

Summary of Stress Analysis Results for the US-APWR Steam Generator

Non-proprietary Version

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Abstract

This report contains a summary of the structural evaluation of the eight Steam Generator (SG) parts prepared in accordance with in MHI's commitment letter (Reference 11) concerning the content of this Technical Report.

The evaluations performed were based on the loading conditions defined in the US-APWR SG Design Specification (Reference 4) and on the design procedures per the 2001 Edition of Section III of the ASME Boiler & Pressure Vessel Code up to and including the 2003 addenda, referred to as the ASME Code of Reference, Section III (Reference 1).

The analyses and results presented demonstrate that the eight parts of the SG that were evaluated satisfy all of the applicable structural limits of the ASME Code of Reference.

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List of Acronyms

The following list defines the acronyms used in this document.

| | |
|------|---------------------------------------|
| AVB | Anti Vibration Bar |
| DCD | Design Control Document |
| FEA | Finite Element Analysis |
| FSRF | Fatigue Strength Reduction Factor |
| LOCA | Loss-of-Coolant Accident |
| RCP | Reactor Coolant Pump |
| RCS | Reactor Coolant System |
| RT | Radiographic Examination |
| SG | Steam Generator |
| SLB | Steam Line Break |
| SRSS | Square-Root-Of-The-Sum-Of-The-Squares |
| SSE | Safe Shutdown Earthquake |
| TSP | Tube Support Plate |

1.0 INTRODUCTION

This Technical Report was prepared consistent with MHI's commitment letter (Reference 11) in support of the US-APWR DCD review process. It contains a summary of the stress analysis results for the US-APWR Steam Generator (SG). The content of this report follows the ASME guidelines for Design Reports (Section III Division 1 Appendix C).

Figure 1-1 shows the general configuration of the US-APWR SG.

This report provides structural evaluations for eight SG parts based on the discussion about MHI's commitment letter (Reference 11) concerning the content of this Technical Report. The eight evaluated SG parts are listed in Table 2-1. This Technical Report summarizes the stress results based upon detailed analyses that demonstrate the validity of the SG component to meet the requirements of the Design Specification (Reference 4).

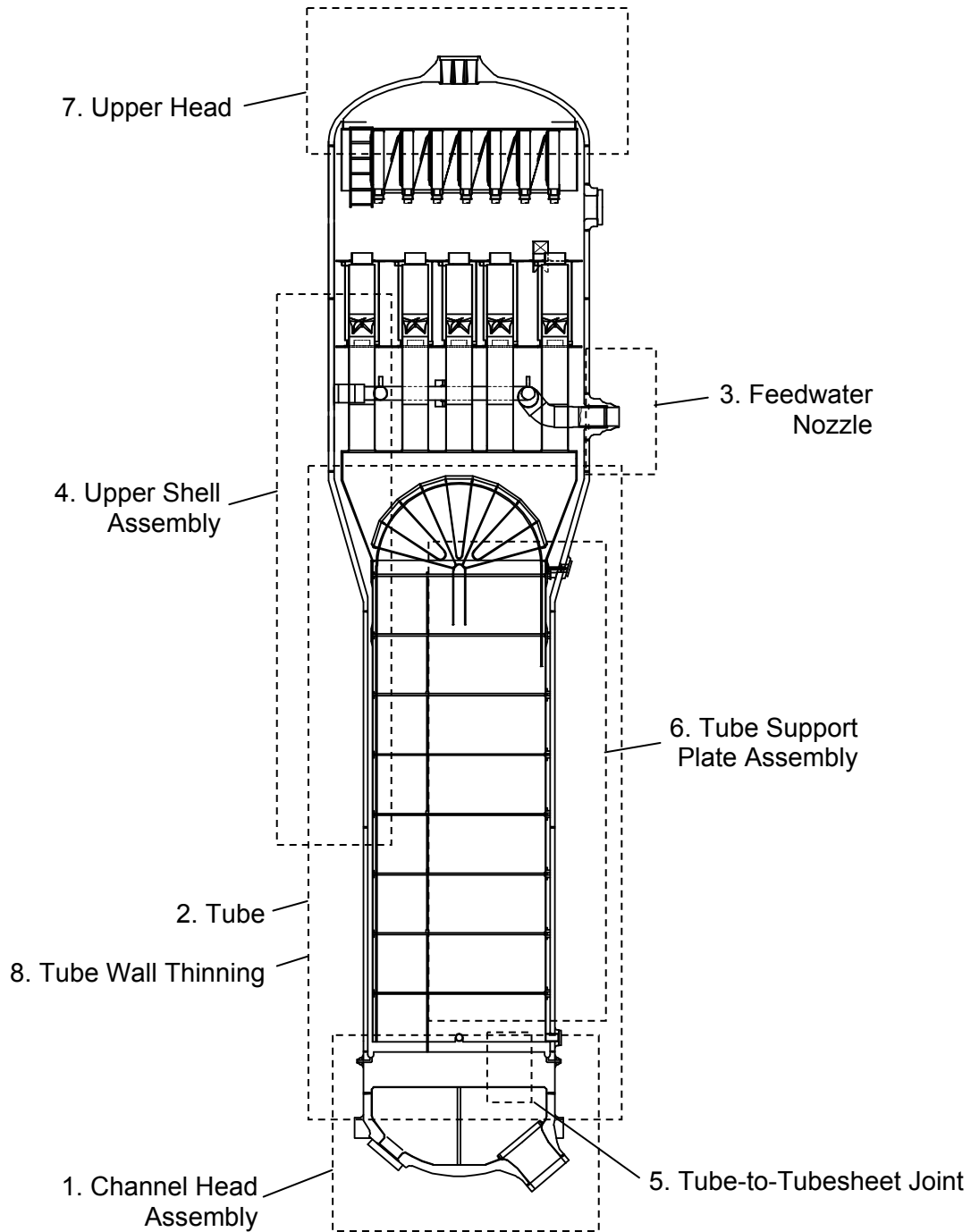


Figure 1-1 SG Evaluated Parts

2.0 SUMMARY OF RESULTS

The eight evaluated parts of the SG, along with the most limiting stress results in each, are listed in Table 2-1 below. The structural analysis results for each of these parts are provided in Section 10.

Table 2-1 Summary of Most Limiting Stress Results

| Section | Evaluated Part | Max Stress / Allowable Ratio ¹ | Highest Fatigue ² Usage Factor |
|----------------|-----------------------------|--|--|
| 10.1 | Channel Head Assembly | | |
| 10.2 | Tubes | | |
| 10.3 | Feedwater Nozzle | | |
| 10.4 | Upper Shell Assembly | | |
| 10.5 | Tube-to-Tubesheet Joint | | |
| 10.6 | Tube Support Plate Assembly | | |
| 10.7 | Upper Head | | |
| 10.8 | Tube Wall Thinning | | |

Note-1: The allowable ratio is the “ratio” of the calculated stress intensity to the allowable stress intensity. Therefore, any ratio less than or equal to 1.0 is acceptable.

$$\text{Ratio} = \frac{\text{Calculated} \cdot \text{Stress} \cdot \text{Intensity}}{\text{Allowable} \cdot \text{Stress} \cdot \text{Intensity}}$$

Note-2: The fatigue calculations performed in this report meet the requirements of the ASME Code of Reference. Environmental fatigue per RG 1.207 will be evaluated separately.

Note-3: Based on primary plus secondary stress limit, excluding thermal bending.

3.0 CONCLUSIONS

The US-APWR SG is designed to the requirements of the ASME Boiler and Pressure Vessel Code, 2001 Edition up to and including the 2003 Addenda for the Design, Service Loadings, Operating Conditions, and Test Conditions as specified in the Design Specification (Reference 4).

From the results summarized in this report and a review of the component design drawings, it is concluded that the US-APWR SG satisfies all of the requirements of the Design Specification.

4.0 NOMENCLATURE

| Symbol | Unit | Definition |
|-------------|-----------------|---|
| P_m | ksi | General Primary Membrane Stress |
| P_L | ksi | Local Primary Membrane Stress |
| P_b | ksi | Primary Bending Stress |
| Q | ksi | Secondary Stress |
| S_m | ksi | Design Stress Intensity |
| S_y | ksi | Yield Stress |
| S_u | ksi | Tensile Strength |
| A_b | in ² | Actual Total Cross-Sectional Area of Bolts at Root of Thread or Section of Least Diameter Under Stress |
| A_m | in ² | Required Total Design Cross-Sectional Area of Bolts, taken as the greater of A_{m1} and A_{m2} |
| A_{m1} | in ² | Total cross-sectional area of bolts at root of thread or section of least diameter under stress, required for Design Condition = W_{m1}/S_b |
| A_{m2} | in ² | Total cross-sectional area of bolts at root of thread or section of least diameter under stress, required for gasket seating = W_{m2}/S_a |
| S_t | ksi | Averaged Stress for Bolt (neglecting stress concentration) |
| $S_t + S_b$ | ksi | Tension plus Bending Stress for Bolt (neglecting stress concentration) |
| W_{m1} | lb | Minimum required bolt load for Design Pressure |
| W_{m2} | lb | Minimum required bolt load for gasket seating |
| y_A | - | Thermal Ratcheting Factor |
| SS | ksi | Thermal Stress Range |
| α | - | Shape Factor |
| P | - | Design Pressure |
| 1/3 SSE | - | Level B Service Loading Earthquake |
| SSE | - | Safe Shutdown Earthquake |

5.0 ASSUMPTIONS AND OPEN ITEMS

5.1 Assumptions

The basic modeling assumptions from the detailed analyses are as follows:

1. The inside diameter is taken as the drawing nominal value.
2. The wall thickness is the drawing nominal value.
3. For the particular cases of the primary side parts, cladding less than 10% of the total thickness is not considered in the stress analysis.
4. For the primary side parts, the corrosion allowance is zero.
5. For the secondary side carbon and low alloy steel parts, the corrosion allowance of 0.06 inches is considered.

5.2 Open Items

There are no open items in this Technical Report.

6.0 ACCEPTANCE CRITERIA

The stress intensity acceptance criteria for Class 1 components are specified in NB-3220, NB-3230, and Appendix F of Section III. Table 6-1 lists the stress limits for parts other than bolts and Table 6-2 lists the stress limits for bolts.

Table 6-1 Class 1 Component Stress Limits (other than Bolts)

| Condition | Stress Category | Stress Limits | Remarks |
|-------------|------------------------------|---|-----------------------------------|
| Design | P_m | S_m | NB-3221.1 |
| | P_L | $1.5 S_m$ | NB-3221.2 |
| | $P_L + P_b$ | $\alpha S_m^{(1)2)}$ or $1.5 S_m$ | NB-3221.3 |
| | Bearing Stress | $S_v^{(6)}$ or $1.5 S_v^{(6)}$ | NB-3227.1(a) |
| | Shear Stress | $0.6 S_m$ | NB-3227.1(b) |
| | Pure Shear Stress | $0.6 S_m$ | NB-3227.2(a) |
| | Triaxial Sress ⁴⁾ | $4 S_m$ | NB-3227.4 |
| Level A & B | $P_L + P_b + Q$ | $3 S_m$ | NB-3222.2 |
| | Thermal Ratchet, SS | $^{(5)} S_v \times y_A$ | NB-3222.5 |
| | Usage Factor | 1.0 | NB-3222.4 |
| | Bearing Stress | $S_v^{(6)}$ or $1.5 S_v^{(6)}$ | NB-3227.1(a) |
| | Shear Stress | $0.6 S_m$ | NB-3227.1(b) |
| | Pure Shear Stress | $0.6 S_m$ | NB-3227.2(a) |
| | Triaxial Sress ⁴⁾ | $4 S_m$ | NB-3224.3 |
| Level B | P_m | $1.1 S_m$ | NB-3223 |
| | P_L | $1.5 (1.1 S_m)$ | NB-3223 |
| | $P_L + P_b$ | $\alpha (1.1 S_m)^{(1)2)}$ or $1.5 (1.1 S_m)$ | NB-3223 |
| Level C | P_m | Max ($1.2 S_m, S_y$) Max ($1.1 S_m, 0.9 S_v$) ³⁾ | NB-3224.1 |
| | P_L | Max ($1.8 S_m, 1.5 S_v$) | NB-3224.1 |
| | $P_L + P_b$ | Max ($\alpha (1.2 S_m), \alpha S_y$) ¹⁾²⁾ or Max ($1.8 S_m, 1.5 S_v$) | NB-3224.1 |
| | Bearing Stress | $S_v^{(6)}$ or $1.5 S_v^{(6)}$ | NB-3227.1(a) |
| | Shear Stress | $0.6 S_m$ | NB-3227.1(b) |
| | Pure Shear Stress | $0.6 S_m$ | NB-3227.2(a) |
| | Triaxial Sress ⁴⁾ | $4.8 S_m$ | NB-3224.3 |
| Level D | P_m | For ferritic materials, $0.7 S_u$ For austenitic and high alloy steels, Min ($2.4 S_m, 0.7 S_u$) | NB-3225 (Appendix F-1331.1) |
| | P_L | For ferritic materials, $1.5 (0.7 S_u)$ For austenitic and high alloy steels, $1.5 \text{ Min } (2.4 S_m, 0.7 S_u)$ | |
| | $P_L + P_b$ | For ferritic materials, $1.5 (0.7 S_u)$ For austenitic and high alloy steels, $1.5 \text{ Min } (2.4 S_m, 0.7 S_u)$ | |
| | Pure Shear | $0.42 S_u$ | |
| Test | P_m | $0.9 S_y$ | NB-3226 |

**Summary of Stress Analysis Results for
the US-APWR Steam Generator**

MUAP-09006-NP (R0)

| | | | |
|--|-------------------------------|--|--------------|
| | $P_m + P_b$ | (1.35 S_y) - for $P_m \leq 0.67 S_y$ (or 0.9 αS_y for non-rectangular sections) (2.15 $S_y - 1.2 P_m$) - for $0.67 S_y < P_m \leq 0.9 S_y$ | |
| | Bearing Stress | S_y ⁶⁾ or 1.5 S_y ⁶⁾ | NB-3227.1(a) |
| | Shear Stress | 0.6 S_m | NB-3227.1(b) |
| | Pure Shear Stress | 0.6 S_m | NB-3227.2(a) |
| | Triaxial Stress ⁴⁾ | 4 S_m | NB-3227.4 |

- Note-1 The shape factor of α for solid rectangular sections is 1.5, α shall not exceed 1.5.
- Note-2 “ α ” is considered where stresses are classified as primary bending.
- Note-3 The stress limits for pressure loading alone for ferritic material.
- Note-4 NB-3227.4 states that the Triaxial Stress limit is 4 S_m and does not apply to Level D. NB-3224.3 states the Level C limit is 4.8 S_m .
- Note-5 NB-3222.5 requires evaluation of Thermal Stress Ratcheting for Level A Service Loads. In all cases where elastic analysis indicates that the primary membrane stress is less than S_m and the primary plus secondary stress is less than 3 S_m , then thermal stress ratcheting will not occur.
- Note-6 S_y when the distance to a free edge is less than the distance over which the bearing load is applied; 1.5 S_y when the distance to a free edge is larger.

Table 6-2 Class 1 Bolt Stress Limits

| Condition | Stress Category | Stress Limits | Remarks |
|-------------|--|--|--------------------|
| Design | A_b | A_m | NB-3231, E-1000 |
| Level A & B | Average Service Stress ¹⁾ , S_t | 2 S_m | NB-3232.1 |
| | Max Service Stress ¹⁾ , $S_t + S_b$ | 3 S_m | NB-3232.2 |
| | Fatigue Usage Factor ²⁾ | 1.0 | NB-3232.3 |
| Level C | Average Service Stress ¹⁾ , S_t | 2 S_m | NB-3234 |
| | Max Service Stress ¹⁾ , $S_t + S_b$ | 3 S_m | NB-3234 |
| Level D | Average Tensile Stress ³⁾ , S_t | Min (S_y , 0.7 S_u) | NB-3235 & F-1335.1 |
| | Max Tensile Stress ³⁾ , $S_t + S_b$ | S_u | NB-3235 & F-1335.1 |
| | Average bolt shear | Min (0.6 S_y , 0.42 S_u) | F-1335.2 |
| | Combined tensile and shear | $f_t^2 / F_{tb}^2 + f_v^2 / F_{vb}^2 \leq 1$ ⁴⁾ | F-1335.3 |
| | Distance from bolt center to edge | $d [0.5 + 1.2 (fp / S_u)]$ ⁵⁾ | F-1335.4(a) |
| | Nominal bearing stress | 2.1 S_u | F-1335.4(b) |

- Note-1 Includes preload, pressure, and differential thermal expansion, excludes stress concentrations.
- Note-2 Includes a fatigue strength reduction factor of 4 for the threads.
- Note-3 Includes preload, pressure, differential thermal expansion, and prying action produced by deformation of the connected parts, excludes stress concentrations.
- Note-4 f_t =computed tensile stress, f_v =computed shear stress, F_{tb} =allowable tensile stress at operating temperature, F_{vb} =allowable shear stress at operating temperature.
- Note-5 d = nominal bolt diameter; fp = nominal bearing stress.

7.0 DESIGN INPUT

7.1 Geometry

The US-APWR SG basic design drawings used to supply dimensions for the stress analyses are taken from Reference 5. Figures describing the detailed geometry and dimensions of the parts evaluated are provided in Section 10.

7.2 Material

The materials of construction for the SG pressure boundary and internals are listed in Table 7-1

Table 7-1 Materials of Construction

| Part or Assembly | Material |
|---|--|
| Channel Head, Primary Nozzles & Manways | SA-508 Grade 3 Class 2 |
| Tubesheet | SA-508 Grade 3 Class 2 |
| Upper Head, Nozzles & Manways | SA-508 Grade 3 Class 2 |
| Transition Cone | SA-508 Grade 3 Class 2 |
| Secondary Shell Barrels | SA-508 Grade 3 Class 2 or SA-533 Type B Class 2 plate |
| Manway Covers | SA-533 Type B Class 2 |
| Manway and Hand Hole Studs | SA-193 Grade B7 |
| Primary Nozzle Safe Ends | SA-182 Grade F316 or F316LN |
| Tubes | Alloy 690TT SA-163 UNS N06690 |
| Divider Plate | Alloy 690TT SB-168 UNS N06690 |
| Feedwater Nozzle Thermal Sleeve | Alloy 690TT SB-167 UNS N06690 |
| Tube Supports | SA-240 Type 405 |
| Stay Rods | SA-193 Grade B7 |
| Feedwater Distribution Ring | SA-335 Grade P22 |
| Wrapper and Supports | SA-516 Grade 70 |

The material strength properties used in the stress analyses are provided in Tables 7-2 through 7- 7, below. The strength properties were obtained from ASME Section II (Ref 2).

**Table 7-2 Material Properties for SA-508 Grade 3, Class 2
(Channel head, tubesheet, cone, head, barrels, etc.)**

| Temperature, °F | S _m (ksi) | S _y (ksi) | S _u (ksi) |
|-----------------|----------------------|----------------------|----------------------|
| 70 | 30.0 | 65.0 | 90.0 |
| 100 | 30.0 | 65.0 | 90.0 |
| 200 | 30.0 | 61.2 | 90.0 |
| 300 | 30.0 | 59.1 | 90.0 |
| 400 | 30.0 | 57.5 | 90.0 |
| 500 | 30.0 | 56.1 | 90.0 |
| 600 | 30.0 | 54.7 | 90.0 |
| 650 | 30.0 | 53.9 | 90.0 |

**Table 7-3 Material Properties for SA-533 Type B, Class 2
(Manway Covers)**

| Temperature, °F | S _m (ksi) | S _y (ksi) | S _u (ksi) |
|-----------------|----------------------|----------------------|----------------------|
| 70 | 30.0 | 70.0 | 90.0 |
| 100 | 30.0 | 70.0 | 90.0 |
| 200 | 30.0 | 65.9 | 90.0 |
| 300 | 30.0 | 63.7 | 90.0 |
| 400 | 30.0 | 61.9 | 90.0 |
| 500 | 30.0 | 60.4 | 90.0 |
| 600 | 30.0 | 58.9 | 90.0 |
| 650 | 30.0 | 58.0 | 90.0 |

**Table 7-4 Material Properties for Alloy 690TT SB-163
UNS N06690 (Tubes)**

| Temperature, °F | S _m (ksi) | S _y (ksi) | S _u (ksi) |
|-----------------|----------------------|----------------------|----------------------|
| 70 | 26.7 | 40.0 | 85.0 |
| 100 | 26.7 | 40.0 | 85.0 |
| 200 | 26.7 | 36.2 | 85.0 |
| 300 | 26.7 | 34.1 | 84.0 |

**Table 7-4 Material Properties for Alloy 690TT SB-163
UNS N06690 (Tubes)**

| Temperature, °F | S _m (ksi) | S _y (ksi) | S _u (ksi) |
|-----------------|----------------------|----------------------|----------------------|
| 400 | 26.7 | 32.7 | 82.0 |
| 500 | 26.7 | 31.9 | 80.8 |
| 600 | 26.7 | 31.5 | 80.2 |
| 650 | 26.7 | 31.5 | 80.0 |

**Table 7-5 Material Properties for Alloy 690TT SB-167,
168 UNS N06690 (not tubes)**

| Temperature, °F | S _m (ksi) | S _y (ksi) | S _u (ksi) |
|-----------------|----------------------|----------------------|----------------------|
| 70 | 23.3 | 35.0 | 85.0 |
| 100 | 23.3 | 35.0 | 85.0 |
| 200 | 23.3 | 31.7 | 85.0 |
| 300 | 23.3 | 29.8 | 84.0 |
| 400 | 23.3 | 28.6 | 82.0 |
| 500 | 23.3 | 27.9 | 80.8 |
| 600 | 23.3 | 27.6 | 80.2 |
| 650 | 23.3 | 27.5 | 80.0 |

**Table 7-6 Material Properties for SA-182 Grade F316LN
(Primary Nozzle safe ends)**

| Temperature, °F | S _m (ksi) | S _y (ksi) | S _u (ksi) |
|-----------------|----------------------|----------------------|----------------------|
| 70 | 20.0 | 30.0 | 75.0 |
| 100 | 20.0 | 30.0 | 75.0 |
| 200 | 20.0 | 25.5 | 75.0 |
| 300 | 20.0 | 22.9 | 70.7 |
| 400 | 18.9 | 21.0 | 67.1 |
| 500 | 17.5 | 19.5 | 64.6 |
| 600 | 16.5 | 18.3 | 63.3 |
| 650 | 16.0 | 17.8 | 62.8 |

**Table 7-7 Material Properties for SA-240 Type 405
(Tube Supports)**

| Temperature, °F | S _m (ksi) | S _y (ksi) | S _u (ksi) |
|-----------------|----------------------|----------------------|----------------------|
| 70 | 16.7 | 25.0 | 60.0 |
| 100 | 16.7 | 25.0 | 60.0 |
| 200 | 15.3 | 23.0 | 60.0 |
| 300 | 14.8 | 22.2 | 58.8 |
| 400 | 14.5 | 21.8 | 57.8 |
| 500 | 14.3 | 21.5 | 56.9 |
| 600 | 14.0 | 21.0 | 55.5 |
| 650 | 13.8 | 20.7 | 54.4 |

7.3 Loads, Load Combinations, and Transients

The loads, load combinations and transients are defined in the Design Specification. Following is a summary of those used for the SG structural evaluations.

7.3.1 Pressure Loads and Temperature

Table 7-8 Pressures and Temperatures

| Parameter | Value |
|--|-----------------------|
| Primary side design pressure | 2500 psia (2485 psig) |
| Primary side design temperature | 650°F |
| Secondary side design pressure | 1200 psia (1185 psig) |
| Secondary side design temperature | 568°F |
| Maximum primary-to-secondary differential pressure | 1600 psi |
| Maximum secondary-to-primary differential pressure | 670 psi |
| Maximum primary-to-secondary temperature | 650°F |
| Primary side hydrostatic test pressure | 3122 psia (3107 psig) |
| Secondary side hydrostatic test pressure | 1497 psia (1482 psig) |
| Minimum hydrostatic test temperature | 70°F |

Note: hydrotest to be conducted with opposite side at atmospheric pressure

7.3.2 External Mechanical Loads

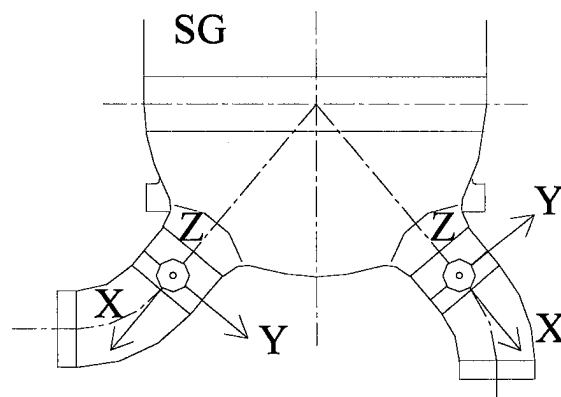
The external loads are dead weight, thermal expansion loads, seismic loads and accident loads. The external loads used in this report come from the Design Specification.

Table 7-10 to 7-16 provide the external loads on the SG. Table 7-17 provides the load combinations and Table 7-18 lists the design transients.

The bolt preload values for the manway studs is the minimum required bolt load for the design pressure calculated in accordance with Article E-1000 of the ASME code.

Table 7-9 Loads Applied to the Primary Inlet Nozzle

| Loading | | Fx (kips) | Fy (kips) | Fz (kips) | Mx (kips · in) | My (kips · in) | Mz (kips · in) | |
|-------------------|-----------|--------------|--------------|--------------|-------------------|-------------------|-------------------|--|
| Dead Weight | Loop-A,D | | | | | | | |
| | Loop-B,C | | | | | | | |
| Thermal | Loop -A,D | Gr.1 | | | | | | |
| | | Gr.2 | | | | | | |
| | | Gr.3 | | | | | | |
| | | Gr.4 | | | | | | |
| | | Gr.5 | | | | | | |
| | | Gr.6 | | | | | | |
| | | Gr.7 | | | | | | |
| | | Gr.8 | | | | | | |
| | | Gr.9-1 | | | | | | |
| | | Gr.9-2 | | | | | | |
| | Loop -B,C | Gr.1 | | | | | | |
| | | Gr.2 | | | | | | |
| | | Gr.3 | | | | | | |
| | | Gr.4 | | | | | | |
| | | Gr.5 | | | | | | |
| | | Gr.6 | | | | | | |
| | | Gr.7 | | | | | | |
| | | Gr.8 | | | | | | |
| | | Gr.9-1 | | | | | | |
| | | Gr.9-2 | | | | | | |
| Seismic (1/3 SSE) | | | | | | | | |
| Seismic (SSE) | | | | | | | | |
| Accident 1 | | | | | | | | |
| Accident 2 | | | | | | | | |



SG Inlet Nozzle

SG Outlet Nozzle

Table 7-10 Loads Applied to the Primary Outlet Nozzle

| Loading | | Fx (kips) | Fy (kips) | Fz (kips) | Mx (kips · in) | My (kips · in) | Mz (kips · in) | |
|-------------|-------------------|--------------|--------------|--------------|-------------------|-------------------|-------------------|--|
| Dead Weight | Loop-A,D | | | | | | | |
| | Loop-B,C | | | | | | | |
| Thermal | Loop -A,D | Gr.1 | | | | | | |
| | | Gr.2 | | | | | | |
| | | Gr.3 | | | | | | |
| | | Gr.4 | | | | | | |
| | | Gr.5 | | | | | | |
| | | Gr.6 | | | | | | |
| | | Gr.7 | | | | | | |
| | | Gr.8 | | | | | | |
| | | Gr.9-1 | | | | | | |
| | | Gr.9-2 | | | | | | |
| | Loop -B,C | Gr.1 | | | | | | |
| | | Gr.2 | | | | | | |
| | | Gr.3 | | | | | | |
| | | Gr.4 | | | | | | |
| | | Gr.5 | | | | | | |
| | | Gr.6 | | | | | | |
| | | Gr.7 | | | | | | |
| | | Gr.8 | | | | | | |
| | | Gr.9-1 | | | | | | |
| | | Gr.9-2 | | | | | | |
| | Seismic (1/3 SSE) | | | | | | | |
| | Seismic (SSE) | | | | | | | |
| Accident 1 | | | | | | | | |
| Accident 2 | | | | | | | | |

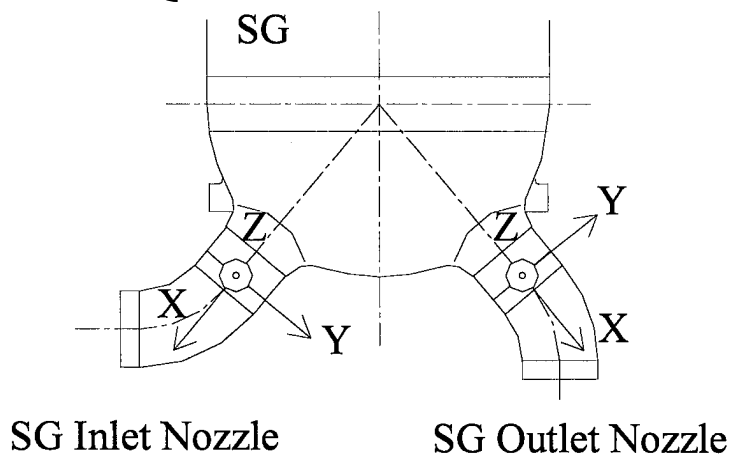


Table 7-11 Loads Applied to the Channel Head Support Pad-1

| Loading | | Fx (kips) | Fy (kips) | Fz (kips) | Mx (kips·in) | My (kips·in) | Mz (kips·in) | |
|-------------------|----------|--------------|--------------|--------------|-----------------|-----------------|-----------------|--|
| Dead Weight | Loop-A,D | | | | | | | |
| | Loop-B,C | | | | | | | |
| Thermal | Loop-A,D | Gr.1 | | | | | | |
| | | Gr.2 | | | | | | |
| | | Gr.3 | | | | | | |
| | | Gr.4 | | | | | | |
| | | Gr.5 | | | | | | |
| | | Gr.6 | | | | | | |
| | | Gr.7 | | | | | | |
| | | Gr.8 | | | | | | |
| | | Gr.9-1 | | | | | | |
| | | Gr.9-2 | | | | | | |
| | Loop-B,C | Gr.1 | | | | | | |
| | | Gr.2 | | | | | | |
| | | Gr.3 | | | | | | |
| | | Gr.4 | | | | | | |
| | | Gr.5 | | | | | | |
| | | Gr.6 | | | | | | |
| | | Gr.7 | | | | | | |
| | | Gr.8 | | | | | | |
| | | Gr.9-1 | | | | | | |
| | | Gr.9-2 | | | | | | |
| Seismic (1/3 SSE) | | | | | | | | |
| Seismic (SSE) | | | | | | | | |
| Accident 1 | | | | | | | | |
| Accident 2 | | | | | | | | |

SG Lower Support
Point(2)

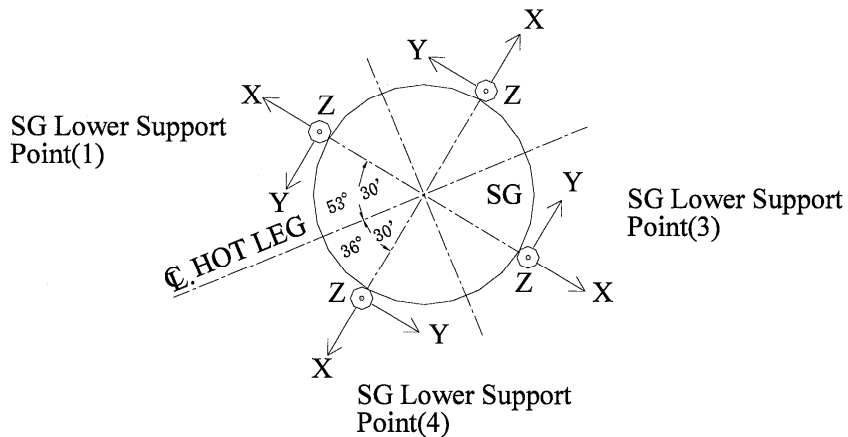


Table 7-11 Loads Applied to the Channel Head Support Pad-2

| Loading | | Fx (kips) | Fy (kips) | Fz (kips) | Mx (kips · in) | My (kips · in) | Mz (kips · in) | |
|-------------------|----------|--------------|--------------|--------------|-------------------|-------------------|-------------------|--|
| Dead Weight | Loop-A,D | | | | | | | |
| | Loop-B,C | | | | | | | |
| Thermal | Loop-A,D | Gr.1 | | | | | | |
| | | Gr.2 | | | | | | |
| | | Gr.3 | | | | | | |
| | | Gr.4 | | | | | | |
| | | Gr.5 | | | | | | |
| | | Gr.6 | | | | | | |
| | | Gr.7 | | | | | | |
| | | Gr.8 | | | | | | |
| | | Gr.9-1 | | | | | | |
| | | Gr.9-2 | | | | | | |
| | Loop-B,C | Gr.1 | | | | | | |
| | | Gr.2 | | | | | | |
| | | Gr.3 | | | | | | |
| | | Gr.4 | | | | | | |
| | | Gr.5 | | | | | | |
| | | Gr.6 | | | | | | |
| | | Gr.7 | | | | | | |
| | | Gr.8 | | | | | | |
| | | Gr.9-1 | | | | | | |
| | | Gr.9-2 | | | | | | |
| Seismic (1/3 SSE) | | | | | | | | |
| Seismic (SSE) | | | | | | | | |
| Accident 1 | | | | | | | | |
| Accident 2 | | | | | | | | |

Table 7-11 Loads Applied to the Channel Head Support Pad-3

| Loading | | Fx (kips) | Fy (kips) | Fz (kips) | Mx (kips · in) | My (kips · in) | Mz (kips · in) | |
|-------------------|----------|--------------|--------------|--------------|-------------------|-------------------|-------------------|--|
| Dead Weight | Loop-A,D | | | | | | | |
| | Loop-B,C | | | | | | | |
| Thermal | Loop-A,D | Gr.1 | | | | | | |
| | | Gr.2 | | | | | | |
| | | Gr.3 | | | | | | |
| | | Gr.4 | | | | | | |
| | | Gr.5 | | | | | | |
| | | Gr.6 | | | | | | |
| | | Gr.7 | | | | | | |
| | | Gr.8 | | | | | | |
| | | Gr.9-1 | | | | | | |
| | | Gr.9-2 | | | | | | |
| | Loop-B,C | Gr.1 | | | | | | |
| | | Gr.2 | | | | | | |
| | | Gr.3 | | | | | | |
| | | Gr.4 | | | | | | |
| | | Gr.5 | | | | | | |
| | | Gr.6 | | | | | | |
| | | Gr.7 | | | | | | |
| | | Gr.8 | | | | | | |
| | | Gr.9-1 | | | | | | |
| | | Gr.9-2 | | | | | | |
| Seismic (1/3 SSE) | | | | | | | | |
| Seismic (SSE) | | | | | | | | |
| Accident 1 | | | | | | | | |
| Accident 2 | | | | | | | | |

Table 7-11 Loads Applied to the Channel Head Support Pad-4

| Loading | | Fx (kips) | Fy (kips) | Fz (kips) | Mx (kips · in) | My (kips · in) | Mz (kips · in) | |
|-------------------|----------|--------------|--------------|--------------|-------------------|-------------------|-------------------|--|
| Dead Weight | Loop-A,D | | | | | | | |
| | Loop-B,C | | | | | | | |
| Thermal | Loop-A,D | Gr.1 | | | | | | |
| | | Gr.2 | | | | | | |
| | | Gr.3 | | | | | | |
| | | Gr.4 | | | | | | |
| | | Gr.5 | | | | | | |
| | | Gr.6 | | | | | | |
| | | Gr.7 | | | | | | |
| | | Gr.8 | | | | | | |
| | | Gr.9-1 | | | | | | |
| | | Gr.9-2 | | | | | | |
| | Loop-B,C | Gr.1 | | | | | | |
| | | Gr.2 | | | | | | |
| | | Gr.3 | | | | | | |
| | | Gr.4 | | | | | | |
| | | Gr.5 | | | | | | |
| | | Gr.6 | | | | | | |
| | | Gr.7 | | | | | | |
| | | Gr.8 | | | | | | |
| | | Gr.9-1 | | | | | | |
| | | Gr.9-2 | | | | | | |
| Seismic (1/3 SSE) | | | | | | | | |
| Seismic (SSE) | | | | | | | | |
| Accident 1 | | | | | | | | |
| Accident 2 | | | | | | | | |

Table 7-12 Loads Applied to the Intermediate Lateral Supports

| Loading | Fx (kips) | Fy (kips) | Fz (kips) | Mx (kips · in) | My (kips · in) | Mz (kips · in) |
|-------------------|--------------|--------------|--------------|-------------------|-------------------|-------------------|
| Dead Weight | | | | | | |
| Thermal | | | | | | |
| Seismic (1/3 SSE) | | | | | | |
| Seismic (SSE) | | | | | | |
| Accident 1 | | | | | | |
| Accident 2 | | | | | | |

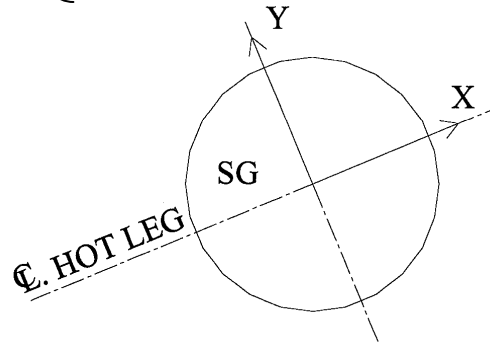


Table 7-13 Loads Applied to the Upper Lateral Supports

| Loading | Fx (kips) | Fy (kips) | Fz (kips) | Mx (kips · in) | My (kips · in) | Mz (kips · in) |
|-------------------|--------------|--------------|--------------|-------------------|-------------------|-------------------|
| Dead Weight | | | | | | |
| Thermal | | | | | | |
| Seismic (1/3 SSE) | | | | | | |
| Seismic (SSE) | | | | | | |
| Accident 1 | | | | | | |
| Accident 2 | | | | | | |

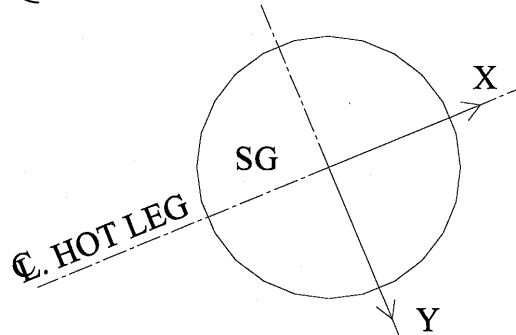


Table 7-14 Loads Applied to the Feedwater Nozzle

| Loading | | Fx (kips) | Fy (kips) | Fz (kips) | Mx (kips · in) | My (kips · in) | Mz (kips · in) |
|---------------------------------|--------------|--------------|--------------|--------------|-------------------|-------------------|-------------------|
| Dead Weight ¹⁾ | | | | | | | |
| Thermal | Loop-A, D | a | | | | | |
| | | b | | | | | |
| | | c | | | | | |
| | Loop-B, C | a | | | | | |
| | | b | | | | | |
| | | c | | | | | |
| Seismic (1/3 SSE) ¹⁾ | | | | | | | |
| Seismic (SSE) ¹⁾ | | | | | | | |
| Accident ¹⁾ | | | | | | | |

Note-1: ()

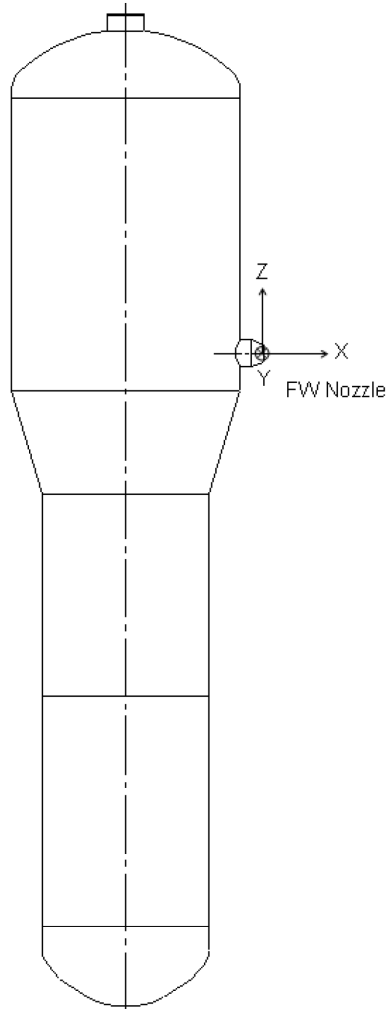
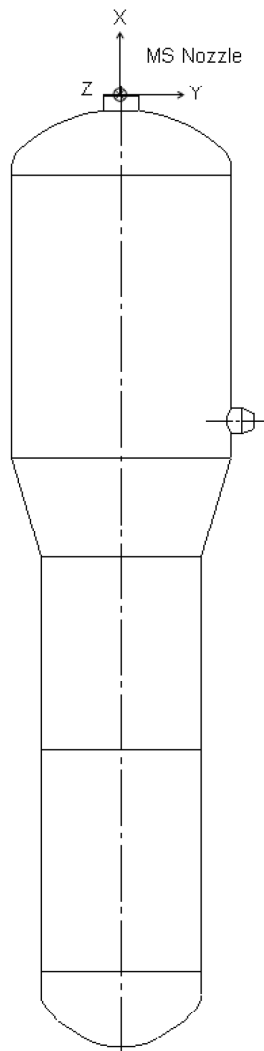


Table 7-15 Loads Applied to the Steam Nozzle

| Loading | | Fx (kips) | Fy (kips) | Fz (kips) | Mx (kips·in) | My (kips·in) | Mz (kips·in) |
|---------------------------------|-----------|--------------|--------------|--------------|-----------------|-----------------|-----------------|
| Dead Weight ¹⁾ | | | | | | | |
| Thermal | Loop-A, D | | | | | | |
| | Loop-B, C | | | | | | |
| Seismic (1/3 SSE) ¹⁾ | | | | | | | |
| Seismic (SSE) ¹⁾ | | | | | | | |
| Mechanical ¹⁾²⁾ | | | | | | | |
| Accident ¹⁾ | | | | | | | |

Note-1:

Note-2:



7.3.3 Thermal and Pressure Transient Loads

The design transients used in the structural evaluations are listed in the Table 7-16. These transients were determined based on a 60-year plant operating period and are classified as ASME Level A, Level B, Level C, Level D service conditions, or Test conditions. depending on the expected frequency of occurrence and severity of the event.

Table 7-16 Design Transients

| Level A Service Conditions | | | |
|-----------------------------------|---|-----------------|--|
| Mark | Transient | Occurrence | Remark |
| I-a | Plant heat-up (50F/h) | 120 | |
| I-b | Plant cooldown (100F/h) | 120 | Includes Transient for Loss of offsite power with natural circulation cooldown (10 times) and Safe shutdown (1 time) |
| I-c-1 | Ramp load increase between 15% and 100% of full power (5% or full power per minute) | 600 | |
| I-c-2 | Ramp load increase between 50% and 100% of full power (5% or full power per minute) | 19,200 | |
| I-d-1 | Ramp load decrease between 15% and 100% of full power (5% or full power per minute) | 600 | |
| I-d-2 | Ramp load decrease between 50% and 100% of full power (5% or full power per minute) | 19,200 | |
| I-e | Step load increase of 10% of full power | 600 | |
| I-f | Step load decrease of 10% of full power | 600 | |
| I-g | Large step load decrease with turbine bypass | 60 | |
| I-h i) | Steady-state fluctuations and load regulation (Steady state fluctuations) | 1×10^6 | $P_P \pm 50\text{psi}$, T_{hot} , T_{cold} , $T_{\text{ave}} \pm 3.1\text{F}$ |
| I-h ii) | Steady-state fluctuations and load regulation (Load regulation) | 8×10^5 | |
| I-i | Main feedwater cycling | 2,100 | |
| I-j | Refueling | 60 | Water is replaced in 10minutes |
| I-k | Ramp load increase between 0% and 15% of full power | 600 | |
| I-l | Ramp load decrease between 0% and 15% of full power | 600 | |
| I-m | RCP startup | 3,000 | |
| I-n | RCP shutdown | 3,000 | |
| I-o | Core lifetime extension | 60 | |
| I-p | Primary leakage test | 120 | |
| I-q | Turbine roll test | 10 | |
| I-s | Secondary leakage test | 120 | |
| Level B Service Conditions | | | |
| II-a | Loss of load | 60 | |
| II-b | Loss of offsite power | 60 | |
| II-c | Partial loss of reactor coolant flow | 30 | |
| II-d i) | Reactor trip from full power With no inadvertent cooldown | 60 | |

Table 7-16 Design Transients

| | | | |
|----------------------------------|--|-----|---|
| II-d ii) | Reactor trip from full power With cooldown and no safety injection | 30 | Includes Transient for excessive feedwater flow |
| II-d iii) | Reactor trip from full power With cooldown and safety injection | 10 | |
| II-e | Inadvertent RCS depressurization | 30 | |
| II-f | Control rod drop | 30 | |
| II-g | Inadvertent safeguards actuation | 30 | |
| II-h | Emergency feedwater cycling | 700 | |
| II-i | Cold over-pressure | 30 | |
| II-j | Excessive feedwater flow | — | Covered by Transient for reactor trip from full power ii) |
| II-k | Loss of offsite power with natural circulation cooldown | — | Covered by Transient for plant cooldown |
| II-l | Partial loss of emergency feedwater | 30 | Use Figure for Transient of loss of offsite power |
| II-m | Safe Shutdown | — | Covered by Transient for plant cooldown |
| Level C Service Condition | | | |
| III-a | Small loss of coolant accident | 5 | |
| III-b | Small steam line break | 5 | |
| III-c | Complete loss of flow | 5 | |
| III-d | Small feedwater line break | 5 | |
| III-e | SG tube rupture | 5 | |
| Level D Service Condition | | | |
| IV-a | Large loss of coolant accident | 1 | |
| IV-b | Large steam line break | 1 | |
| IV-c | RCP locked rotor | 1 | |
| IV-d | Control rod ejection | 1 | |
| IV-e | Large feedwater line break | 1 | |
| Test Condition | | | |
| V-a | Primary-side hydrostatic test | 10 | |
| V-b | Secondary-side hydrostatic test | 10 | |

7.3.4 Load Combinations

The loading conditions consist of various combinations of pressure, thermal and external loads. The loads combinations considered in the analysis are listed in the Table below.

The names used for the external loads refer directly to the names specified in Table 7-9 through 7-15.

Table 7-17 Load Combinations

| System Operating Condition | Service Stress Limit | Service Loading Combination |
|----------------------------|----------------------|---|
| Design | Design | Design Pressure Dead Weight Loads Mechanical Loads Thermal Loads ¹⁾ |
| Normal | Level A | Level A Thermal & Pressure Transients Dead Weight Loads Mechanical Loads Thermal Loads ¹⁾ |
| Upset | Level B | Level B Maximum Pressure ²⁾ Level B Thermal & Pressure Transients Dead Weight Loads Mechanical Loads Thermal Loads ¹⁾ Seismic(1/3 SSE) Loads |
| Emergency | Level C | Level C Maximum Pressure Level C Thermal & Pressure Transients ³⁾ Dead Weight Loads Mechanical Loads Thermal Loads ¹⁾ |
| Faulted | Level D | Level D Maximum Pressure Dead Weight Loads Mechanical Loads Thermal Loads ¹⁾ \pm SRSS(Seismic(SSE) Loads + Accident Loads ⁴⁾) |
| Test | Test | Hydrostatic Test Pressure |

Note-1; Applied to the nozzle within the limits of reinforcement for the primary stress evaluation.

Note-2; Applied for the primary stress evaluation.

Note-3; Applied for the bolts instead of Maximum Pressure.

Note-4; If more than one Accident Loads, each are to be analyzed separately.

8.0 METHODOLOGY

The ABAQUS computer program was used to determine loads, temperature distributions, stresses, and deformations. ABAQUS is a general purpose finite element computer program used by MHI in the design and analysis of nuclear components. ABAQUS is available in the public domain and has been used by MHI for U.S. replacement SG and replacement reactor vessel closure head projects.

8.1 Heat Transfer Coefficients and Thermal Analysis

Heat transfer coefficients on the inner and outer surfaces of the component are required to define the temperature distributions during transients. Classical Handbook heat transfer equations (References 8) were used to calculate the heat transfer coefficients.

Finite element thermal analyses were performed for all Level A and Level B transients to define the time-dependent temperature distributions in the structure. The primary and secondary fluid temperature versus time curves were applied to all wetted surfaces with appropriate heat transfer coefficients as discussed above. The outside surfaces under the vessel insulation were considered adiabatic.

8.2 Stress Analysis

Finite element stress analyses were performed for given loads and boundary conditions. The thermal loads were input from the thermal solution into each node of the structural model. The calculation of NB-3200 stress intensities, stress classifications, and stress evaluations were performed using a set of in-house proprietary computer programs (CLASS2D, CLASS3D, EDITSTRS, EVALPRI, EVALSEFAV, and RATCHET). These programs are described in Section 9.

Figure 8-1 shows the stress evaluation process.

CLASS2D and CLASS3D classify the stresses resulting from pressure, thermal loads, and externally applied forces and moments. EDITSTRS creates input files for the stress evaluation programs EVALPRI, EVALSEFAV, and RATCHET. EVALPRI and EVALSEFAV quantify the primary stress intensities, quantify the primary plus secondary stress ranges, and perform the fatigue evaluation. The RATCHET program was used for the thermal ratchet evaluation.

Detailed assumptions associated with the finite element model development and mesh refinement are documented in the detailed calculations. Finite element models were verified by hand calculations using handbook equations.

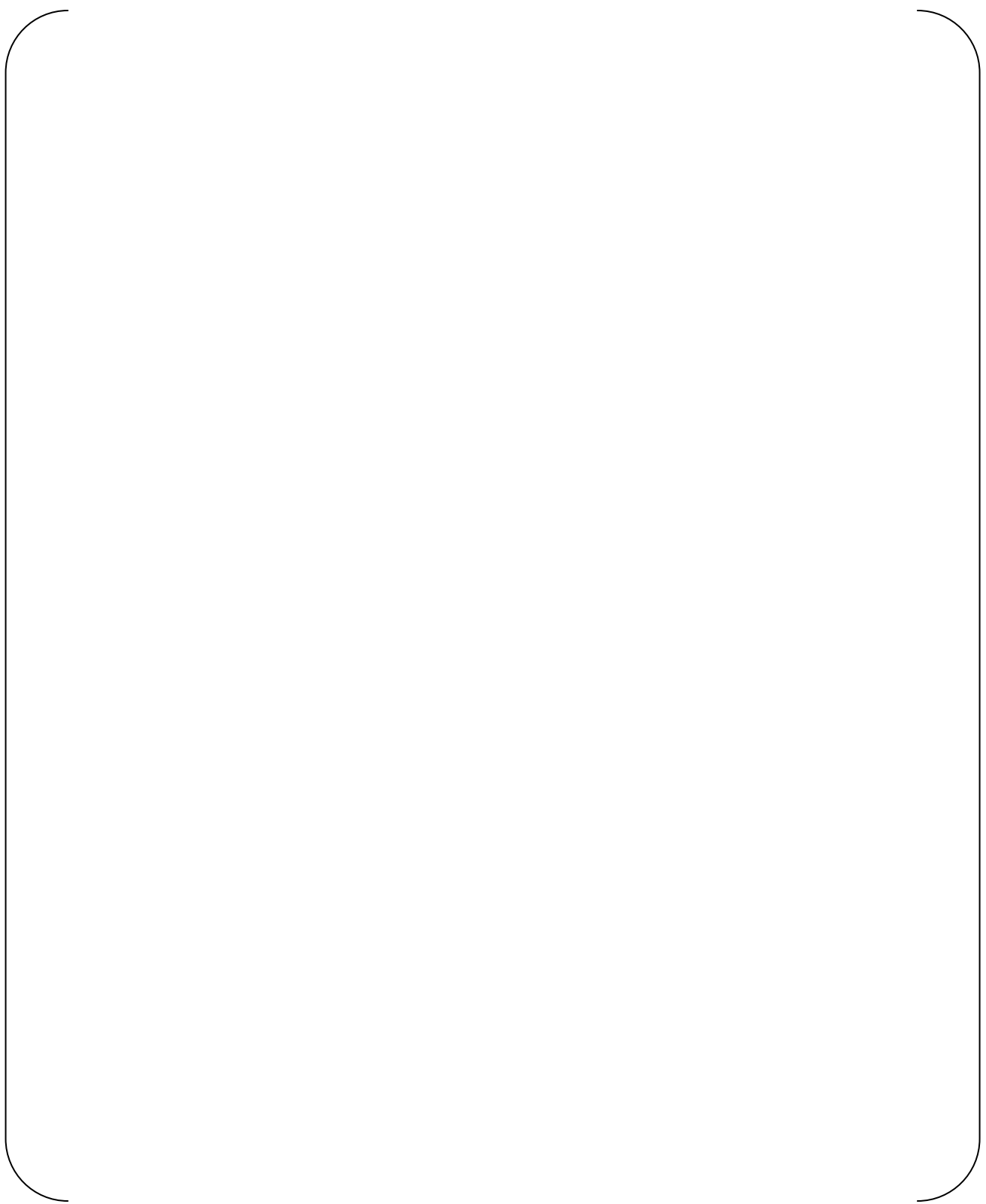


Figure 8-1 Stress Evaluation Process

8.3 Fatigue Analysis Model and Method

The fatigue analysis was based on the rules of NB-3216.2 and NB-3222.4(e) of ASME Section III (Ref 1). These rules require calculation of the total stress, including the peak stress, to determine the allowable number of stress cycles for the specified service loadings at every point in the structure. In some cases, a fatigue strength reduction factor (FSRF) was used where the peak stress could not be accurately calculated. In these cases, the factor was applied to the surface stress produced by a linear stress distribution (through the wall thickness) that produced the identical displacement / rotation of the section (i.e. equivalent structural equilibrium).

The design transients for ASME Level A and B service conditions (Table 7-16) were used in the evaluation of cyclic fatigue. The effect of 300 cycles of a 1/3 SSE seismic event was included in the evaluation of cyclic fatigue, treated as a Level B service condition. The number of cycles assumed for the 1/3 SSE seismic event was based on a fatigue usage factor equivalent to that for a single SSE event of 20 cycles.

9.0 COMPUTER PROGRAMS USED

Refer to Figure 8-1 for a visual description of the Stress Evaluation Process. The Table 9-1 provides a brief description of each of the computer programs used.

Table 9-1 Computer Program Description

| No. | Program Name | Version | Description |
|-----|--------------|---------|---|
| 1 | ABAQUS | 6.7-1 | ABAQUS is a general purpose finite element computer code that performs a wide range of linear and nonlinear engineering simulations |
| 2 | CLASS2D | 3.0 | CLASS2D is an MHI Code for classifying the stresses for axisymmetric models |
| 3 | CLASS3D | 3.0 | CLASS3D is an MHI Code for classifying the stresses for 3D solid models |
| 4 | EDITSTRS | 3.0 | EDITSTRS is an MHI Code that creates input files for the stress evaluation programs |
| 5 | EVALPRI | 5.0 | EVALPRI is an MHI Code that performs the primary stress evaluation |
| 6 | EVALSEFAV | 4.0 | EVALSEFAV is an MHI Code that performs the secondary stress and fatigue evaluation |
| 7 | RATCHET | 5.0 | RATCHET is an MHI Code that evaluates thermal stress ratcheting |
| 8 | ASMETEMP | 0.0 | ASMETEMP is an MHI Code that creates temperature files for the stress evaluation program |

All these computer programs were verified and validated and are maintained in compliance with the MHI quality assurance program. The computer programs were validated using one of the methods described below. Verification tests demonstrate the capability of the computer program to produce valid results for the test problems encompassing the range of permitted usage defined by the program documentation.

- Hand calculations
- Known solution for similar or standard problem
- Acceptable experimental test results
- Published analytical results
- Results from other similar verified programs

10.0 STRUCTURAL ANALYSIS RESULTS

This Section summarizes the results of the analyses for the eight parts of the SG. The stress calculations were carried out by a combination of finite element analysis (FEA) and hand calculations. The general element types used for creation of the finite element model were the 20-node quadratic heat transfer brick and the 20-node quadratic brick from the ABAQUS element library, for heat transfer analysis and structural analysis, respectively.

The reported results are generally conservative and larger than the actual values if more detailed calculations were performed; but since they all meet the ASME Code allowable limits, further analysis is not necessary.

10.1 Channel Head Assembly

10.1.1 Modeling & Analysis

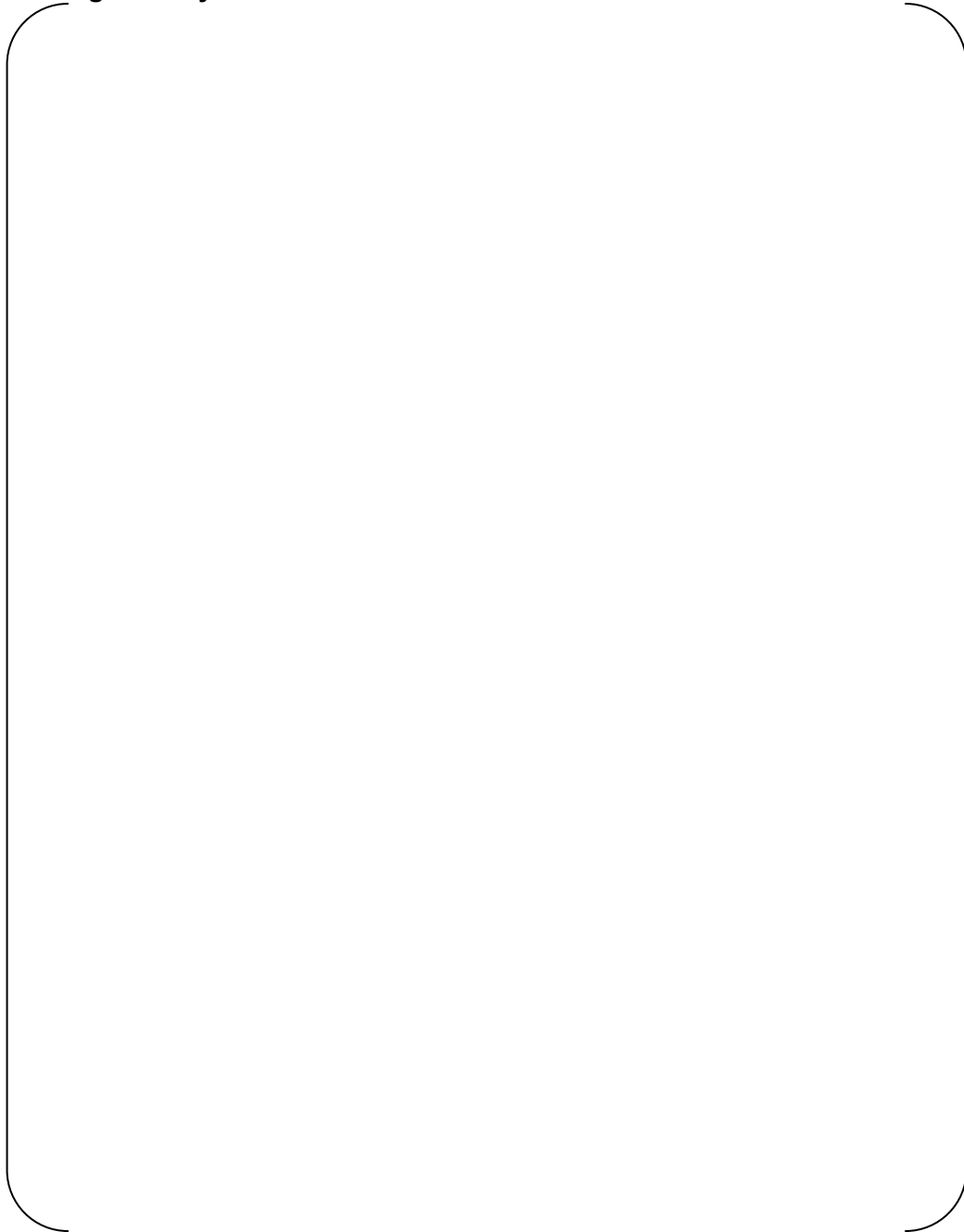


Figure 10.1-1 Channel Head Assembly Dimensions

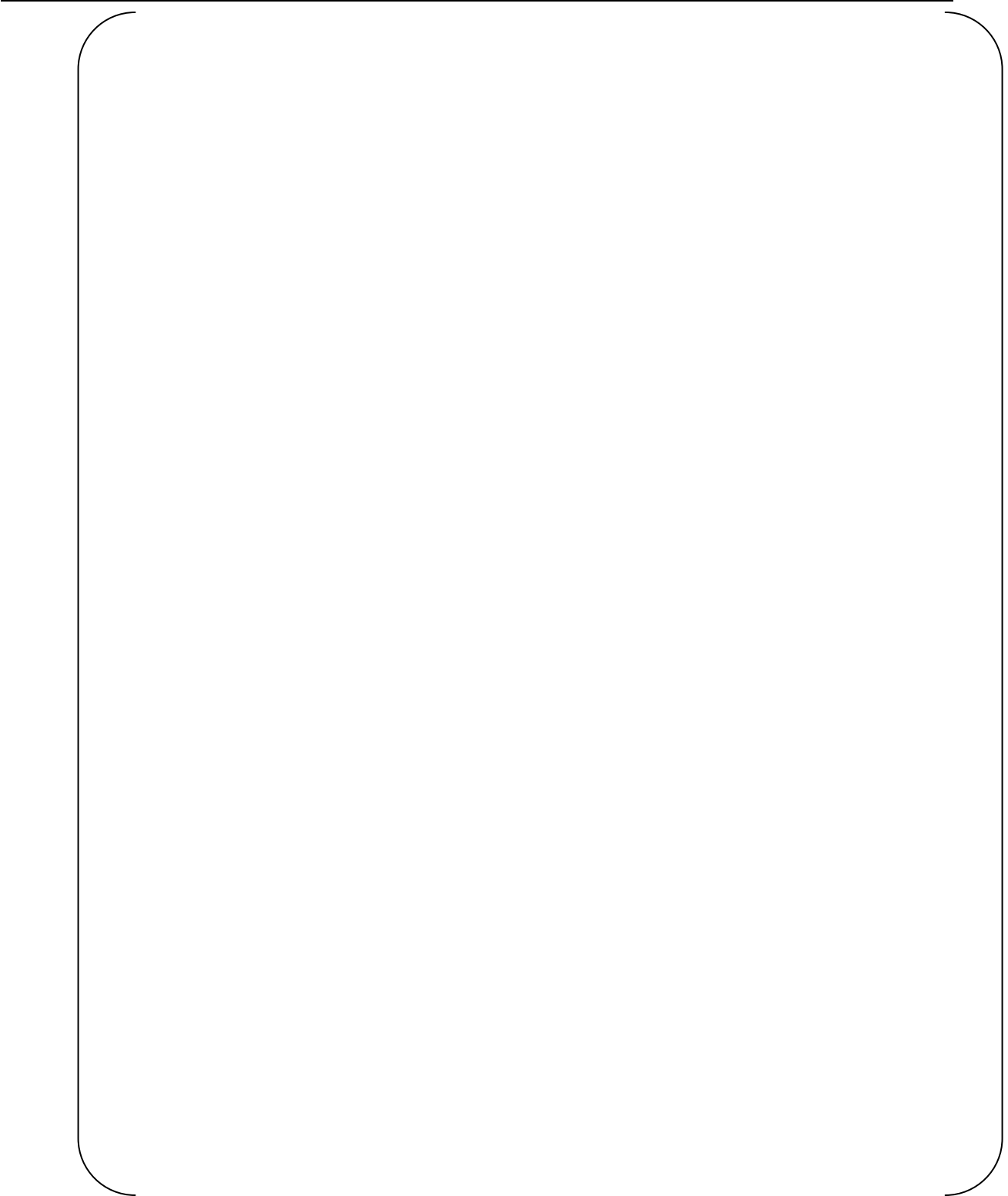


Figure 10.1-2 Channel Head Assembly Dimensions

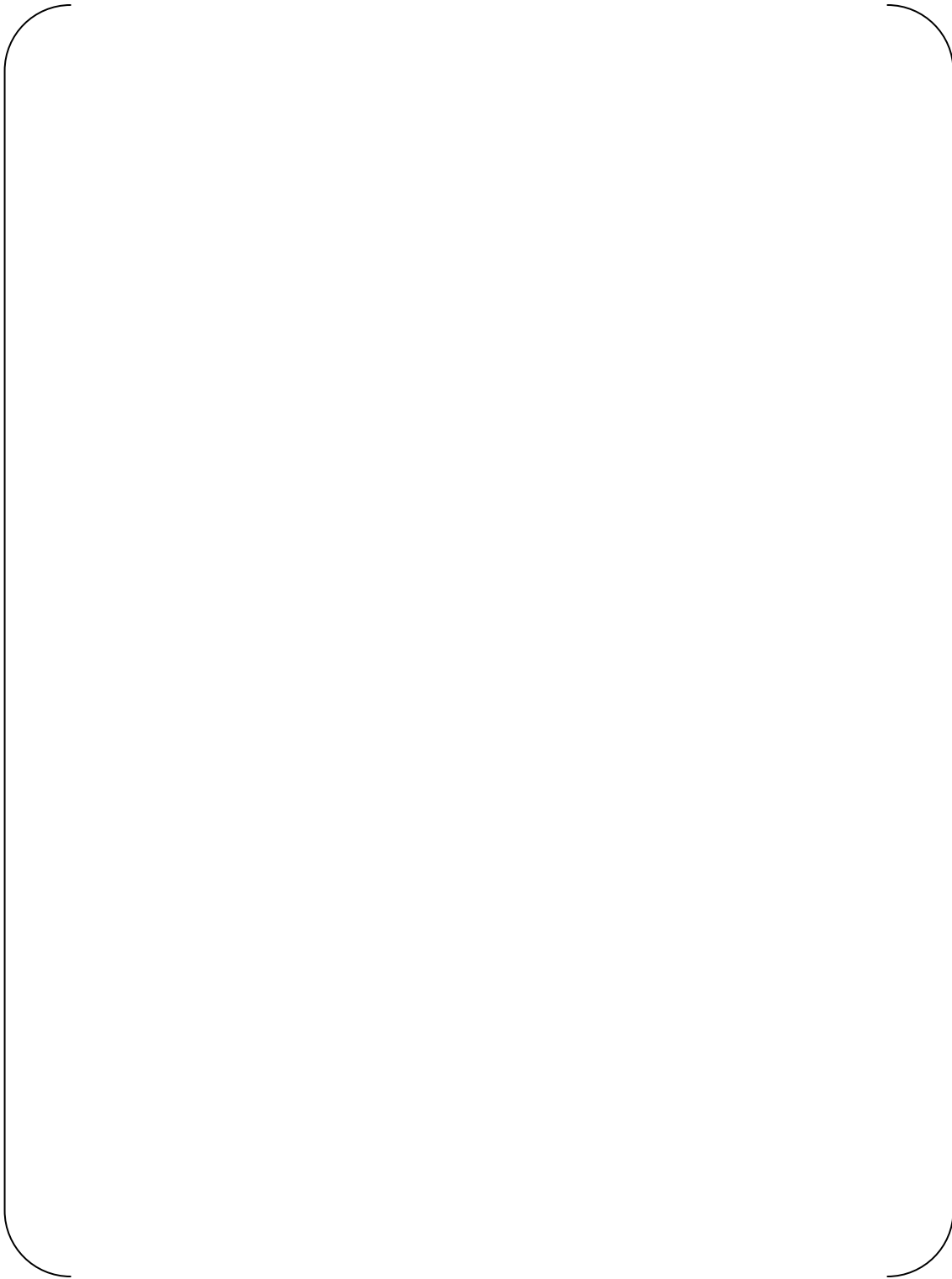


Figure 10.1-3 Channel Head Assembly Dimensions

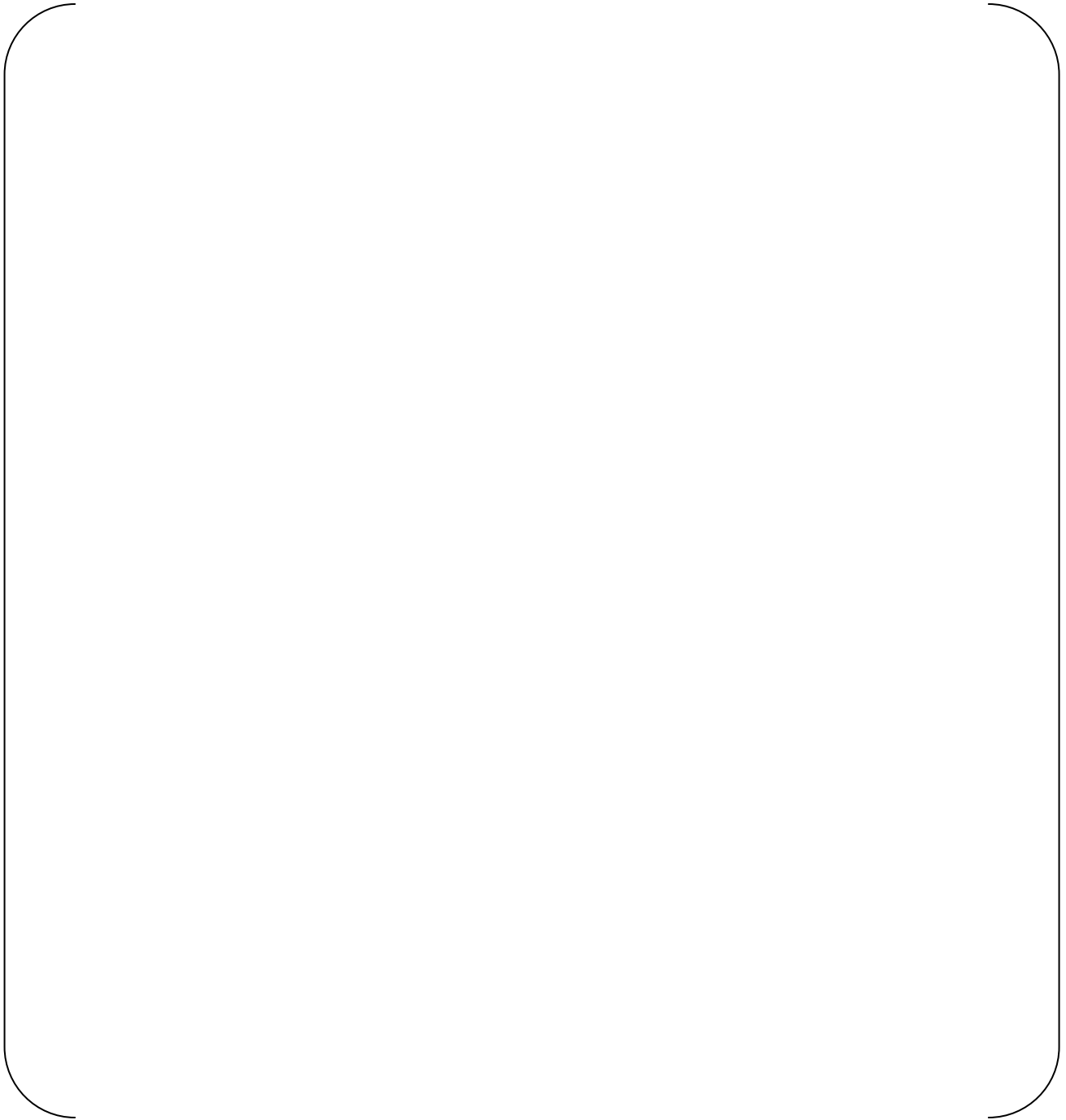


Figure 10.1-4 Channel Head Finite Element Model

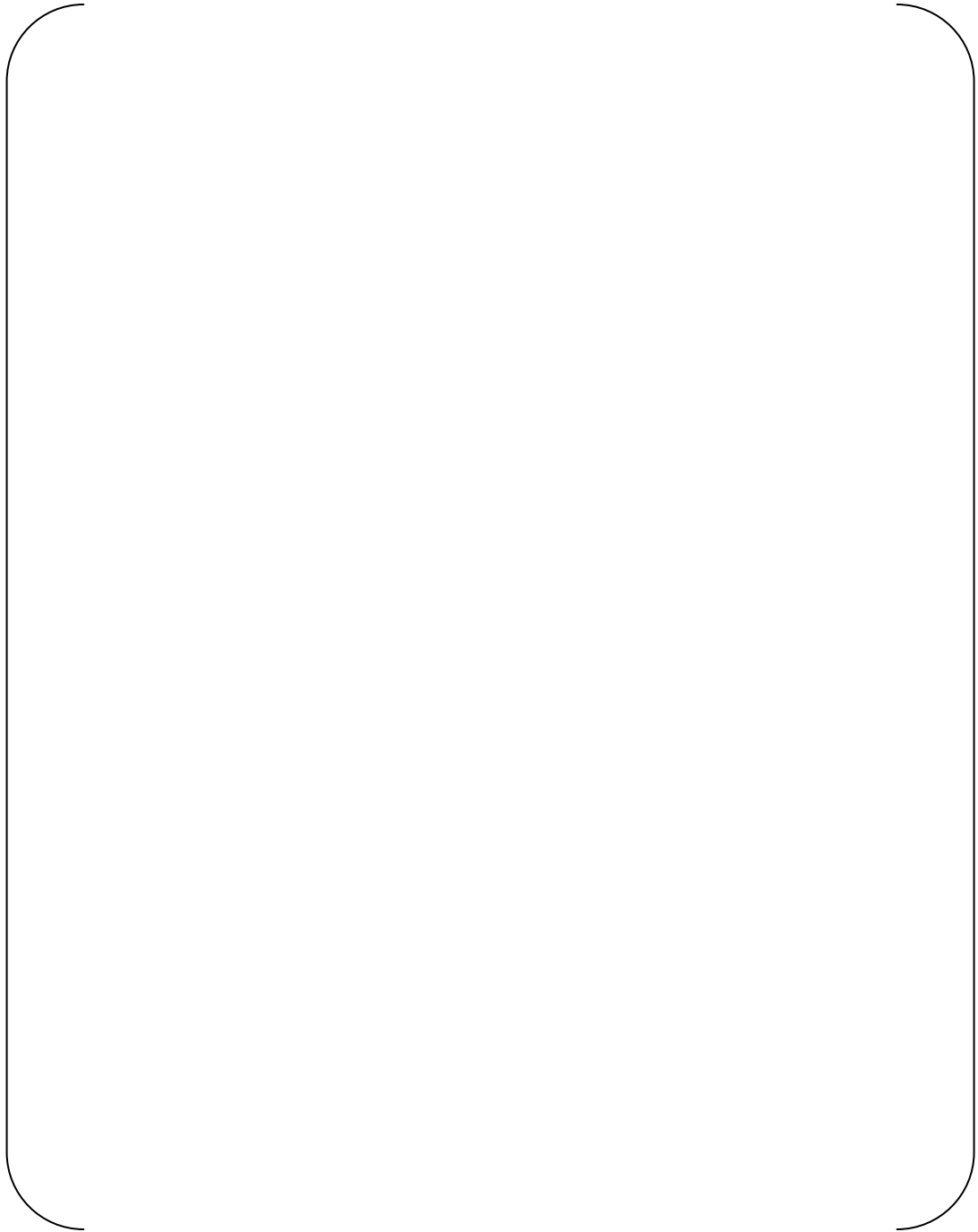


Figure 10.1-5 Channel Head Finite Element Model

10.1.2 Stress Results

The stress-to-allowable ratios (calculated stress divided by allowable value), the fatigue cumulative usage factors, and the thermal stress ratchet results for the most limiting locations in the SG channel head are summarized in the Table 10-1.

Table 10-1 Channel Head Assembly Result Summary

| Condition | Part | Stress-to-Allowable Ratio | | | | Fatigue |
|-------------|------|---------------------------|--------------------|-----------------|----------------------------|--------------|
| | | Primary Stress | | | Primary + Secondary Stress | |
| | | P_m | P_L or P_L+P_b | Triaxial Stress | P_L+P_b+Q | Usage Factor |
| Design | | | | | | |
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| Level A / B | | | | | | |
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| Level C | | | | | | |
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Table 10-1 Channel Head Assembly Result Summary

| Condition | Part | Stress-to-Allowable Ratio | | | | Fatigue |
|-----------|------|---------------------------|-----------------------|--------------------|----------------------------------|-----------------|
| | | Primary Stress | | | Primary + Secondary Stress | |
| | | P_m | P_L or P_L+P_b | Triaxial Stress | P_L+P_b+Q | Usage Factor |
| Level D | | | | | | |
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| Test | | | | | | |
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10.2 Tubes

10.2.1 Modeling and Analysis

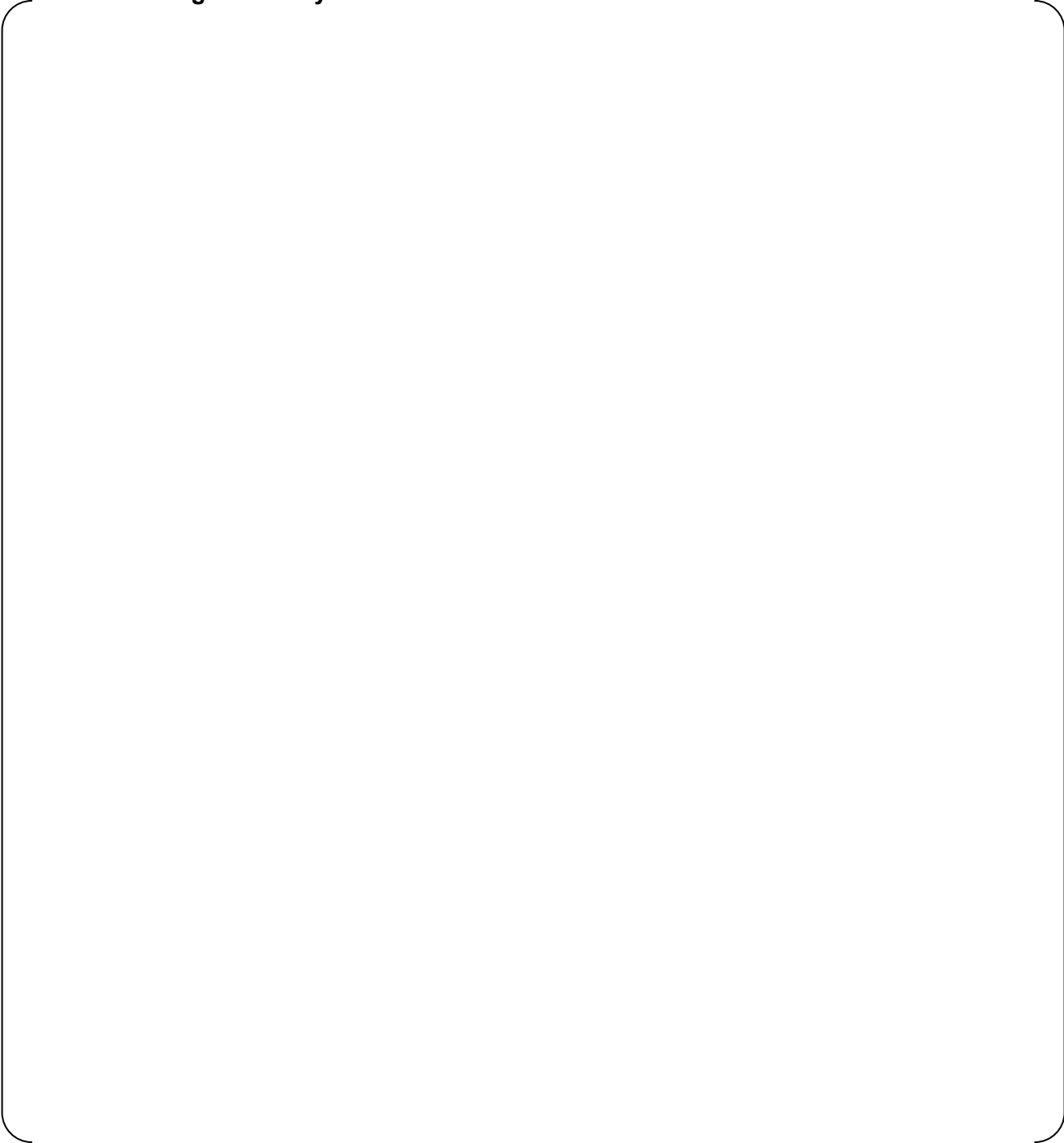


Figure 10.2-1 Tube Model Dimensions

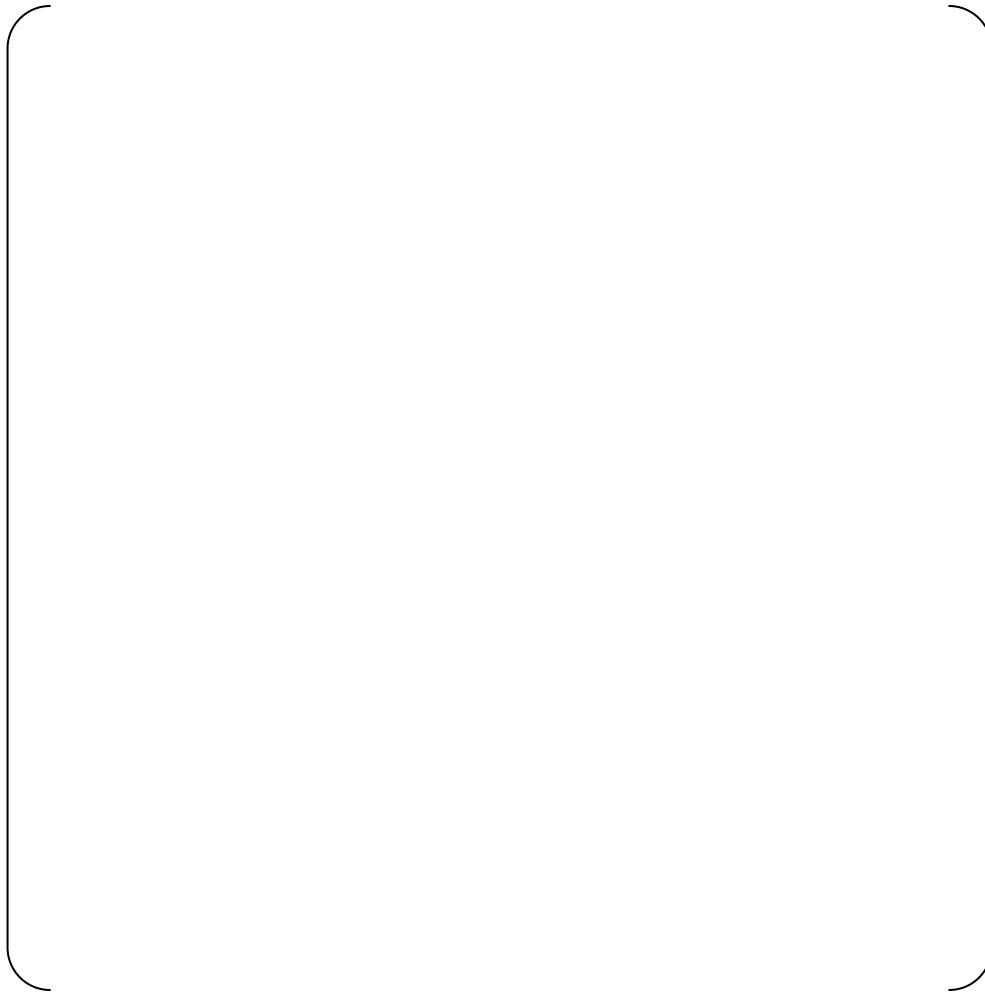


Figure 10.2-2 Tube Finite Element Model

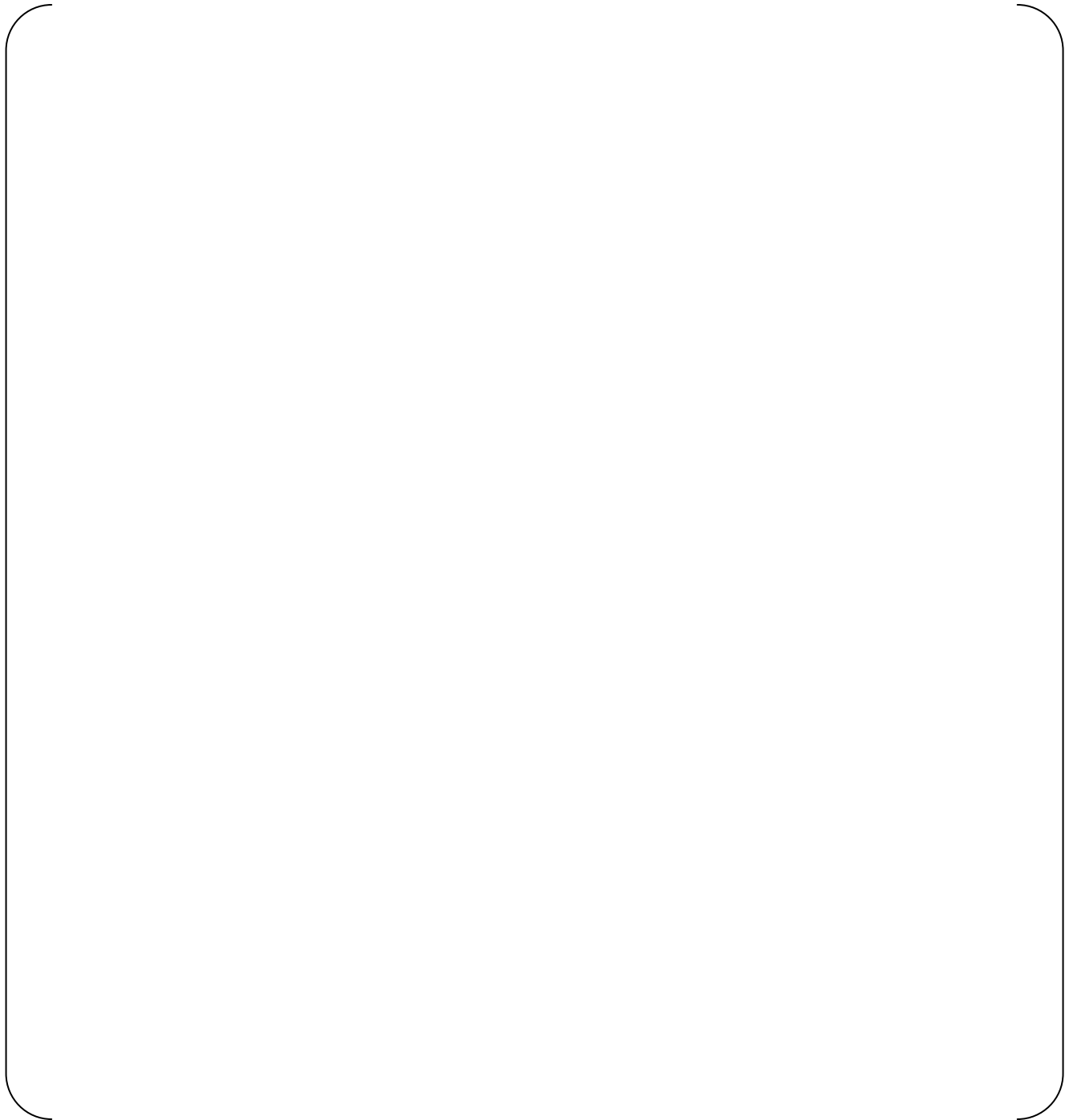


Figure 10.2-3 Tube Model Evaluation Cross Sections

10.2.2 Stress Results

The stress-to-allowable ratios (calculated stress divided by allowable value), the fatigue cumulative usage factors, and the thermal stress ratchet results for the most limiting SG tube locations are summarized in the Table 10-2.

Table 10-2 Tube Result Summary

| Condition | Part | Stress-to-Allowable Ratio | | | | Fatigue | Thermal Ratchet |
|-------------------|------|---------------------------|--------------------|-----------------|-------------------------------|--------------|-----------------|
| | | Primary Stress | | | Primary plus Secondary Stress | | |
| | | P_m | P_L or P_L+P_b | Triaxial Stress | P_L+P_b+Q | Usage Factor | |
| Design | | | | | | | |
| | | | | | | | |
| Level A / Level B | | | | | | | |
| | | | | | | | |
| Level C | | | | | | | |
| | | | | | | | |
| Level D | | | | | | | |
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| Test | | | | | | | |
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10.3 Feedwater Nozzle

10.3.1 Modeling and Analysis

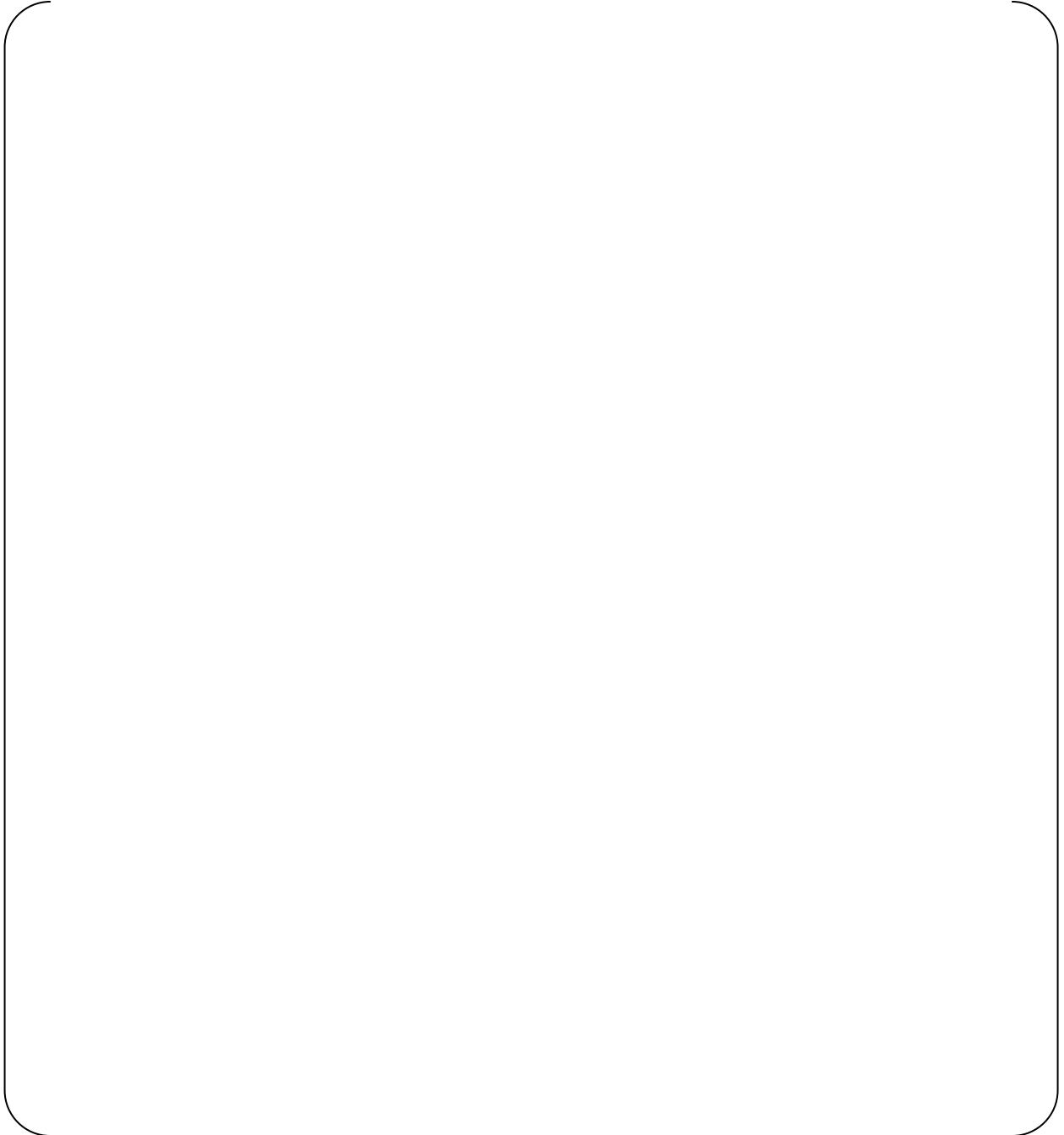


Figure 10.3-1 Feedwater Nozzle Dimensions

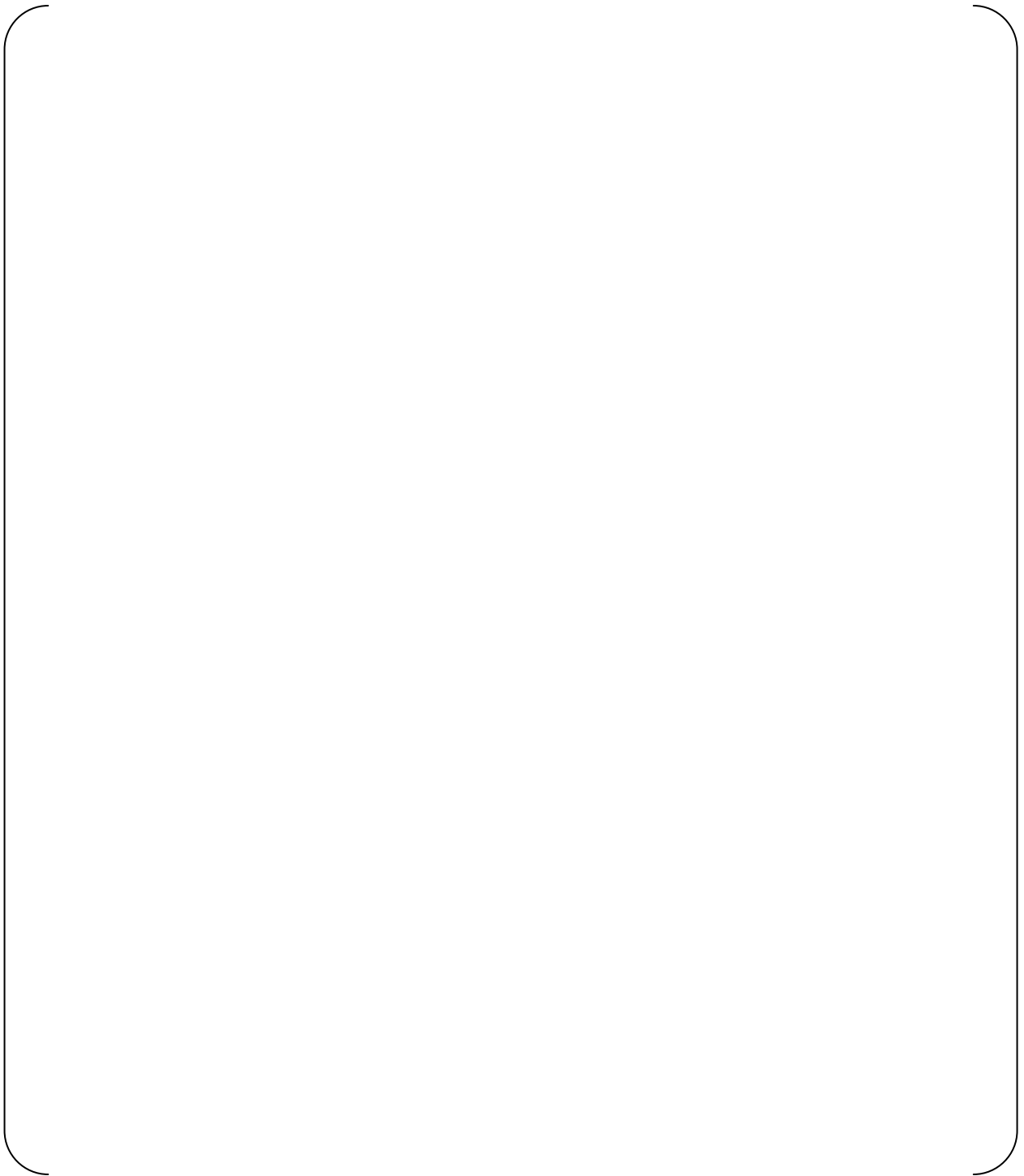


Figure 10.3-2 Feedwater Nozzle Finite Element Model

10.3.2 Stress Results

The stress-to-allowable ratios (calculated stress divided by allowable value), the fatigue cumulative usage factors, and the thermal stress ratchet results for the most limiting locations in the SG feedwater nozzle are summarized in the Table 10-3.

Table 10-3 Feedwater Nozzle Result Summary

| Condition | Part | Stress-to-Allowable Ratio | | | | Fatigue | Thermal Ratchet |
|----------------------|------|---------------------------|--------------------|-----------------|-------------------------------|--------------|-----------------|
| | | Primary Stress | | | Primary plus Secondary Stress | | |
| | | P_m | P_L or P_L+P_b | Triaxial Stress | P_L+P_b+Q | Usage Factor | |
| Design | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| Level A / Level B | | | | | | | |
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| Level C | | | | | | | |
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| Level D | | | | | | | |
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| Test | | | | | | | |
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10.4 Upper Shell Assembly (Shell / Cone / Shell)

10.4.1 Modeling and Analysis



Figure 10.4-1 Upper Shell Assembly Dimensions

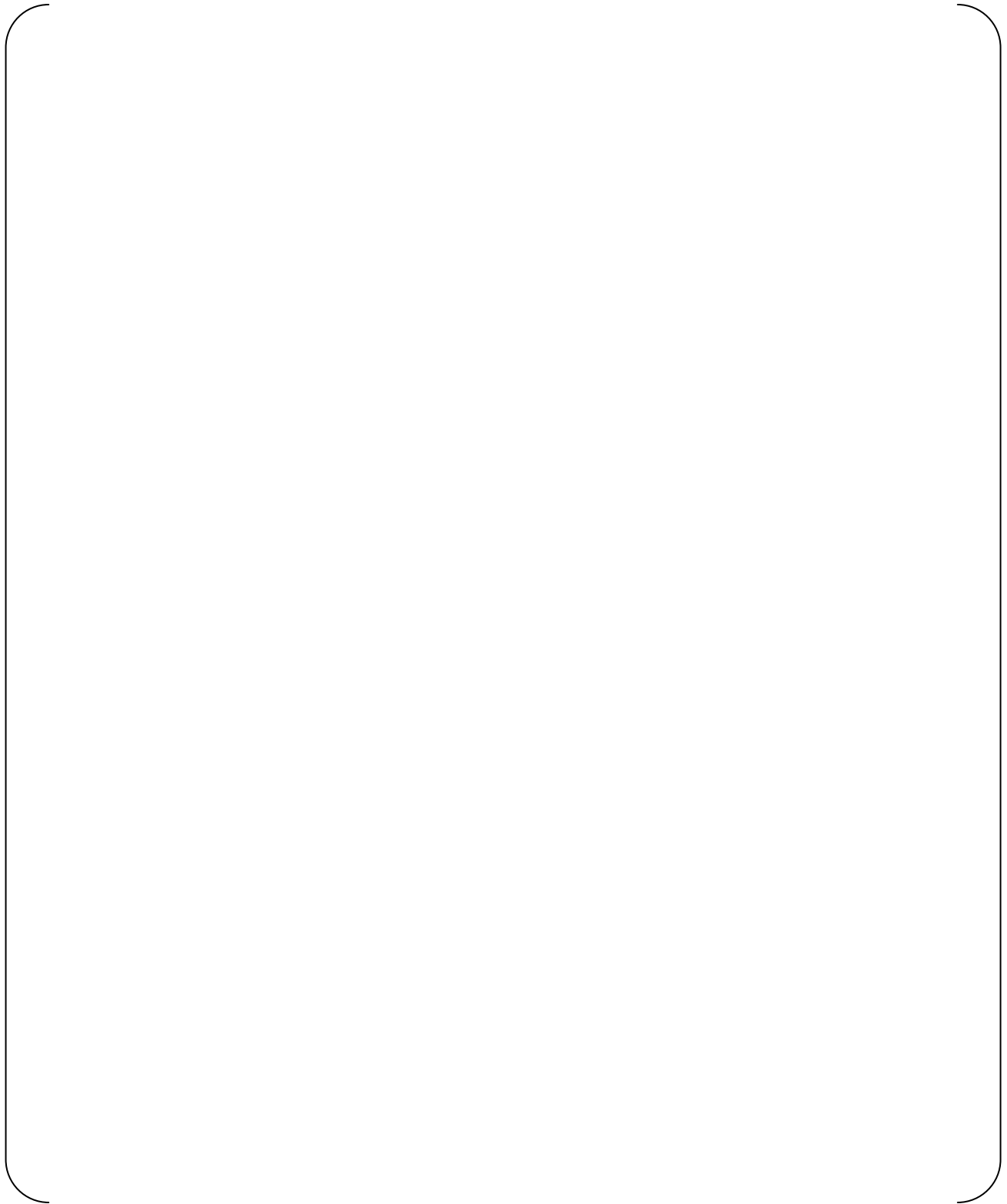


Figure 10.4-2 Upper Shell Assembly Finite Element Model

10.4.2 Stress Results

The stress-to-allowable ratios (calculated stress divided by allowable value), the fatigue cumulative usage factors, and the thermal stress ratchet results for the most limiting locations in the SG upper shell assembly are summarized in the Table 10-4.

Table 10-4 Upper Shell Assembly Result Summary

| Condition | Part | Stress-to-Allowable Ratio | | | | Fatigue | Thermal Ratchet |
|-------------|------|---------------------------|--------------------|-----------------|----------------------------|--------------|-----------------|
| | | Primary Stress | | | Primary + Secondary Stress | | |
| | | P_m | P_L or P_L+P_b | Triaxial Stress | P_L+P_b+Q | Usage Factor | |
| Design | | | | | | | |
| | | | | | | | |
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| | | | | | | | |
| Level A / B | | | | | | | |
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| Level C | | | | | | | |
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| Level D | | | | | | | |
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Table 10-4 Upper Shell Assembly Result Summary

| Condition | Part | Stress-to-Allowable Ratio | | | | Fatigue | Thermal Ratchet |
|-----------|------|---------------------------|--------------------|-----------------|----------------------------|--------------|-----------------|
| | | Primary Stress | | | Primary + Secondary Stress | | |
| | | P_m | P_L or P_L+P_b | Triaxial Stress | P_L+P_b+Q | Usage Factor | |
| Test | | | | | | | |
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10.5 Tube-to-Tubesheet Joint

10.5.1 Modeling and Analysis

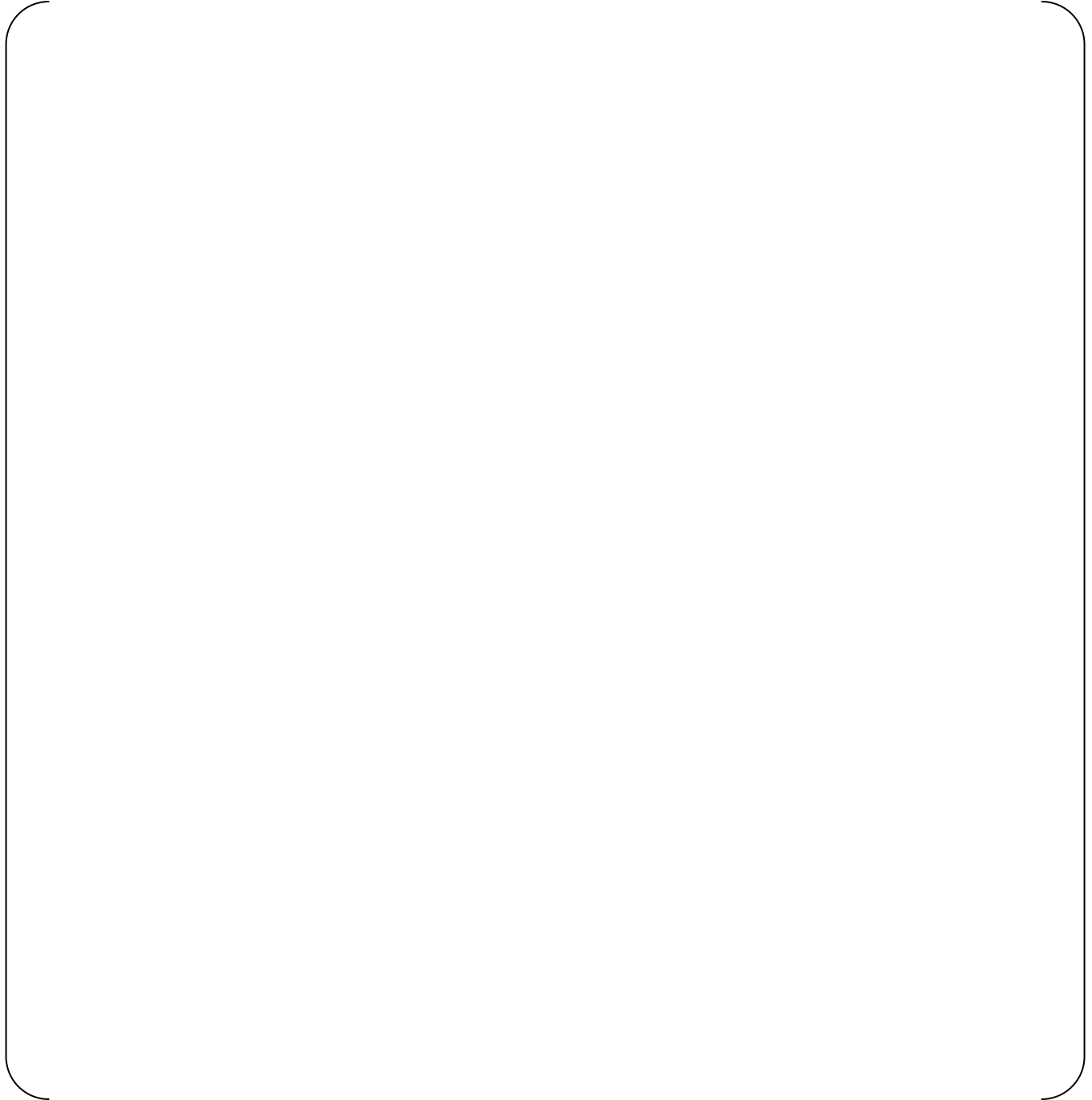


Figure 10.5-1 Tube-to-Tubesheet Joint Dimensions

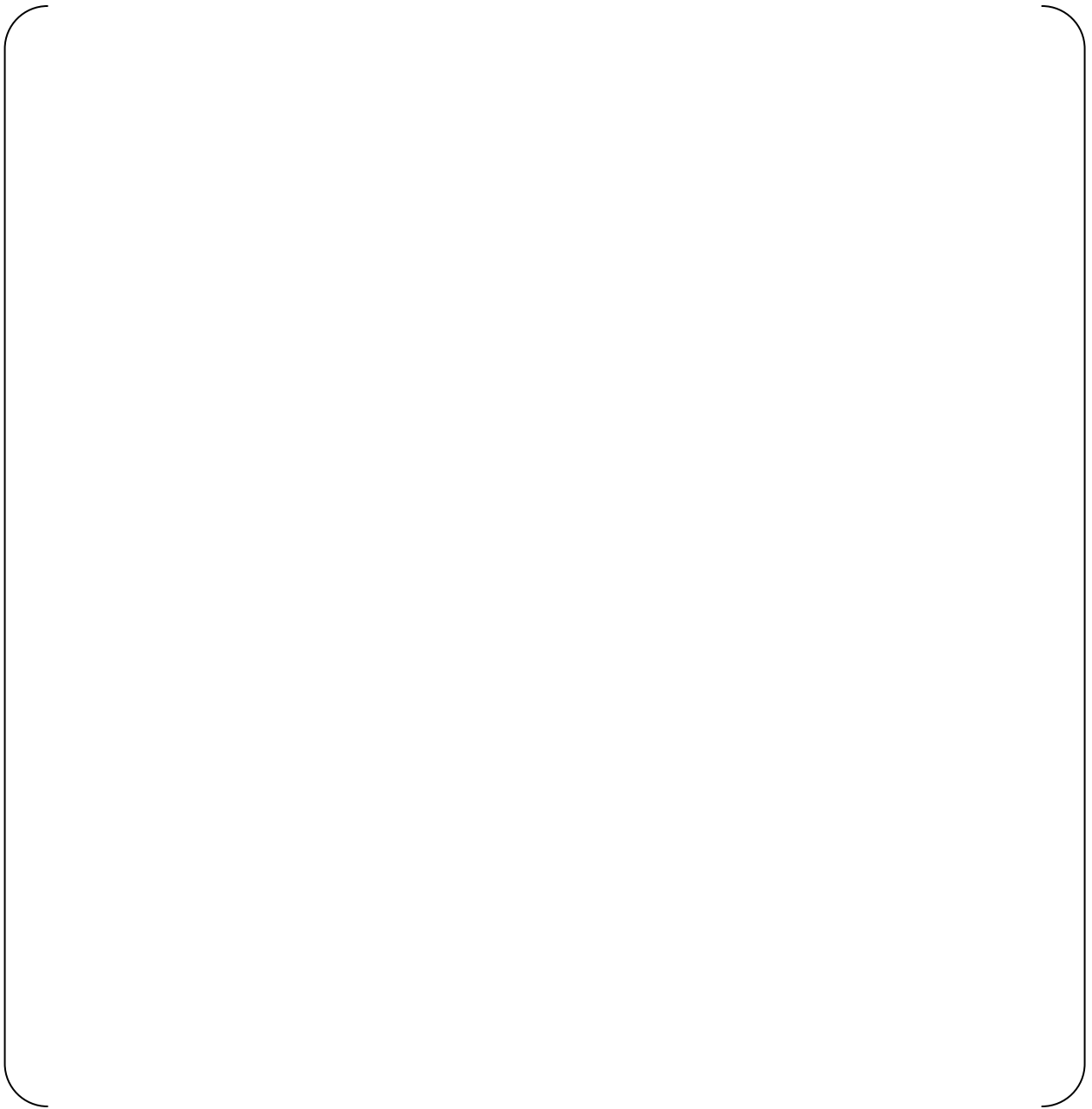


Figure 10.5-2 Tube-to-Tubesheet Joint Finite Element Model

10.5.2 Stress Results

The stress-to-allowable ratios (calculated stress divided by allowable value), and the fatigue cumulative usage factor for the most limiting locations in the tube-to-tubesheet joint are summarized 10-5.

Table 10-5 Tube-to-Tubesheet Joint Result Summary

| Condition | Stress-to-Allowable Ratio | | | | Fatigue |
|-------------------|---------------------------|-----------------------|--------------------|----------------------------------|-----------------|
| | Primary Stress | | | Primary plus Secondary Stress | |
| | P_m | P_L or P_L+P_b | Triaxial Stress | P_L+P_b+Q | Usage Factor |
| Design | | | | | |
| Level A / Level B | | | | | |
| Level C | | | | | |
| Level D | | | | | |
| Test | | | | | |

10.6 Tube Support Plate Assembly

10.6.1 Modeling and Analysis

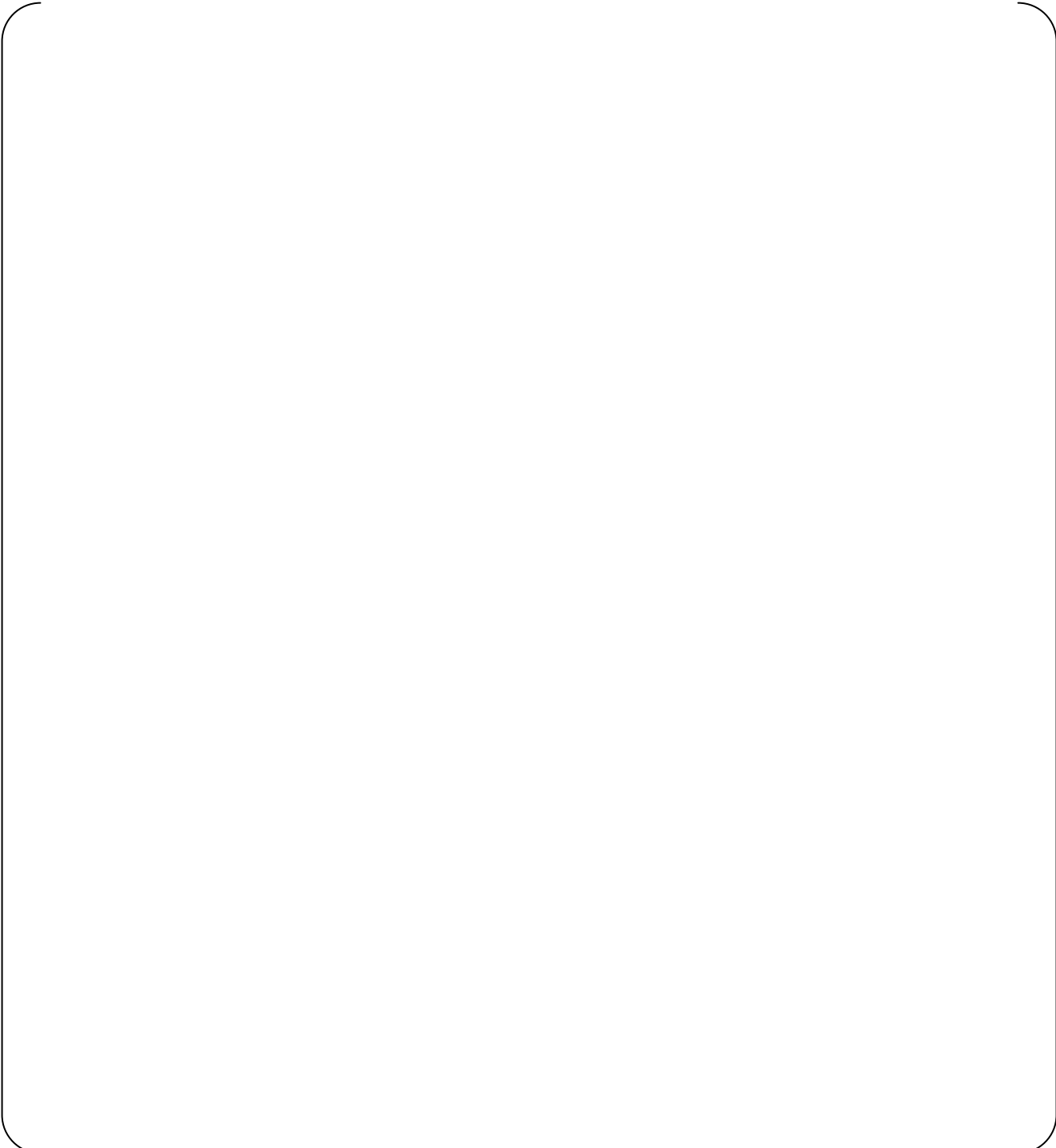


Figure 10.6-1 Tube Support Plate Assembly Dimensions

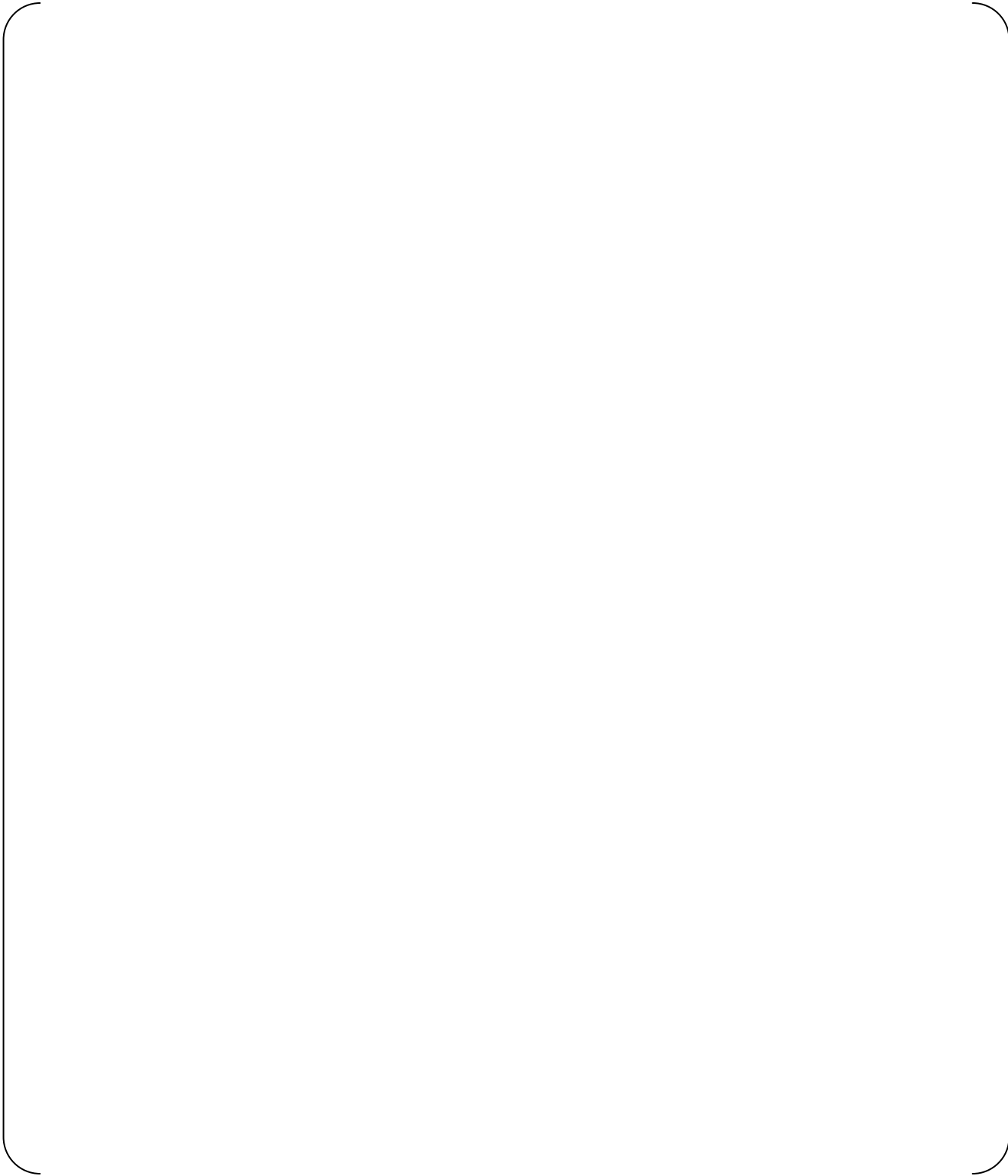


Figure 10.6-2 TSP Assembly Finite Element Model

10.6.2 Stress Results

The tube support plate and stayrod stress-to-allowable ratios (calculated stress divided by allowable value) are summarized in Table 10-6. The in-plane structural limits for the tube support plate are based on empirical data (for Level B no yielding is permitted; for Level D deformation is permitted but no tube contact).

Table 10-6 Tube Support Plate Assembly Result Summary

| Evaluated direction | Condition | Part | Evaluation | Stress-to-Allowable Ratio |
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10.7 Upper Head

10.7.1 Modeling and Analysis

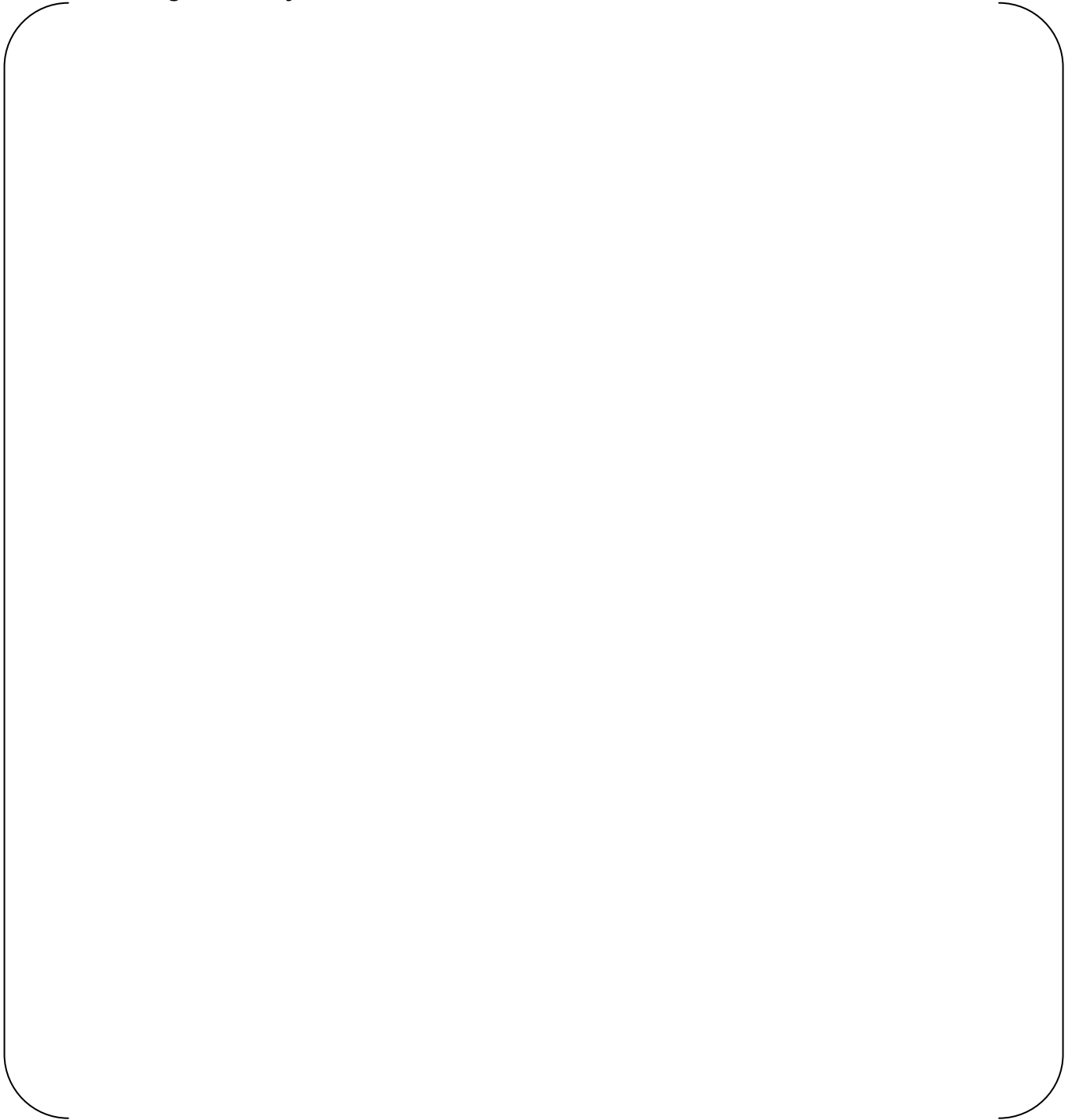


Figure 10.7-1 Upper Head Dimensions

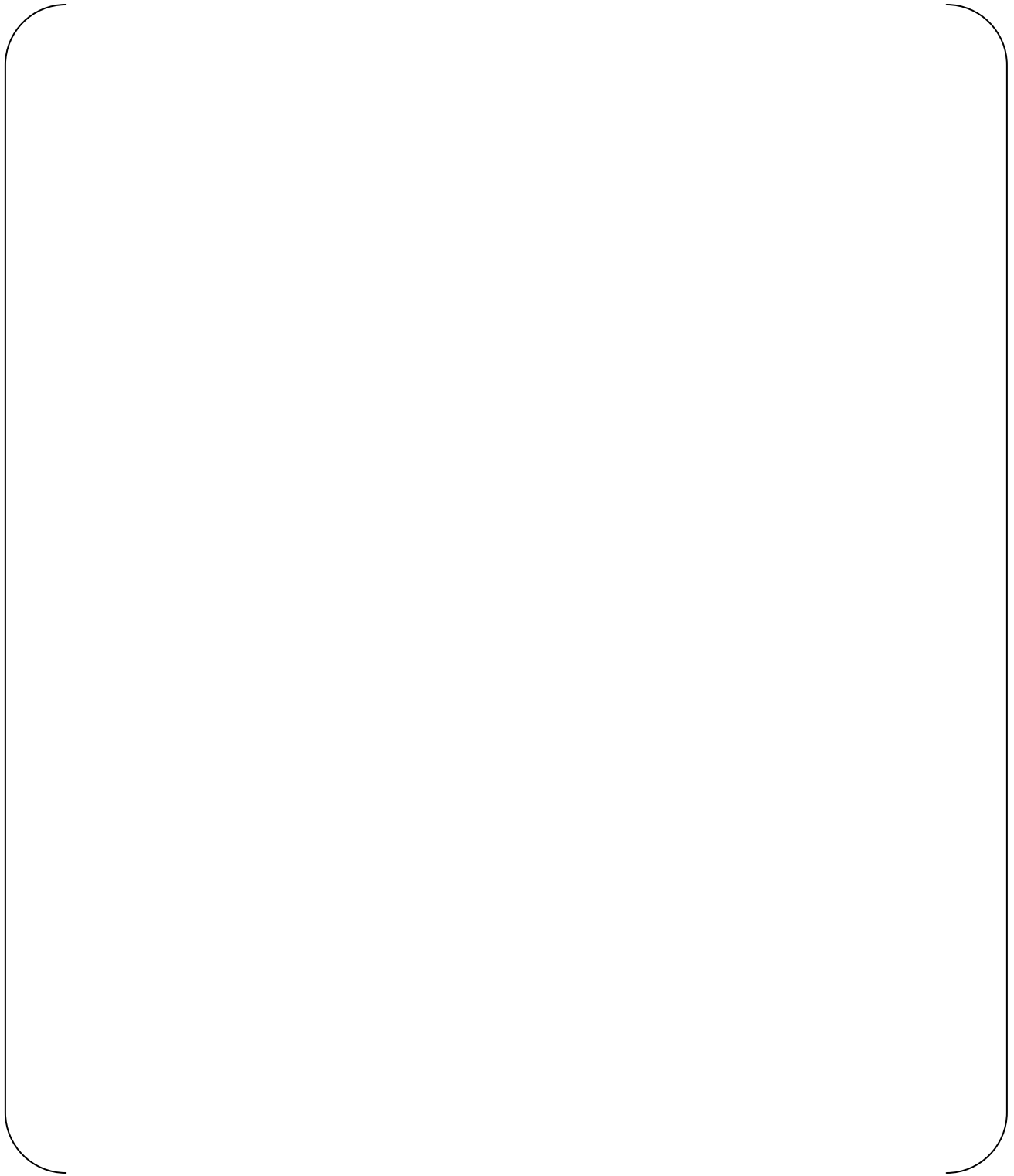


Figure 10.7-2 Upper Head Finite Element Model

10.7.2 Stress Results

The stress-to-allowable ratios (calculated stress divided by allowable value), the fatigue cumulative usage factor, and the thermal stress ratchet results for the most limiting locations in the SG upper head are summarized in the Table 10-7.

Table 10-7 Upper Head Result Summary

| Condition | Part | Stress-to-Allowable Ratio | | | | Fatigue | Thermal Ratchet |
|-------------------|------|---------------------------|--------------------|-----------------|----------------------------|--------------|-----------------|
| | | Primary Stress | | | Primary + Secondary Stress | | |
| | | P_m | P_L or P_L+P_b | Triaxial Stress | P_L+P_b+Q | Usage Factor | |
| Design | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| Level A / Level B | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| Level C | | | | | | | |
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| | | | | | | | |
| Level D | | | | | | | |
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| | | | | | | | |
| Test | | | | | | | |
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10.8 Tube Wall Thinning (RG 1.121 Analysis)

10.8.1 Tube Evaluation Methodology



10.8.2 Stress Results





11.0 FRACTURE MECHANICS ASSESSMENT

When the bulk fluid temperature drops to a low level, brittle failure becomes a concern. Events that are analyzed for brittle fracture include heatup / cooldown and the primary & secondary leak tests. For such cases, non-ductile failure evaluations are carried out for postulated flaws of several sizes. The analysis is normally based on a flaw size equal to 1/4 the thickness of the component. In the portions where this flaw size is overly conservative, a smaller flaw size is evaluated. These smaller flaws are selected with consideration of the current inspection techniques. This approach is in accordance with the rules of ASME Section III Appendix-G.

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