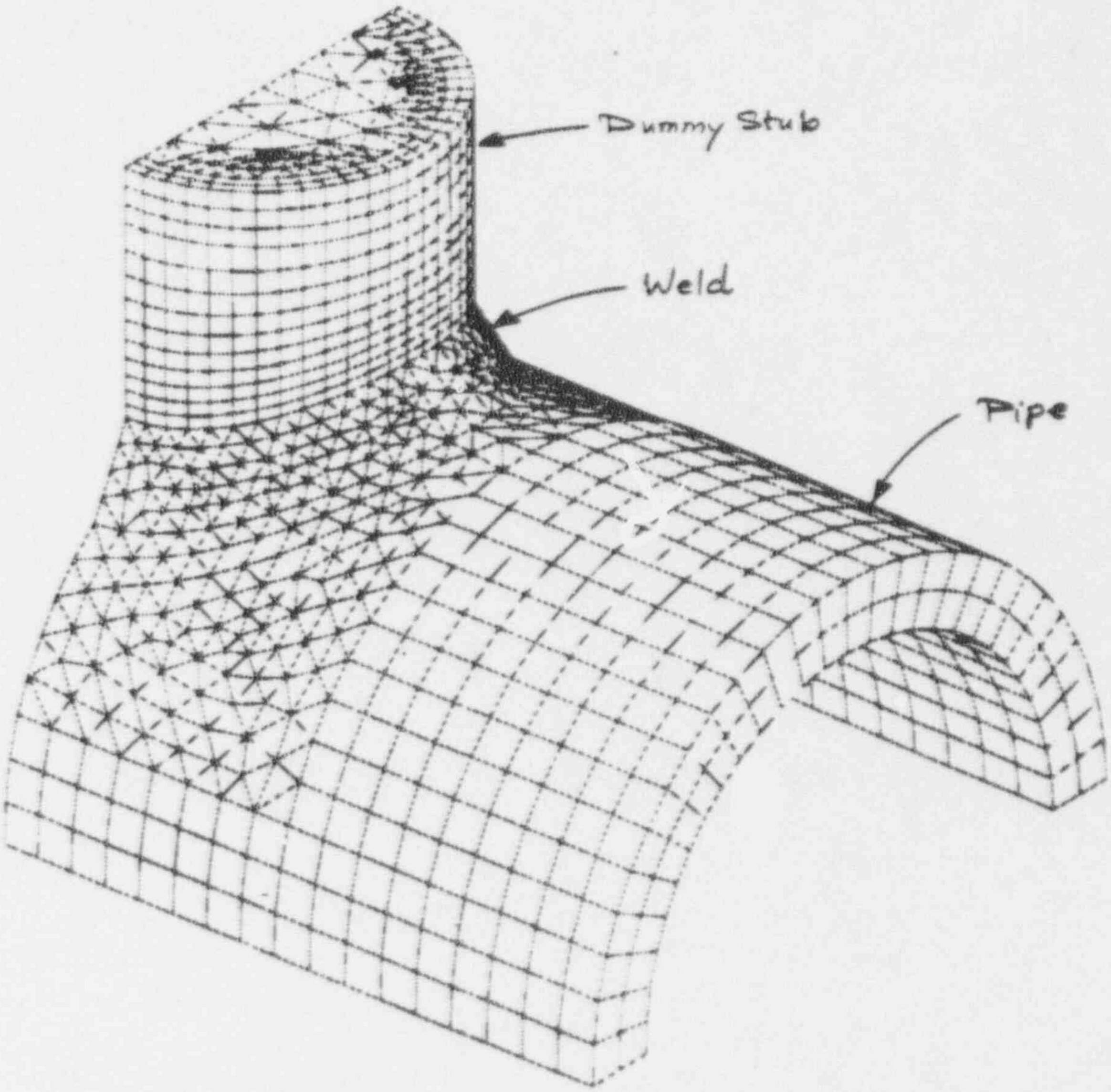


Figure 5.12 Finite Element Model of the Dummy Pipe (Rear View)

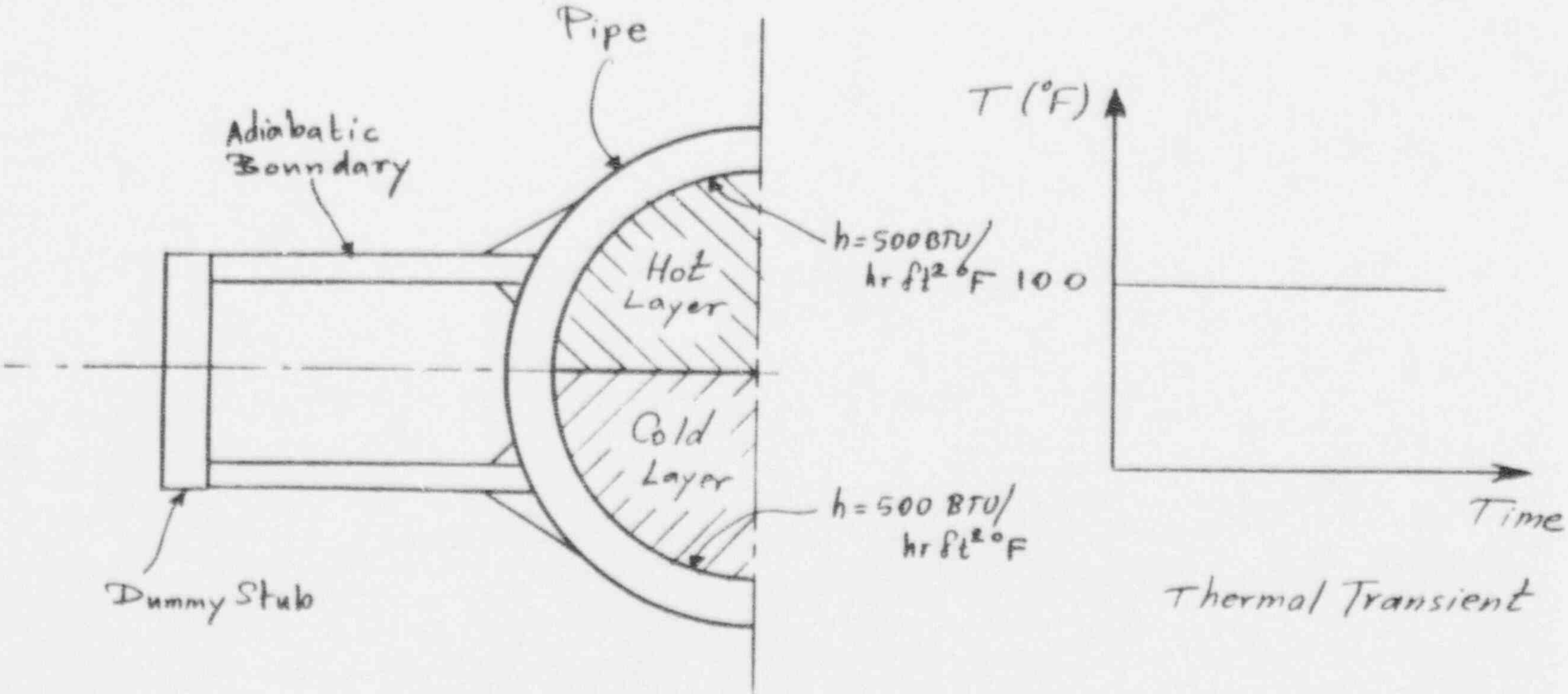


Figure 5.13 Unit Thermal Shock (100°F) at Dummy Pipe Location

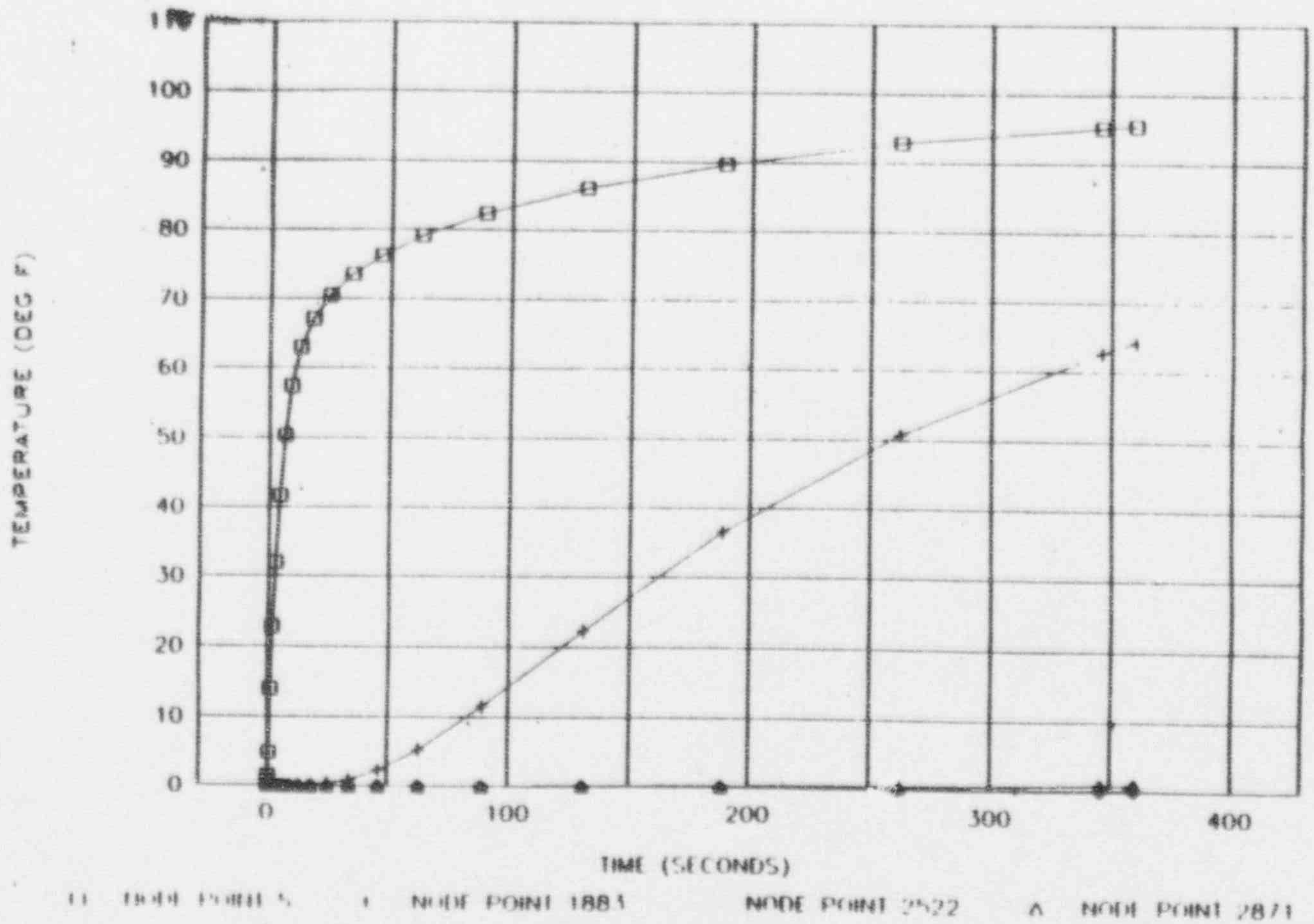


Figure 5.14 Temperature Time History on a Hot Layer Section and a Cold Layer Section

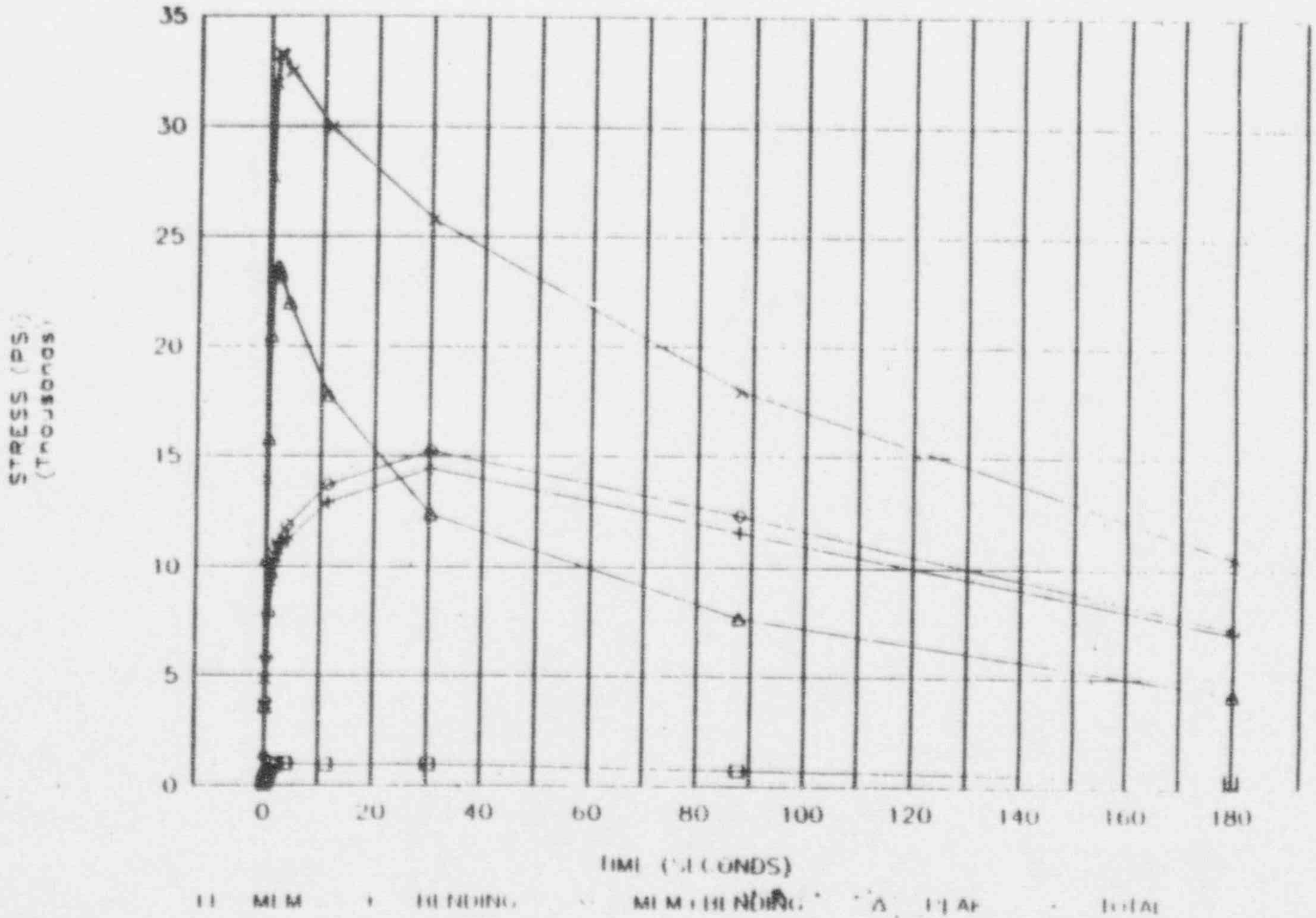


Figure 5.15 Stress Components Time History on a Hot Layer Section
(Section 5-1883)

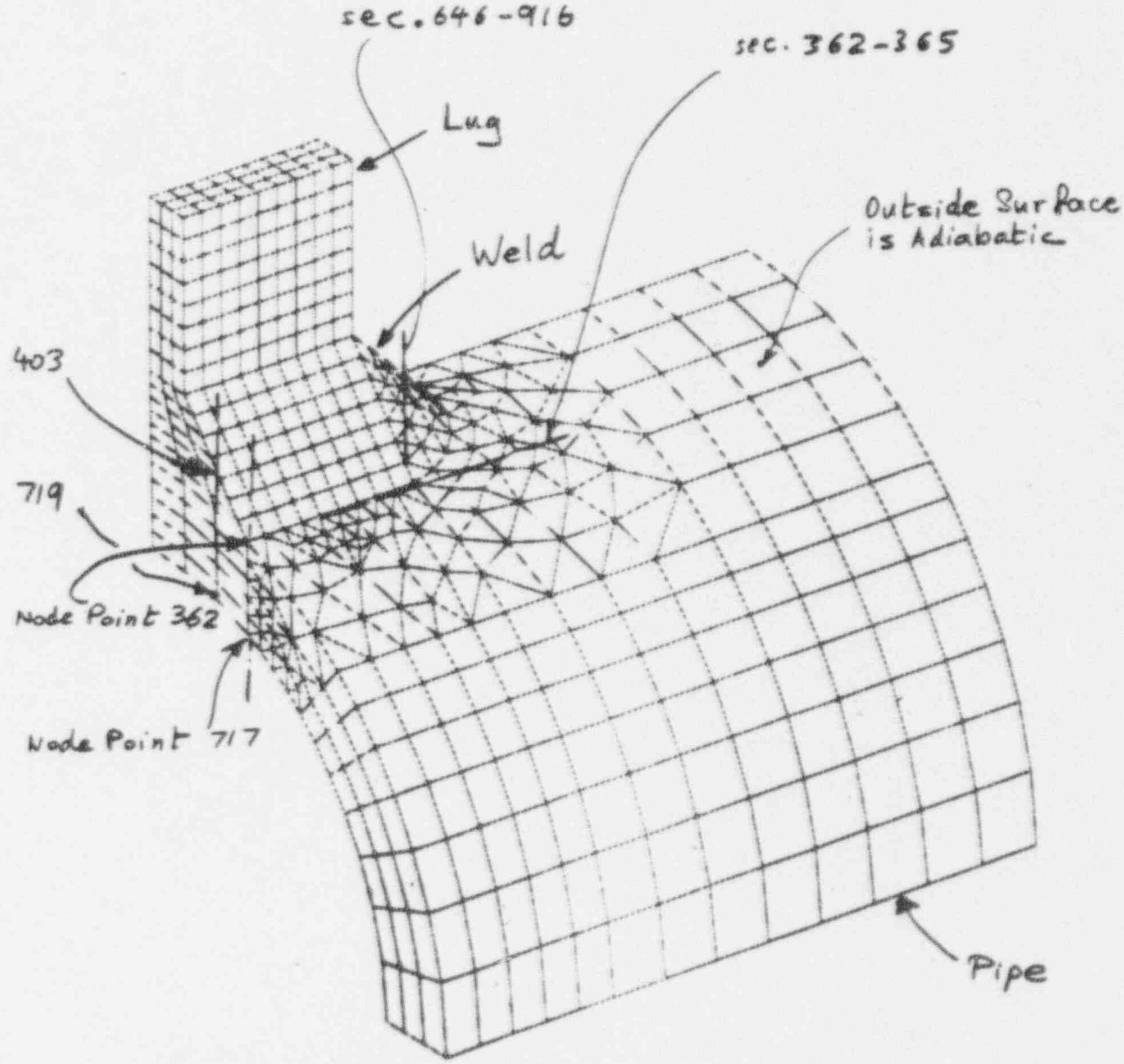


Figure 5.16 Computer Plot of the Finite Element Model of the Rectangular Lug Showing Sections Selected for Stress Calculations

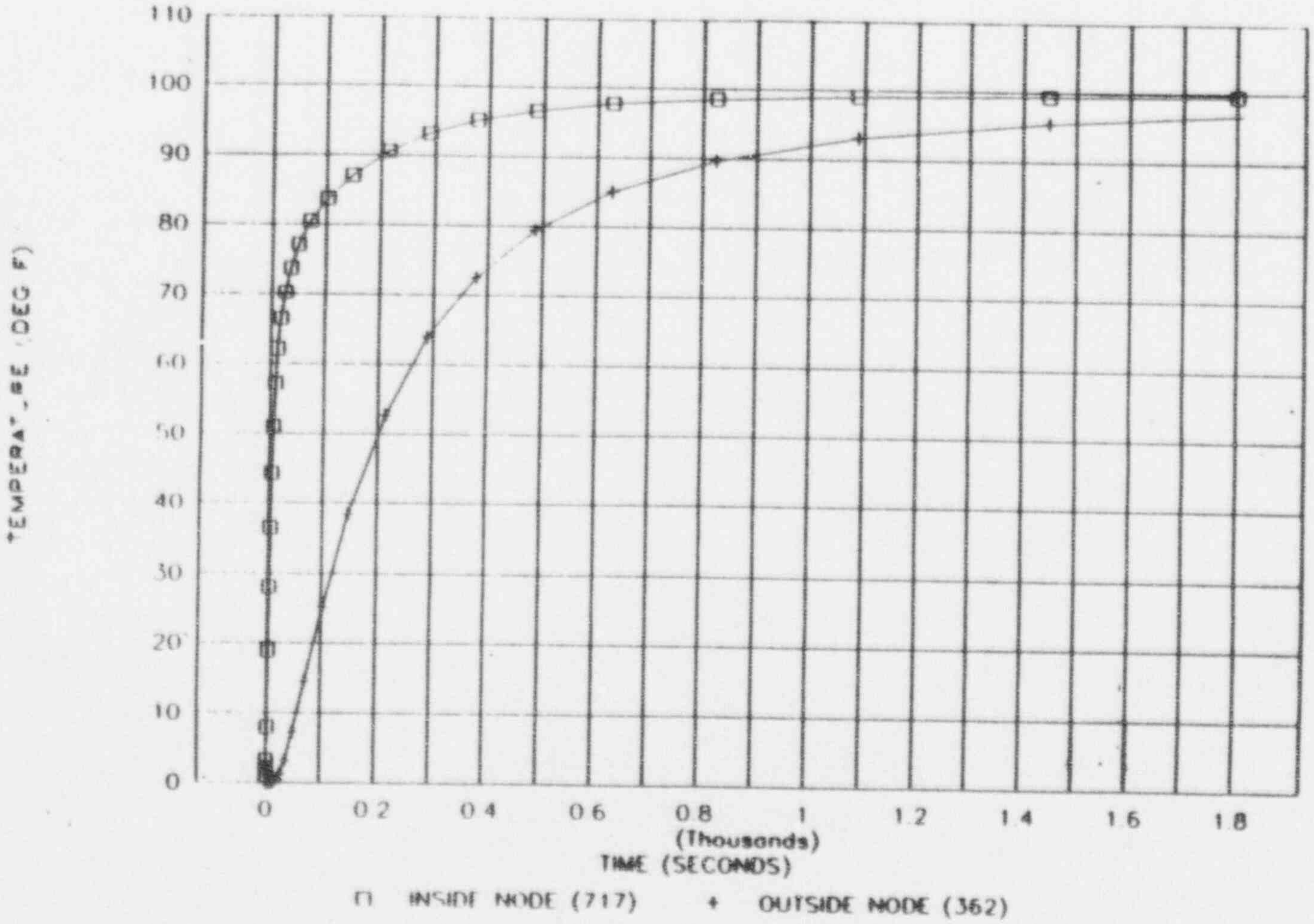


Figure 5.17 Temperature Time History on Section 717-362

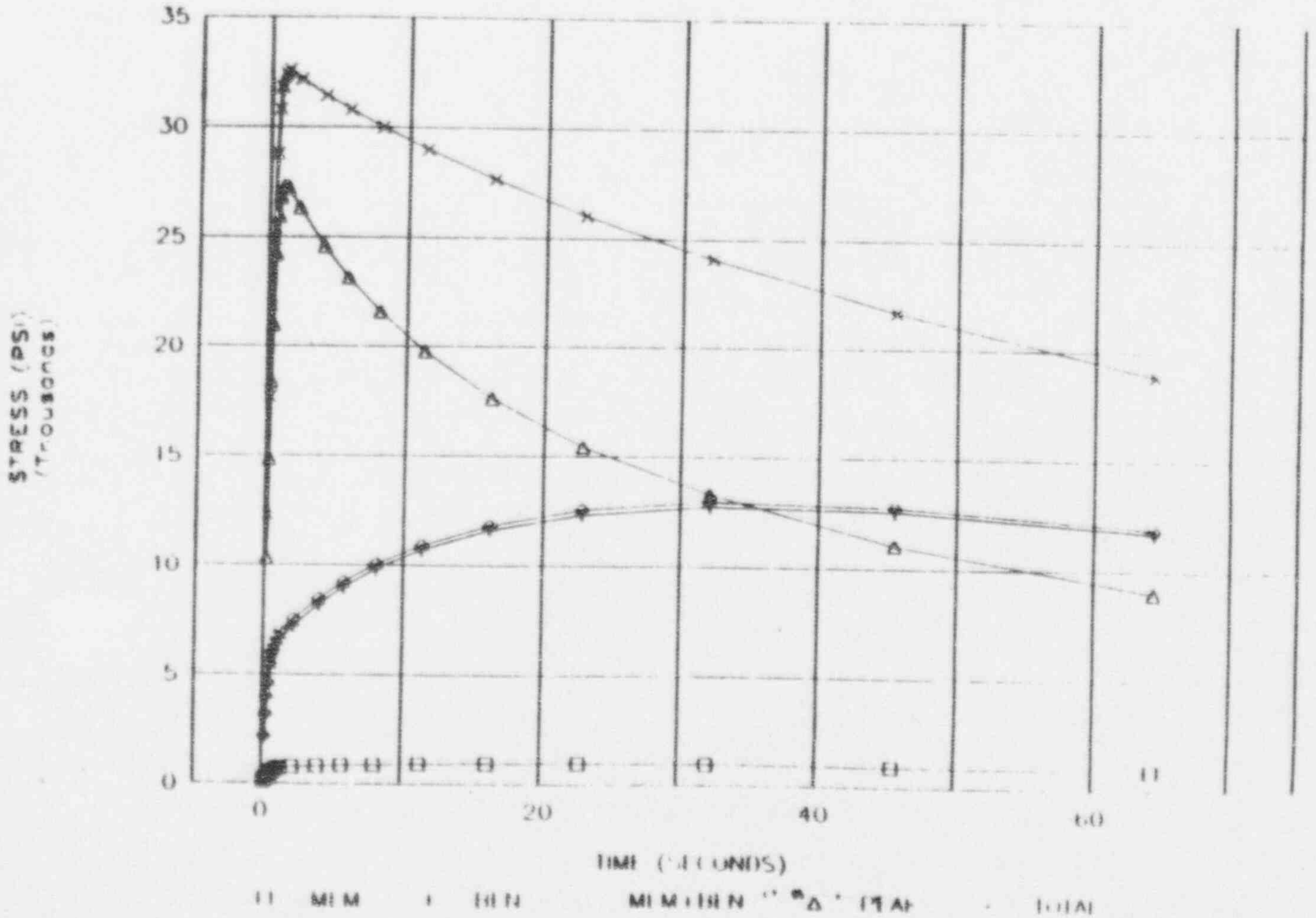


Figure 5.18 Stress Components Time History in the Full Penetration Weld (Section 719-403)

5.3 Surge Line Evaluation\Fatigue Analysis

Evaluation of the pressurizer surge line, including fatigue analysis, was performed in response to the requirements of Bulletin 88-11, Item 1-d. This evaluation also includes the pressurizer surge nozzle, the RCS hot leg surge nozzle and integral attachments. It is recommended by Bulletin 88-11, the analysis was performed per a recent ASME Code edition. Accordingly, the 1986 Code Edition was used throughout the fatigue analysis. In addition to the ASME Code, Code Cases N-122-1 (for the rigid support rectangular lug) and N-391-1 (for the dummy pipe) were used to evaluate the surge line at the locations of the integral attachments.

A summary of the methodology of this evaluation is presented in this section as follows:

(a) Applicable ASME Code Analysis Criteria (Section 5.3.1)

A summary of the applicable ASME Code design equations is included in Section 5.3.1.

(b) Piping ASME Code Evaluation (Section 5.3.2)

The methodology for ASME Code evaluation of the surge line piping is explained in Section 5.3.2.

(c) Nozzle Evaluation (Section 5.3.3)

Section 5.3.3 includes the methodology and the criteria for the evaluation of the RCS hot leg surge nozzle and the pressurizer surge nozzle.

(d) Rigid Support Lug (Section 5.3.4(a))

The analysis methodology of the rigid support rectangular lug is explained in Section 5.3.4(a). Both the ASME Code and Code Case N-122-1 were used in the analysis.

(e) Dummy Pipe Evaluation (Section 5.3.4(b))

The analysis methodology of the dummy pipe welded to the surge line (used as part of the snubber support assembly) is explained in Section 5.3.4(b). Both the ASME Code and Code Case N-391-1 were used in the analysis.

(f) Thermal Ratchet Check (Section 5.3.5)

Thermal ratchet check is required by the Code when the primary plus secondary stress intensity allowable is exceeded. The methodology of this check is explained in Section 5.3.5.

(g) Thermal Striping Evaluation (Section 5.3.6)

Thermal striping analysis methodology is outlined in Section 5.3.6.

5.3.1 Applicable ASME Code Analysis Criteria

The following ASME Code vessel and piping rules were evaluated for the effects of all specified loads, including thermal stratification, on nozzles and integral attachments:

NB-3200 - Design by Analysis (used for nozzles)

NB-3221 (Design Conditions)
Thermal stratification does not impact design conditions.

NB-3222 Level A Service Limits
NB-3222.1 Primary membrane and bending stress limits (not impacted by thermal stratification).
NB-3222.2, 3, 4
Primary plus secondary, and primary plus secondary plus peak stress intensity. These conditions are impacted by thermal stratification.

$$P_L + P_b + Q \leq 3\ S_m$$

U (usage factor) ≤ 1.0 (includes Level B and Test conditions)
If the above limit is not satisfied, then K_e should be calculated for fatigue evaluation per NB-3228.5 based on the value of (P_L + P_b + Q) shown above. Also, apply the rules of NB-3228.5 below,

NB-3228.5 $P_L + P_b + Q \leq 3\ S_m$ excluding thermal bending stress.

U ≤ 1.0 (includes Test conditions).

NB-3222.5 Thermal stress ratchet check. This condition is impacted by thermal stratification.

NB-3223 (Level B service limits), NB-3224 (Level C service limits), NB-3225 (Level D service limits) and NB-3226 (Test limits) are not impacted by thermal stratification, and the original analysis is valid. It should be noted that Test condition has been included in the fatigue evaluation.

NB-3600 - Piping Design

NB-3652 (Design Conditions)
Thermal stratification does not impact design conditions.

NB-3653 Level A Service Limits
NB-3653.1 Primary plus secondary stress intensity range limit (Equation 10). This is impacted by thermal stratification.
If Equation (10) limit is exceeded, then

NB-3653.6 Simplified elastic-plastic analysis:

Equation (12) stress ≤ 3 S_m[1]

Equation (13) stress ≤ 3 S_m

K_e should be calculated for fatigue evaluation.

NB-3653.7 Thermal stress ratchet check.

NB-3653.2, 3, 4, 5

Primary plus secondary plus peak stress intensity range. These conditions are impacted by thermal stratification.

U ≤ 1.0 (includes Level B and Test conditions).

NB-3654 (Level B service limits), NB-3655 (Level C service limits), NB-3656 (Level D service limits) and NB-3657 (Test limits) are not impacted by thermal stratification, and the original analysis is valid. It should be noted that Test condition has been included in the fatigue evaluation.

Load Combinations

Condition	Local Combination
Design	Pressure, Deadweight
Level A (primary stress only)	Pressure, Deadweight
Level B (primary stress only)	Pressure, Deadweight, OBE
Level A and B (primary+secondary)	Pressure, Deadweight, OBE, Thermal including stratification
Level C (primary stress only)	Emergency conditions not specified
Level D	Pressure, Deadweight, SSE, LOCA

ASME Code stress and fatigue evaluations were performed at 18 piping locations, 5 welded attachment locations, and 2 nozzle locations (see Section 2 for a summary of the results).

Note (1): Locations where Equation (12) limit is exceeded are enveloped by the shakedown analysis in Reference 6 (see Section VI, page VI-1), since the calculated stress in this analysis is less than the stress calculated in that reference.

5.3.2 Piping ASME Code Evaluation

Surge line piping evaluation was performed per the rules of Subsection NB-3650 of the ASME Code. The following Code equations were included in the evaluation:

a• Code Equation 10 stress (S_n) is given by
For non-OBE transients:

$$S_n = C_1 \frac{P_o D_o}{2t} + C_2 \frac{D}{2I} M_i + C_3 E_{ab} \left| \alpha_a T_a - \alpha_b T_b \right| \leq 3S_m$$

For OBE transient

$$S_n = C_1 \frac{P_o D_o}{2t} + C_2 \frac{D_o}{2I} M_i + [A] + C_3 E_{ab} \left| \alpha_a T_a - \alpha_b T_b \right| \leq 3S_m,$$

[A] = maximum of $(2C_2\ M_{OBE}\ D/2I)$ or $(C_2\ (M_i + M_{OBE})\ D/2I)$

b• Code Equation 12 stress (S_e) is given by:

$$S_e = C_2 \frac{D_o}{2I} M_i^* \leq 3S_m$$

See also note (1) on page VII-66.

c• Code Equation 13 stress is given by:
For non-OBE transient pairs

$$C_1 P_o \frac{D_o}{2t} + C_2 \frac{M_{DW}}{2I} D + C_3' E_{ab} \left| \alpha_a T_a - \alpha_b T_b \right| \leq 3S_m$$

For OBE transients

$$C_1 P_o \frac{D_o}{2t} + C_2 \frac{M_{OBE} + M_{DW}}{2I} D + C_3' E_{ab} \left| \alpha_a T_a - \alpha_b T_b \right| \leq 3S_m$$

where

M_{OBE} = resultant OBE moment, in.-lb

M_{DW} = maximum deadweight moment, in.-lb

P_o = pressure range for the transient pair, psi

C_1 and C_2 = secondary stress indices for the specific component under investigation (NB-3680)

D_o = nominal outside diameter of pipe, in. (NB-3683.1)

t = nominal wall thickness of pipe, in. (NB-3683.1)

D = diameter of interest (either inside or outside diameter), in.

I = moment of inertia of pipe, in.^{4}

α_a (α_b) = coefficient of thermal expansion on side a(b) of a gross structural discontinuity, at room temperature, 1/°F (NB-3653.1)

T_a (T_b) = range of average temperature on side a(b) of gross structural discontinuity or material discontinuity, °F. For generally cylindrical shapes, the averaging of T (NB-3652.3) shall be over a distance of $\sqrt{d_a t_a}$ for T_a and $\sqrt{d_b t_b}$ for T_b

E_{ab} = average modulus of elasticity of the two sides of a a gross structural discontinuity or material discontinuity at room temperature, psi ASME (Appendix I Table I-6.0)

C_3' = valus in Table NB-3681(a)-1

M_i = maximum thermal bending moment calculated as follows:

$$M_i = \frac{T_{PRZ}-70}{653-70}(Case\ 1\ moment) + \frac{T_{HL}-70}{650-70}(Case\ 2\ moment) +$$

$$\frac{0.5(T_{PRZ}+T_{HL})-70}{80-70}(Case\ 3\ moment) +$$

$$0.95\frac{(T_{PRZ}-T_{HL})}{10}(Case\ 4\ momemt)$$

where

T_{PRZ} and T_{HL} = pressurizer temperature and the hot let temperature, respectively.

Also, Case 1 through Case 4 refer to the four base load cases described in Section 5.2 of this summary report. A factor of 0.95 appears in the last term represents the ratio between the maximum stratification temperature in the pipe and the system temperature difference ($\Delta T_{SYS} = T_{PRZ} - T_{HL}$).

d• Primary + secondary + peak stress

The primary plus secondary plus peak stress is given by

$$K_1 C_1 \frac{P_o r_o}{2t} + [C] + K_3 \sigma_{ramp} (\frac{dT}{dt})_{max}$$

The [C] term appears in the transients with axisymmetric thermal shock, namely, transients number 3a, 3b, 4a, 4b, 5, 6, 7, 27 and 28 (see Section 4.3 of this report). It is given by the maximum of the following:

$$K_2 C_2 (\frac{M_i D}{2I} + \frac{M_{OBE} D}{2I}) + \Delta T_{max} \sigma^A_{ss}, \quad or$$

$$K_2 C_2 (0.1493 \frac{M_i D}{2I} + \frac{M_{OBE} D}{2I}) + \Delta T_{max} (2\sigma^A_{max} + \sigma^A_{ss})$$

where

M_{OBE} = resultant operating basis earthquake (OBE) moment (used only for OBE transients)

C_1, C_2, K_1 and K_2 = stress indices

$\sigma_{ss}{}^A$ and $\sigma_{max}{}^A$ = peak and steady-state stresses for a 1°F axisymmetric thermal shock

ΔT_{max} = maximum temperature difference during the transient

The scale factor of 0.1493 is the value of the global bending stress when the local bending reaches a peak of 1.0 (normalized value)

M_i = maximum thermal bending (calculated above)

As illustrated in Figure 5.19, for all piping locations, the global stress and local stress will build up at different rates. The local stress is due to the skin effects of the thermal shock, and the global stress due to the thermal bending moments caused by thermal stratification. Figure 5.19 shows that there are two possibilities for the stress range depending on the relative magnitudes of the local and global stresses. This explains the [C] term above.

For transients other than those listed above, stratified flow conditions are assumed. Same equations are used except that ΔT_{max} is the maximum top-to-bottom temperature difference, and σ_{max} and σ_{ss} are the peak and steady-state stresses for a 1°F stratified thermal shock.

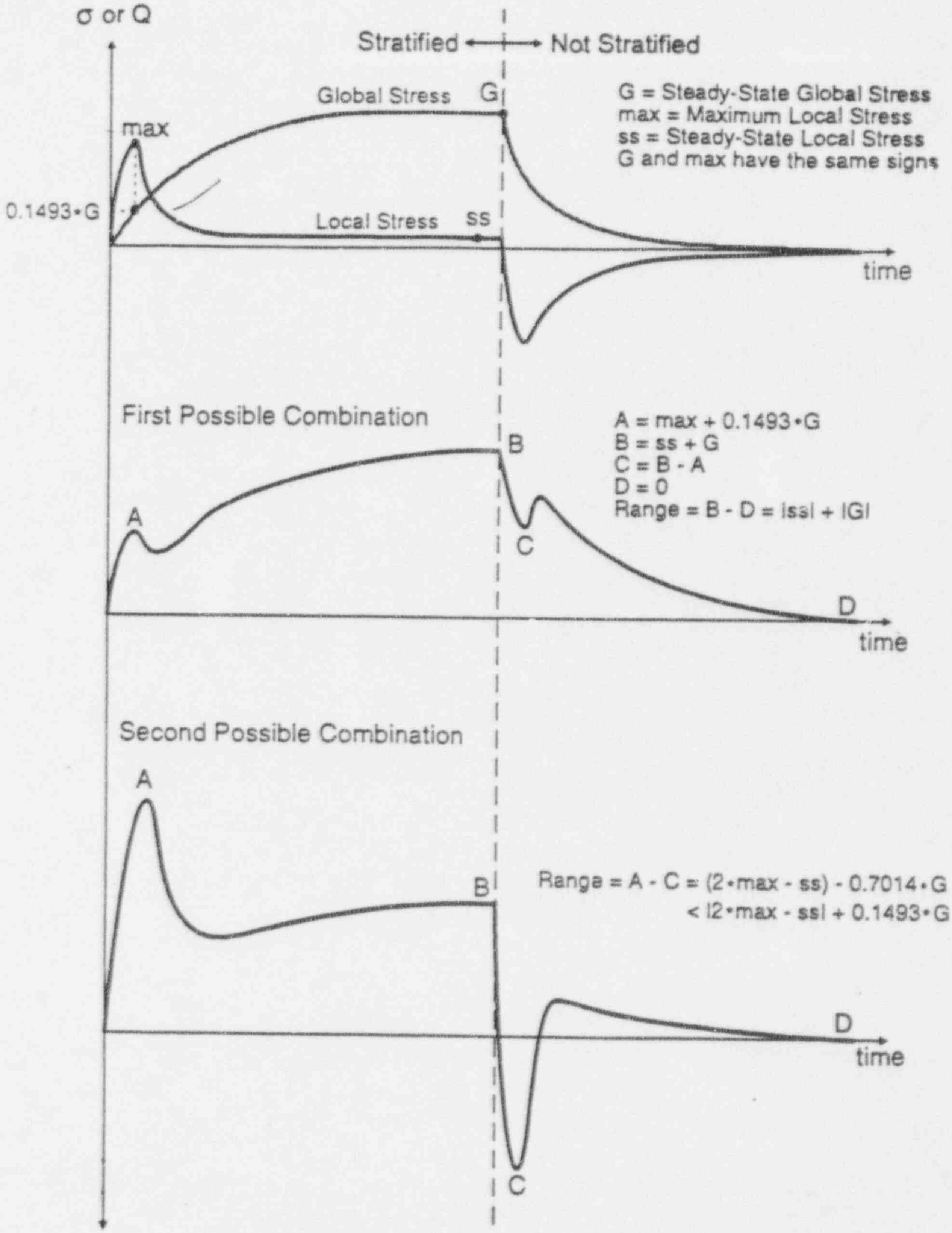


Figure 5.19 Typical Transient Thermal Stress Response for Piping Locations

It should be noted that the ΔT_{max} term was not used for transients 10a and 10b because these transients do not have a thermal shock.

Fatigue evaluation was performed per the rules of NB-3653.6, which can be summarized as follows:

$$S_a = 0.5*(\frac{E_{fatiguecurve}}{E_{analysis}})*K_e*(peakstress)$$

where

S_a = alternating stress

$E_{fatigue\ curve}$ = Young's modulus used in Appendix I of the ASME Code in the fatigue curve

$E_{analysis}$ = Young's modulus used in the analysis

and K_e is calculated as follows:

- $S_n \leq 3S_m$:

$$K_e = 1.0$$

- $3S_m \leq S_n \leq 3mS_m$:

$$K_e = 1.0 + \frac{(1-n)}{n(m-1)}(\frac{S_n}{3S_m} - 1)$$

- $S_n \geq 3mS_m$

$$K_e = 1/n$$

The parameters m and n are obtained from Table NB-3228.3(b)-1.

5.3.3 Nozzle Evaluation

Two-dimensional axisymmetric finite element models of the RCS hot leg surge nozzle and the pressurizer surge nozzle were generated, and several base load cases were analyzed as explained in Section 5.2.4 of this summary report. These base load cases include a thermal shock, mechanical loadings including internal pressure. Results of the thermal base load case was used to calculate the secondary stress index C_2, and mechanical base load cases were used to calculate C_1 at the most critical location of the nozzle assembly (the nozzle safe end).

The nozzles were evaluated per the rules of NB-3200 (design by analysis) by calculating the maximum primary plus secondary stress intensity. This stress intensity was calculated as the sum of two terms as follows:

$$P_L + P_b + Q = (P_L + P_b + Q)_T + (P_L + P_b + Q)_M \qquad (1)$$

where (see also ASME Section NB-3200),

P_L = local membrane stress,

P_b = bending stress,

Q = self-equilibrating stress necessary to satisfy continuity of structure.

The first term on the right hand side of Equation (1) is the thermal term given by:

$$(P_L+P_b+Q)_T = [B] + \sigma_{ramp}\left(\frac{dT}{dt}\right)$$

The [B] term appears in the transients with axisymmetric thermal shock, namely, transients number 3a, 3b, 4a, 4b, 5, 6, 7, 27 and 28 (see Section 4.3 of this summary report). It is given by the maximum of the following:

$$(2Q_{max} - Q_{ss})\Delta T, \text{ or}$$

$$C_2 \frac{D}{2I} M_i + Q_{max}\Delta T$$

where Q_{max} and Q_{ss} are the maximum and steady-state secondary stresses due to a 1°F axisymmetric thermal shock. Similarly, σ_{ramp} is the maximum inside diameter stress in a straight pipe due to a 1°F/hr linear heatup, and the term $(dT/dt)_{max}$ is the maximum heatup or cooldown rate of the transient in question.

The mechanical term on the right hand side of Equation (1) is given by:

$$(P_L+P_b+Q)_M=C_1\frac{D_o}{2t}P_o+C_2\frac{D}{I}M_{OBE}$$

where

M_{OBE} = operating basis earthquake (OBE) moment

P_o = pressure range for the transient pair

C_1 and C_2 = secondary stress indices

D_o = pipe outside diameter

t = pipe wall thickness

D = diameter of interest (either inside or outside diameter)

I = moment of inertia of the pipe cross section

The limit for (P_L + P_b + Q) is $3S_m$ per NB-3222.2. If this limit is exceeded, then simplified elastic-plastic analysis is invoked per NB-3228.5, and a penalty factor is calculated for use in the fatigue analysis. Furthermore, a thermal stress ratchet per NB-3222.5 is to be performed.

The primary plus secondary plus peak stress evaluation is performed using the methodology summarized in Section 5.3.2 of this calculation. However, since both nozzles are located on vertical segments of the surge line, they are not subjected to stratified flow conditions. Accordingly, the ΔT_{max} term, associated with stratified transients, was not used for the nozzles.

5.3.4 Integral Attachments

(a) Rigid Support Lug

The surge line piping located at the rigid support rectangular lug was evaluated similar to other piping locations except that the Code equations have some additional terms. Specifically, Equation 10 of NB-3653 becomes:

$$S_n = C_1 \frac{P_o D_o}{2t} + C_2 \frac{D_o M_i}{2I} + S_{n1} \quad \leq \quad 3S_m$$

where the term S_{n1} is defined in Code Case N-122-1 (Reference 36) as follows:

$$S_{n1} = \frac{C_T W}{A_1} + \frac{C_L M_L}{Z_{1L}} + \frac{C_N M_N}{Z_{1N}} + \frac{Q_1}{2L_1 L_a} + \frac{Q_2}{2L_2 L_b} + M_T$$

where W, M_L, M_N, Q_1 Q_2 and M_T are loads on the lug (see Figure 5.20). However, the only non-zero component is W acting on the lug:

$$W = F_1(T_{PRZ}-70) + F_2(T_{HL}-70) + F_3\frac{(T_{PRZ}-70)}{10}$$

$$+ F_4 \frac{\Delta T_{stratification}}{10} + F_{OBE}$$

where F_1 through F_4 are obtained from the base load cases (see Section 5.2), and F_{OBE} is the lug force during an OBE seismic event.

The C_T factor is calculated in accordance with the Code Case.

If Equation 10 stress limit is exceeded, then equations 12 and 13 are evaluated, and a thermal stress ratchet check is performed. In this case, additional stress limits per Code Case N-122-1 are checked:

$$S_{n1}^{**} \quad \leq \quad 2.5Sy$$

where

$$S_{n1}^{**} = \frac{C_T}{A_1} W^{**}$$

The load component W^{**} is calculated using the same expression as W.

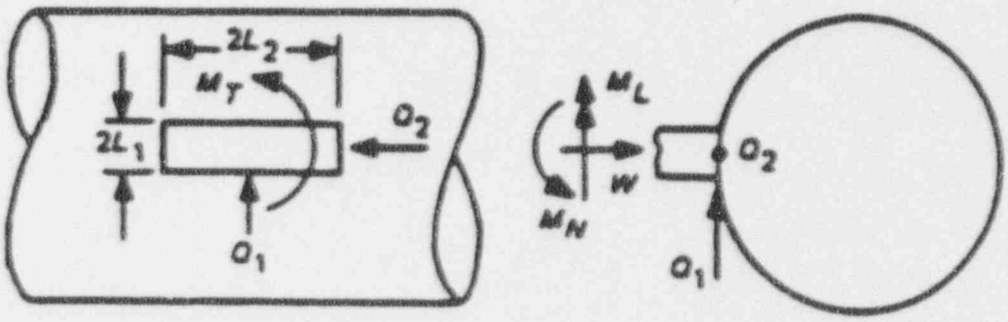


Figure 5.20 Rectangular Weld Attachment Load Components
(Code Case N-122-1)

The peak stress is calculated per NB-3600 with the following term added:

$$S_{p1} = K_1 S_{n1} + K_1 E \alpha \mid T_T - T_w \mid$$

where K_1 = 1.3 for ground full penetration welds per Code Case N-122-1, the second term represents the temperature difference between the lug and the pipe wall.

(b) Dummy Pipe

The surge line piping located at the dummy pipe was evaluated similar to other piping locations except that the Code equations have some additional terms. Specifically, Equation 10 of NB-3653 becomes:

$$S_n = C_1 \frac{P_o D_o}{2t} + C_2 \frac{D_o M_i}{2I} + S_{NT} \leq 3S_m$$

where the term S_{NT} is defined in Code Case N-391-1 (Reference 37) as follows:

$$S_{NT} = \frac{C_w W}{A_T} + 1.7 E\alpha \left| T_T - T_w \right|$$

where load components are defined in Figure 5.21 (W is the only non-zero component). The average local temperatures in the dummy pipe and the pipe wall are represented bt T_T and T_w, respectively. The index C_w is obtained from Code Case N-391-1. Also A_T is the cross sectional area of the dummy pipe. The value of the load (W) is non-zero for OBE transients, and zero for all other transients. Its value was obtained from OBE seismic analysis of the surge line.

If Equation 10 is exceeded, then Equations 12 and 13 are evaluated. It should be noted that S_{NT} is not included in either of these two equations.

The peak stress is calculated per NB-3600 with the following term added:

$$S_{PT} = K_T S_{NT}$$

where

K_T = 1.8 for full penetration welds on the outside diameter, and
K_T = 1.0 for full penetration welds on the inside diameter

per Code Case N-391-1, the second term represents the temperature difference between the dummy pipe and the pipe wall.

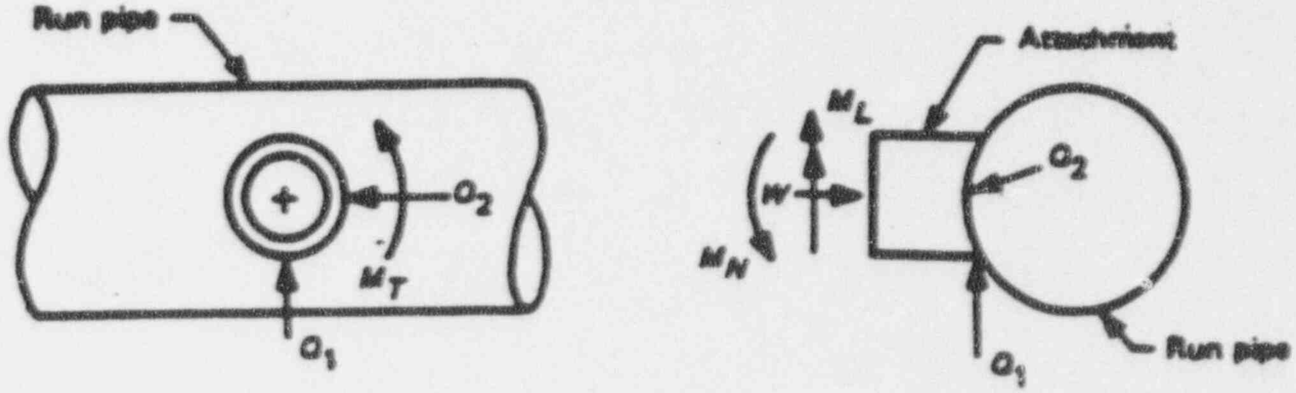


Figure 5.21 Circular Weld Attachment Load Components
(Code Case N-391-1)

5.3.5 Thermal Ratchet Check

ASME Code equation results for the surge line piping, summarized in Section 2 of this attachment, show that the stress limit of Equation 10 of NB-3653 was exceeded at some locations. Similarly, the stress limit of NB-3222.2 was exceeded at both the RCS hot leg and the pressurizer surge nozzles. Accordingly, as required by the ASME Code, a thermal ratchet stress check was performed as follows:

According to the rules of NB-3653.7, the range of ΔT_1 cannot exceed that calculated as follows:

$$\Delta T_1 \quad range \quad \leq \quad \frac{y' S_y}{0.7 E\alpha} C_4$$

where

y' = 3.33, 2.00, 1.20, and 0.80 for x=0.3, 0.5, 0.7, and 0.8, respectively

x = $(PD_o/2t)(1/S_y)$

P = maximum pressure for the set of conditions under consideration, psi

C_4 = 1.1 for ferritic material
= 1.3 for austenitic material

E = Young's modulus, psi

α = coefficient of thermal expansion, 1/°F

S_y = yield strength, psi, taken at the average fluid temperature of the transient

The above check was performed at the piping locations at which Equation 10 was exceeded. Similar check was performed per NB-3222.5 on the surge nozzles to ensure that the Code requirements are met.

5.3.6 Thermal Striping Evaluation

Thermal striping in the surge line was characterized, in the CEOG report on thermal stratification in the surge line (Reference 3), with a maximum fluid ΔT of 140°F and 28°F at oscillation frequency of 1 Hz and 0.25 Hz, respectively. The maximum alternating stress range resulted from a ΔT of 140°F at oscillation frequency of 0.25 Hz with heat transfer coefficient of 3,500 BTU/hr ft^2 °F and the following fluid properties:

thermal conductivity = 9.81 BTU/hr ft °F,
thermal diffusivity = 0.16 ft^2/hr.

A thermal striping loading spectrum was developed, and is summarized in Table 5.1. This spectrum is based on the design basis transients given in Section 4 of this summary report.

Table 5.1 Thermal Striping Loading Spectrum

Service Condition	Number of Cycles	ΔT_{SYS} (°F)
Normal	300	340
	1500	250
	1600	200
	2000	150
	175420	90
	4580	89
	34080	86
	17640	80
	200	73
	30000	60
	2000000	32
Upset	30	250
	40	80
	5	46
	195	32

Each cycle in Table 5.1 initiates a cyclic striping process with initial fluid temperature fluctuation listed in Table 5.1. The amplitude of the fluid temperature fluctuation is assumed to decay with time. The decay correlation was developed, and is documented, in the Westinghouse Owner's Group (WOG) report on thermal stratification in the pressurizer surge line (Reference 34). The magnitude of stress variation due to thermal cycling is given by (Reference 39):

$$\sigma_{alt} = [\frac{\eta E\alpha}{2(1-\nu)}]\,\Delta T_{fluid}$$

where, E is Young's modulus, ν is Poisson's ratio, α is the coefficient of thermal expansion, η is a frequency correction factor AND ΔT_{fluid} is the amplitude of the fluid temperature cycling near the pipe wall. Based on Reference 2 methodology, ΔT_{fluid} is calculated from ΔT_{SYS} as follows:

$$\Delta T_{fluid} = \left(\frac{140}{340}\right) \Delta T_{SYS}$$

The frequency correction factor, η, was calculated using the methodology of Reference 37 as follows:

$$\eta = \frac{1}{\sqrt{1+2\theta+2\theta^2}},$$

$$\theta = \frac{k}{h}\sqrt{\frac{\omega}{2\beta}}$$

where k is thermal conductivity, h is the heat transfer coefficient between the fluid and the pipe wall, ω is the fluid oscillation frequency and β is the thermal diffusivity.

Finally, the accumulative fatigue usage factor due to thermal striping was calculated by dividing ΔT_{fluid} into 5°F increments, then calculating the number of striping cycles, at frequency ω, consistent with Figure 5.1 in each of the 5°F increments. For each temperature increment, the alternating stress and the number of striping cycles are paired and the corresponding partial fatigue usage factor is calculated using the ASME Code fatigue curve. The fatigue usage factor was then obtained by summation of the partial factors.

5.4 Liquid Sample Line

The piping analysis computer program ME-101 is used to perform the Deadweight, Thermal and Seismic Inertia analyses. The mathematical model was generated based on the piping design condition. Code Case N411 is utilized by using seismic response spectra curves with damping values of 2% - 5% (extrapolated from 1% damping curves) for Operating Basis Earthquake (OBE). Design Basis Earthquake (DBE) is conservatively taken 2 x OBE.

The piping stresses are checked in accordance with the rules of ASME Boiler and Pressure Vessel Code, Section III, 1974 through 1974 Summer Addenda, which is the design code. The pipe support loads were calculated, and the final evaluation of design loads is performed separately in the pipe support calculations.

Thermal plus DBE seismic displacements are reviewed for excessive displacement (>1"), and valve accelerations are evaluated and checked against the allowable acceleration.

6 REFERENCES

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2. Calculation number M-DSC-046, Revision 4,"Pressurizer Surge Line."

3. Combustion Engineering Owners Group (CEOG) Report Number CEN-NPSD 546-P, Revision 1-P,"Pressurizer Surge Line Flow Stratification Evaluation," ABB Combustion Engineering Nuclear Power, December 1991.

4. Drawing number S2-1201-ML-015, Revision 3, Line S2-1201-ML-015-12"-A-EEO from the Hot Leg to the Pressurizer.

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9. Report number S023-919-74-0, Revision 1, Figure 7.5,"Internal Details, San Onofre III 96" I.D. Pressurizer," surge nozzle thermal sleeve details.

10. Drawing number S023-923-23-3, Revision 6,"Nozzle Details, San Onofre II Piping", RCS hot leg surge nozzle details.

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7 NOMENCLATURE

A = area, in^2.

α = coefficient of thermal expansion, in/in °F.

β = coefficient of volumetric thermal expansion, 1/°F.

C = specific heat, BTU/lb_m °F.

D_i = inside diameter, in.

D_o = outside diameter, in.

E = Young's modulus, psi.

F = force, lb.

F_{sh} = shearing force, lb.

F_x, F_y and F_z = components of force (F) in the direction of x, y and z, respectively, lb.

g = gravitational acceleration, ft/sec^2.

h = heat transfer coefficient, BTU/hr ft^2 °F.

I = moment of Inertia, in^4.

k = thermal conductivity, BTU/hr ft^2 °F.

M = moment, in-lb.

M_b = bending moment, in-lb.

M_t = torsional moment, in-lb.

M_x, M_y and M_z = components of moment (M) in the direction of x, y and z, respectively, in-lb.

M_{OBE} = resultant operating basis earthquake moment, in-lb

ν = Poisson's ratio.

P = pressure, psi.

P_r = Prandtl number.

r = radius, in.

7 NOMENCLATURE - cont.

R_e = Reynolds number.

Ri = Richardson number.

ρ = density, lb_m/in^3.

S_m = stress intensity, ksi.

Δx = thermal displacement in the x-direction, in.

Δy = thermal displacement in the y-direction, in.

Δz = thermal displacement in the z-direction, in.

t = wall thickness, in.

T = temperature, °F.

ΔT = temperature differential, °F.

Δu = displacement in the x-direction, in.

Δv = displacement in the y-direction, in.

Δw = displacement in the z-direction, in.

V = velocity, ft/sec.