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U. S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, D. C. 20555-0001

Edwin I. Hatch Nuclear Plant – Unit 2
Relief Request Reactor Pressure Vessel Stud HNP-ISI-RR-05-02

Ladies and Gentlemen:

Pursuant to 10 CFR 50.55a(g)(5)(iii), Southern Nuclear Operating Company (SNC) hereby requests Nuclear Regulatory Commission (NRC) approval of proposed Relief Request HNP-ISI-RR-05-02. This Relief Request will allow Hatch Nuclear Plant (HNP) Unit 2 to continue operation with a flaw indication on one reactor pressure vessel (RPV) stud.

Enclosure 1 provides proposed Relief Request HNP-ISI-RR-05-02. Enclosure 2 provides the Dominion Engineering, Inc. (DEI) evaluation report supporting continued operation.

This letter contains no NRC commitments. If you have any questions, please contact Jamie Coleman at 205.992.6611.

Respectfully submitted,

C. A. Gayheart
Regulatory Affairs Director

CAG/RMJ

Enclosures:
1. Proposed Relief Request HNP-ISI-RR-05-02
2. Dominion Engineering, Inc. (DEI) Evaluation

Cc:
Regional Administrator, Region II
NRR Project Manager – Hatch
Senior Resident Inspector – Hatch
RTYPE: CHA02.004

Edwin I. Hatch Nuclear Plant – Unit 2
Relief Request Reactor Pressure Vessel Stud HNP-ISI-RR-05-02

Enclosure 1

Proposed Relief Request HNP-ISI-RR-05-02

1. ASME Code Component(s) Affected

Code Class:	ASME Section XI Code Class 1
Component Numbers:	Not Applicable
Code References:	ASME Section XI, 2007 Edition through 2008 Addenda, IWB-3515.2
Examination Category:	B-G-1
Examination Area:	Pressure Retaining Bolting Greater Than 2 in. (50.8 mm) in Diameter
Item Number(s):	B6.20

2. Requested Date for Approval

Approval is requested prior to the completion of the Unit 2 refueling outage, which begins February 4, 2019.

3. Applicable ASME Code Requirements

ASME Section XI, 2007 Edition through 2008 Addenda, IWA-3515.2(c) Allowable flaws for Volumetric Examination of Studs and Bolts

The 2007 Edition through 2008 addenda of ASME Section XI, IWB-3515.2(c) states: "Any flaw detected by volumetric examination shall be investigated by a surface examination. If confirmed to be a surface flaw, the standards of IWB-3515.1 shall apply. If not a surface flaw, the standards of IWB-3515.2(a) and (b) shall apply".

4. Reason for Request

A flaw indication was found on a Reactor Pressure Vessel (RPV) Stud during a code required volumetric examination during the spring 2017 refueling outage at the Edwin I. Hatch Nuclear Plant Unit 2 (hereinafter referred to as HNP2). The examination was completed in accordance with Table IWB-2500-1, examination category B-G-1, and met the examination volume requirements of Figure IWB-2500-12. During the Inservice Inspection (ISI) of the HNP2 RPV Studs (#1 through #56), a circumferential flaw indication was identified in the RPV stud at location #33. The indication is located at a distance of 41.7 inches from the top of RPV Stud. This correlates to just below or at the surface of the reactor vessel flange. The indication is approximately one inch (1") in length. Qualified Personnel and Procedures (to the requirements of 10 CFR 50 Appendix VIII) were utilized to perform the ultrasonic examination using a 0° beam angle (scanned from the top of the stud) to identify any/all abnormalities. Currently, there are no Appendix VIII Qualified Techniques available to size the indication in the RPV Stud.

In accordance with IWB-3515.2(c), flaws detected by volumetric examination shall be investigated by a surface examination. Due to the location of the flaw indication at or slightly below the reactor flange, removal of RPV Stud #33 is necessary to perform an ASME Section V, Mandatory Appendix 6 (Liquid Penetrant) or Mandatory Appendix 7 (Magnetic Particle) Surface Examination.

After discovery, various attempts were made to remove the stud prior to flooding the reactor cavity for fuel movement and after draindown for vessel reassembly in 2R24. Two different methodologies (Basic Removal and Advanced Removal) were pursued to remove the stud. The first attempt to remove the RPV Stud utilized the "Basic Removal" Technique. This technique includes chasing the stud hole, applying an approved penetrant directly to the stud (includes soak time), installing a STAR adapter to the stud and attempting removal with an impact tool. The "Advanced Removal (Full STAR Tooling)" Technique was also utilized. This technique includes installing an adapter plate, pumping an approved penetrant down the elongation hole and back up the threads, using a vibrator to agitate the stud (attached to the STAR Adaptor) prior to utilizing an impact tool to remove the stud. Both of these attempts were unsuccessful due to schedule limitations, preparation and planning inadequacies, and attempting to work with the reactor vessel head in place.

In the upcoming HNP2 outage (2R25), additional attempts will be made to remove the stud using the methods discussed above with enhancements to the tools, penetrant, and planning. A mockup and practice removal sessions will be utilized to identify best practices and processes to be implemented during the outage. Additionally, the site has scheduled adequate time for removal attempts with planned time after reactor vessel disassembly, to ensure that the head is not an obstruction (i.e. the RPV head is removed from the vessel), and there is contingency for additional time during reassembly. If these attempts are unsuccessful, the stud would remain in place for the remainder of the current ISI Interval.

5. Proposed Relief Request and Basis for Use

Proposed Relief Request

Pursuant to 10 CFR 50.55a(g)(5)(iii), a relief request is requested on the basis that compliance to the specified requirements in the Code is impractical based on not being able to remove RPV stud #33. In the event stud removal is successful, this relief request will not be required.

Southern Nuclear Operating Company (SNC) requests relief from the surface examination requirement of IWB-3515.2(c) in the event that RPV Stud #33 cannot be removed for a code compliant surface examination. Attempts are scheduled and planned to remove RPV Stud #33 during refueling outage 2R25, using enhanced tooling and improved techniques. For Stud #33, ultrasonic examination of the stud will be conducted once per 10-year ISI Interval per Table IWB-2500-1, Category B-G-1, Item B6.20 and Figure 2500-12. To ensure that the flaw does not propagate into the surrounding flange, ultrasonic examination of the threads in the flange will be conducted per Table IWB-2500-1, Category B-G-1, Item B6.40, and Figure 2500-12, except the frequency of ultrasonic examination of the threads in the flange will be once per Inspection Period of the current 10-year ISI Interval in lieu of the code required frequency of once per Interval. Additionally, VT-1 examination of the flange will be conducted concurrently with the aforementioned ultrasonic examination (Item B6.40) of the flange once per Inspection Period for the current 10-year ISI Interval. VT-1 examination includes 1 inch annular surface of flange surrounding RPV stud #33.

Basis for Use

An evaluation has been performed demonstrating that all applicable ASME Code allowable stresses (e.g., stud membrane and membrane plus bending stress, bearing stress, thread shear stress) are met with a single stud analytically assumed out of service, including subsequent operation with the expanded elongation tolerances previously developed for HNP2. The analysis considers the effects of both a single stud left de-tensioned and a stud that fails in service. This evaluation demonstrates that the structural and leakage integrity of the RPV Head Joint will be maintained if Stud #33 is not able to be removed to verify the stud structural integrity by a surface examination. Ultrasonic examinations will be performed in accordance with the requirements of Table IWB-2500-1, Category B-G-1, Items B6.20 and B6.40, except the frequency for ultrasonic examination for Item B6.40 (threads in the flange) will be conducted once per Inspection Period in lieu of once per Interval for the current 10-year ISI Interval. Additionally, VT-1 examination of the flange will be conducted concurrently with the aforementioned ultrasonic examination (B6.40) of the flange once per Inspection Period for the current 10-year ISI Interval. VT-1 examination includes 1 inch annular surface of flange surrounding RPV stud #33. These will ensure that the flaw in the stud is monitored and that no flaw propagation into the surrounding flange occurs. Also a Class 1 System Leakage Test conducted before start up from each refueling outage, per Table IWB-2500-1 Category B-P, will verify the integrity of the RPV Head Joint. The system leakage test pressure for Class 1 Systems shall correspond to rated PRV pressure (at least 1,045 psig) and be attained at a rate in accordance with the approved Pressure / Temperature Limit Curves and approved procedures. If the test pressure results in a temperature greater than 200°F, the pressure may be reduced. After the test conditions have been attained, the VT-2 Examination will be performed. During plant operation, the bleed off line between the double o-ring seal is monitored by a pressure switch with an annunciator in the control room. This allows for continued monitoring of the RPV Head Flange integrity.

Based on the above discussion, the requirement to remove RPV Stud #33 to perform the required surface examination (Liquid Penetrant or Magnetic Particle) represents an unusual difficulty. However, the inability to remove the stud in question does not adversely affect the design requirements of the RPV nor impose a decrease in the level of quality and safety of the HNP Unit 2 RPV.

6. Duration of Proposed Relief Request

This proposed relief request is requested for the current ISI Interval, currently scheduled to end on 12/31/2025, if attempts to remove Stud #33 are unsuccessful in 2R25.

7. Precedents

Edwin I. Hatch Nuclear Plant Letter, dated 2/17/17, to USNRC; Docket Nos. 50-366, "Relief Request Reactor Pressure Vessel Stud Inspection" and the associated NRC SER ML17205A345, dated 8/10/17.

Edwin I. Hatch Nuclear Plant – Unit 2
Relief Request Reactor Pressure Vessel Stud HNP-ISI-RR-05-02

Enclosure 2

Dominion Engineering, Inc. (DEI) Evaluation

CALCULATION

Dominion Engineering, Inc.

Title: Hatch Unit 2 Operation with One Stud Out of Service Evaluation

Calculation No.: C-3944-00-01 Revision No.: 0 Page 1 of 41

RECORD OF REVISIONS

Rev.	Description	Prepared by Date	Checked by Date	Reviewed by Date	Approved by Date
0	Original Issue	J.E.BROUSSARD 2/16/2017 J.E. Broussard Principal Engineer	T.C. 2/16/2017 T.C. Ligon Engineer	T.C. 2/16/2017 T.C. Ligon Engineer	D.J. Gross 2/16/2017 D.J. Gross Principal Engineer

The last revision number to reflect any changes for each section of the calculation is shown in the Table of Contents. The last revision numbers to reflect any changes for tables and figures are shown in the List of Tables and the List of Figures. Changes made in the latest revision, except for Rev. 0 and revisions which change the calculation in its entirety, are indicated by a double line in the right hand margin as shown here.

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CERTIFICATION

The original Edwin I. Hatch Nuclear Plant Unit 2 Reactor Vessel Design Report and previous amendments, as identified in Section 6 of this report, are supplemented by this amendment. The original Design Report and previous amendments, in conjunction with this amendment, reaffirm the structural integrity of the components in accordance with the 1968 Edition of Section III of the ASME Boiler and Pressure Vessel Code, with Addenda through Summer 1970. All requirements of applicable Code revisions are satisfied. This evaluation was performed under Purchase Order number SNG10151695.

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2/16/2017
John E. Broussard, III, PE. Date
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1 PURPOSE

Dominion Engineering, Inc. (DEI) originally provided optimized tensioning and detensioning procedures for Plant Hatch in January 2015 [1], along with design basis evaluations for expanded elongation tolerances. The purpose of this calculation is to provide an update to these evaluations that consider the effect of a single stud out of service. This analysis considers the stresses resulting from two conditions which bound the effects of a stud out of service: (1) operating with one stud left untensioned, and (2) the unlikely condition of a stud that is tensioned then fails in service.

2 SUMMARY OF RESULTS

The average stresses in the studs due to primary load conditions with one stud out of service were calculated using the methodology outlined in Section 5.1. As summarized in this section, all studs continue to meet ASME Code requirements for primary loads with one stud out of service.

The FEA model which was used to develop the current stud tensioning evaluations in DEI Report R-3937-00-01 [1] was used to perform an analysis of the closure flange with one stud out of service, as summarized in Section 5.2. The analysis results are summarized in Table 3. As demonstrated by the results in Table 3, operation of the Hatch Unit 2 RPV with one stud out of service does not result in any component of the RPV closure flange to exceed the design basis ASME Code allowables.

3 INPUT REQUIREMENTS

The following inputs are required to calculate the average stresses in the studs due to primary load conditions with one stud out of service:

1. The RPV design pressure is 1,250 psia and the design temperature is 575°F [1, Table 3-1].
2. The RPV inner o-ring radius is 111.0 inches [1, Table 3-3].
3. The RPV stud circle radius is 117.313 inches [1, Table 3-3].
4. The number of studs in the Hatch Unit 2 RPV is 56 [1, Table 3-1].
5. The stud shank OD is 6.0 inches, the stud shank ID is 1.0 inches, and the stud shank cross section area is 27.489 in^2 [1, Table 3-1].
6. The S_m allowable at design temperature for the RPV studs is 36.3 ksi [1, Table 3-3].

The following inputs are required for the FEA analysis of tensioning effects related to one stud out of service:

7. Reactor vessel head and closure flange dimensions. The geometry of the model developed for this analysis is identical to the one used in the Reference [1]. The model parameters used in this FEA model are detailed in Table 1.
8. Reactor vessel head and closure flange low alloy steel material properties. The material properties of the model developed for this analysis are identical to those used in Reference [1].
9. ASME Code design basis summary. The design basis conditions for the RPV closure flange components updated to include the analyses performed in the 2015 tensioning optimization stress report are summarized in Table 2-1 of Reference [1]. This table includes the updated stress values as well as the appropriate ASME Code comparison and allowable stress value.
10. Primary stress design basis values. The conditions evaluated in the 2015 tensioning optimization stress report do not impact primary conditions, and therefore they were not included. Using the original closure flange design basis report [2] (referenced in the 2015 analysis), the following limiting primary stress values are obtained:
    a. Closure head / head flange general membrane stress: 22.5 ksi compared to an allowable stress of 26.7 ksi (S_m) [2, p. A-16]
    b. Vessel closure shell / flange general membrane stress: 23.8 ksi compared to an allowable stress of 26.7 ksi (S_m) [2, p. A-16]
    c. Closure head / head flange local membrane + bending stress: 28.1 ksi compared to an allowable stress of 40.05 ksi ($1.5S_m$) [2, p. A-23]
    d. Vessel closure shell / flange local membrane + bending stress: 28.2 ksi compared to an allowable stress of 40.05 ksi ($1.5S_m$) [2, p. A-29]

4 ASSUMPTIONS

The following assumptions are used to calculate the average stresses in the studs due to primary load conditions with one stud out of service:

1. The reactor vessel and head are rigid. This is consistent with the usual treatment of primary loads which only considers net forces and moments and not localization of stress from geometry and compliance effects. A consequence of this assumption is that the distribution of stud forces varies linearly with the distance from the neutral axis.
2. The reactor vessel and head exert no contact forces on each other (i.e., the compression forces on the mating surfaces are neglected). These secondary forces serve to mitigate the redistribution of loads when studs fail, so this assumption conservatively maximizes the calculated maximum stud stress value.

3. As a simplifying assumption, each stud is individually treated as a point force. That is, each stud contributes no bending stiffness to the cross section as a whole.
4. The design pressure is assumed to act out to the radius of the inner o-ring of the vessel.

The following assumptions are used for the FEA analysis of tensioning effects related to one stud out of service. These assumptions are consistent with analyses described in Reference [1].

5. All vessel elements were assigned material properties appropriate for low carbon steel at ambient temperature: E = 27.9E6 psi and $\nu = 0.3$. All stud elements were assigned material properties appropriate for low alloy steel at ambient temperature: E = 29.9E6 psi and $\nu = 0.3$. The differences caused by differential thermal expansion of the stud and vessel are negligible and are not considered.
6. The modulus of elasticity in the stud hole regions of the upper and lower flanges were de-rated by the ratio shown in Table 1 to account for the removed material in the stud holes.
7. The contact between the nut and the washer is assumed to occur at a single point location. This is considered a reasonable assumption since the nut and washer mate at a spherical surface, and therefore come into contact all at once.
8. Beam elements that are stiff in bending are used to impose flange rotation on the ends of the studs. Despite the presence of spherical washers between the nut and the upper flange, friction acts to "glue" the nut to the flange once the stud is preloaded. At full pressure load, a modest amount of friction ($\mu < 0.1$) has been demonstrated to be sufficient to transmit the bending stresses which arise from this boundary condition. Thus, the infinite friction assumption is concluded to be more realistic than the assumption of zero friction at the spherical washer.
9. The interface between the head and vessel flanges was simulated by a row of line elements connecting the head and vessel flanges. The location of these interface elements was selected to act at a “reaction radius” empirically determined from the correlation between the model predictions and the actual stud elongation data using the existing tensioning procedure.
10. All studs are assumed to be initially uniformly tensioned to the target stud elongation of 0.0397 inch, equivalent to a stud stress of 37.146 ksi [1, Table 3-1].

5 ANALYSIS

5.1 Stud Primary Stress with One Stud Out of Service

The effect of a stud being out of service on the primary stress in the remaining studs is greater than simply increasing the design basis primary stress by the ratio of original to remaining studs. The change in restraint conditions caused by the inactive stud will tend to create a larger primary load in the studs adjacent to the inactive stud.

We treat the studs as a single cross section loaded in bending by the pressure on the reactor head. Assuming one stud is out of service, and that the resulting force distribution in the studs is a linear function of the distance from the neutral axis of the stud cross section, we enforce the static equilibrium equations on the studs. Note that the linear distribution assumption is a consequence of Assumption 1. An Excel spreadsheet is used to facilitate solution of the equations which are developed.

5.1.1 Average Stud Force

Ignoring for a moment that the 55 remaining studs are not uniformly distributed around the RPV closure, we can compute the average force in the studs according to the following equation. Assuming that the design pressure (in psig) acts out to the location of the inner o-ring radius (characterized by radius R_i), we have:

$$\bar{F} = \frac{PA_h}{55} = \frac{P\left(\pi R_i^2\right)}{55} = \frac{(1235\text{ psig})\left(\pi \times 111.0^2\text{ in}^2\right)}{55} = 869.2\text{ kips} \qquad [5\text{-}1]$$

This value will be used in computing the actual force (and, from there, stress) distribution among the studs in a later section. For comparative purposes, we note that when all studs are intact and tensioned, the corresponding average force is (55/56)•869.2 = 853.6 kips.

5.1.2 Calculation of Stud Force Distribution

Because the out of service stud is located symmetrically about the x-axis, the neutral axis of bending for the remaining studs (considered as a whole) must be oriented parallel to the y-axis in Figure 1. The offset δ from the center of pressure is still an unknown at this point, however. The solution for δ is achieved by writing the static equilibrium equations for the reactor head

$$\begin{aligned} \sum F_z &= \sum_i F_i - PA_h = 0 \\ \sum M_n &= \sum_i F_i\left(x_i - \delta\right) - PA_h(-\delta) = 0 \end{aligned} \qquad [5\text{-}2]$$

where

F_z = net force in the direction parallel to the stud lengths
M_n = net moment about the neutral axis
x_i = x-coordinate of each stud per the axes in Figure 1
δ = parallel offset of the neutral axis from the y-axis as shown in Figure 1
A_h = area of the reactor head on which the pressure force acts

The coordinates x_i can be written in terms of the bolt-circle radius (R_o) and θ_i as defined in Figure 1.

$$x_i = R_o \cos\theta_i, \quad \text{where } \theta_i = \left(\frac{i-29}{56}\right)\times 2\pi \qquad [5\text{-}3]$$

At this point, we assume per Section 4 that the stud force varies linearly with its distance from the neutral axis. The mathematical form of the force distribution in the studs consequently may be expressed as follows, where f is a constant

$$F_i = \bar{F} + f(x_i - \delta) \qquad [5\text{-}4]$$

Substituting Eq. [5-4] into the first of Eqs.[5-2] and taking advantage of the fact that $\sum_i \bar{F} = PA_h$ yields

$$\begin{aligned} &\sum_i\left(\bar{F} + f(x_i - \delta)\right) - PA_h = 0 \;\rightarrow\; \sum_i f(x_i - \delta) = 0 \;\rightarrow \\ &\delta = \tfrac{1}{55}\sum_i x_i = \tfrac{R_o}{55}\sum_i \cos\theta_i \end{aligned} \qquad [5\text{-}5]$$

where Eq. [5-3] has been used for x_i. Since δ is now known, we can substitute Eq. [5-4] into the second of Eqs. [5-2], resulting in the following

$$\sum_{i}\left(\bar{F}+f\left(x_i-\delta\right)\right)\left(x_i-\delta\right)-PA_h(-\delta)=0 \rightarrow$$

$$\sum_{i}\left(\bar{F}+f\left(R_o\cos\theta_i-\delta\right)\right)\left(R_o\cos\theta_i-\delta\right)+PA_h\delta=0 \rightarrow$$

$$f=\left(\frac{-PA_h\delta-\sum_{i}\bar{F}R_o\cos\theta_i+55\bar{F}\delta}{\sum_{i}R_o^2\cos^2\theta_i-\sum_{i}2R_o\delta\cos\theta_i+55\delta^2}\right) \qquad [5\text{-}6]$$

The values for f and δ can be substituted directly back into Eq. [5-4], producing the force distribution for all studs. The final results appear in Table 2. Note that the highest stud force occurs at Stud Location Nos. 2 and 56, as might be expected since these are adjacent to the untensioned stud (No. 1).

5.1.3 Primary Stress Comparison

The distributed primary stud forces are divided by the stud stress area of 27.489 in^2 (Input 5) to calculate the primary stud stresses. The maximum primary stud stress is calculated in Table 2 to be 32.8 ksi, which is less than the S_m allowable of 36.3 ksi; therefore, this condition is satisfied.

5.2 Analysis of Closure Flange with Stud Out of Service

5.2.1 Evaluation Methodology

The effect of one stud out of service on the ASME Code comparison stresses in the reactor vessel closure flange components is evaluated using the same model used in the 2015 tensioning optimization stress report. The approach used to evaluate these conditions is to: (1) determine the stresses in the studs and vessel for the intact case and for the case of a single stud out of service under preload plus design pressure conditions, (2) determine the increase in the stresses when going from the intact to single stud out of service condition, (3) add the calculated increase in stress to the stress given in the design report which includes the effect of plant design transients, and (4) determine if the calculated single stud out of service condition stresses still meet ASME Code requirements.

5.2.2 Reactor Vessel Closure Flange Model

The simulation was performed using the finite element analysis model described in Appendix A of Reference [1]. The modeling methods are summarized in this section; greater detail on the specifics of the model is described in Reference [1].

5.2.2.1 Model Geometry

The vessel shell, head and flange regions were modeled using SOLID45 (3D structural solid) elements with each row of elements corresponding to one stud pitch. Studs were modeled using BEAM4 (3D beam) elements which resist tensile loads and bending moments. A three dimensional model of the Hatch RPV closure flange was simulated as shown in Figure 2. The model considers half the circumference of the closure flange, with symmetry boundary conditions at the circumferential edges.

The 3-D BEAM4 elements used for the studs and tie bars require three real properties: area, moment of inertia, and thickness (used to calculate section modulus). The stud element real properties used in the analysis are reported in Reference [1]. Tie bar properties were selected so that the area is 100 times smaller than the area of the studs, and the moment of inertia is 100 times greater than that of the studs. This has the effect of making the tie bars rigid in bending (as they are being used, the elements have no shear deflection), so that the rotation of the flanges is imposed on the ends of the studs without affecting the stiffness of the adjacent solid elements.

The interface between the head and vessel flanges was simulated by a row of LINK8 (3D spar) elements connecting the head and vessel flanges. The location of these interface elements was selected to act at a "reaction radius" empirically determined from the correlation between the model predictions and the actual stud elongation data using the existing tensioning procedure.

The case of an untensioned stud is simulated by deleting the beam element representing that stud and adjusting the initial strains on the studs adjacent to the untensioned stud to produce the specified preload. If the spar elements simulating the vessel to head contact have axial tensile stresses in the pressurized condition, these elements are deleted and the coupled circumferential and radial constraints at these nodes are removed to simulate the fact that there is no longer a frictional restraining force at this location.

5.2.2.2 Model Boundary Conditions

The nodes at the bottom of the vessel shell were all fixed in the vertical and circumferential directions and allowed to move freely in the radial direction. Additionally, out of plane rotations (ROTX and ROTZ) were restrained on the nodes associated with the tie bar elements. The rotation of the flange was tied to the bending of the stud by coupling the rotational degree of freedom between the node at top of the stud beam element and the center node of the "tie bar" elements at the top of the flange.

As noted previously, symmetry boundary conditions were applied at the circumferential edges of the model. In addition, the stud and tie bar beam elements located at each end of the model (i.e., in the first and last planes) are assigned half of the area and moment of inertia as the rest of the studs because they lie on a plane of symmetry. Similarly, the LINK8 elements representing flange contact located at each end of the model are given half the area of the rest of the flange contact elements.

5.2.3 Analysis Cases

Six cases are evaluated as follows:

Case A1	represents the preload condition with all studs intact
Case A2	represents the operating condition with the vessel at design pressure and with intact studs
Case B1	represents the case of one stud untensioned and with all other studs preloaded to the specified initial stress
Case B2	same as Case B1 with the vessel at design pressure
Case C1	represents the case of all studs preloaded to the specified initial strain with one stud assumed to fail in service
Case C2	same as Case C1 except the vessel is at design pressure

5.2.4 Results Discussion

The results of the finite element analyses are summarized in Table 3. The increases in stress caused by the inactive stud are summarized, and the stresses are compared to the appropriate ASME Code allowables. As noted in Input 9, the ASME Code comparisons and allowables are taken from Table 2-1 of Reference [1]. The following evaluations are considered:

5.2.4.1 RPV Closure Stresses

As shown in Table 3, the stud out of service has little to no impact on the stresses associated with General Primary Membrane Stress Intensity, Primary Local Membrane plus Bending Stress Intensity, and Maximum Stress Intensity Range. Each of these stress values remain below the appropriate ASME Code allowable stresses.

5.2.4.2 RPV Stud Stresses

As shown in Table 3, the stud out of service has a modest immpact on the stresses associated with the stud Maximum Membrane and Maximum Membrane plus Bending stress. Each of these stress values remain below the appropriate ASME Code allowable stresses.

5.2.4.3 RPV Closure Flange Separation

As shown in Table 3, the stud out of service causes an additional flange separation at the o-ring of 0.0078 inch. This increase does not impact an ASME Code allowable. The flange separation is less than the o-ring minimum springback of 0.010 inch cited in Table 3-2 of Reference [1].

5.2.4.4 Fatigue

Per Table 3, the stud out of service increases the maximum stress at: (1) the head flange/shell by 0.24 ksi, (2) the vessel flange/shell by 0.47 ksi and (3) the stud by 0.97 ksi; each of these increases are approximately 1% of the previous design basis stress. According to Table 2-1 of Reference [1], the fatigue usage values in these components are as follows: (1) the head is 0.178, (2) the vessel is 0.679, and (3) the stud is 0.846. These fatigue usage values were calculated for the full service life of the component.

The impact of the 1% increase in stress for a single cycle of operation on these components is negligible. Referring to the fatigue curves in the design basis Code [7], Figures N-415A (vessel and head material) and N-416 (bolting material), it may be demonstrated for higher values of alternating stress that the number of allowable cycles is inversely proportional to the square of the increase in stress. Therefore, even if the components were operated for their full service life with the increase in stress resulting from one stud out of service, the increase in fatigue usage would be the square of the increase in stress, or $1.01^2 = 2\%$. The resulting values would remain below the Code allowable of 1.0.

5.2.4.5 Emergency and Faulted Conditions

Review of the design basis conditions evaluated in the original plant design basis report [2] demonstrates that, for the RPV closure flange components, meeting the ASME Code requirements for normal and upset conditions described in previous sections of this calculation bounds the requirements for emergency and faulted conditions. This is demonstrated on pages A-11 through A-30 of Reference [2] as follows:

- The emergency condition evaluated in Reference [2] is a vessel overpressure event. The evaluated pressure is 1,350 psia, or a factor of 1.08 greater than the normal condition design pressure, but the stress allowables for emergency conditions are 1.2 times the normal condition allowables.
- The faulted condition evaluated in Reference [2] is a pipe rupture event. The evaluated pressure is 1,000 psia, which is lower than the normal condition design pressure.

5.2.5 ANSYS Input Listings

The RPV closure flange stud tensioning analysis described in this section is performed using the ANSYS input listing files _HATCH2.runs, _MACROS.HATCH2, and MACROS.DEI. The _HATCH2.runs input listing defines parameters that are used by _MACROS.HATCH2 and MACROS.DEI to generate the geometry and run the stud out of service analysis cases. The input listings _HATCH2.runs and _MACROS.HATCH2 are provided in Appendix A.

MACROS.DEI is a proprietary input listing developed outside of the scope of this work. It is retained as an electronic file on a data disk [6] along with other software usage QA records required by the DEI QA program [4]. The contents of this data disk are listed in Appendix B. This data disk is retained with the project file for this task (Task 3944) and is available for on-site review by Southern Nuclear personnel.

5.3 Quality Assurance Software Controls

The RPV closure flange stud tensioning analysis described in this calculation was performed on the "ANSYS-A" Dell Precision R7910 workstation, using Windows Server 2012 R2 Standard 64-bit operating system and ANSYS Version 15.0 which was verified on February 6, 2017, as documented in Reference [3]. This software is maintained in accordance with the provisions for control of software described in Dominion Engineering, Inc.'s (DEI's) quality assurance (QA) program for safety-related nuclear work [4].[1] In addition to QA controls associated with the procurement and use of the ANSYS software (e.g., maintenance of the ANSYS Inc. as an approved supplier of the software based on formal auditing and surveillance; formal periodic verification of ANSYS software installation), QA controls associated with all ANSYS batch input listings are also carried out by DEI. These include independent checks of a batch input listing each time it is used; review of all ANSYS Class 3 error reports and QA notices to assess their potential impact on a batch input listing; and independent confirmatory analyses[2] to ensure that the project-specific application of the analysis is appropriate. The review of ANSYS error reports and QA notices as well as the project-specific check calculations are documented formally in a QA memo to project file [5].

The stud primary stress calculations performed in Table 2 were generated using Microsoft Excel 2010 on a Dell Latitude E7440 with an Intel Core i7 processor and running Microsoft Windows 7. The one-time-use Microsoft Excel spreadsheet "Hatch 2 Stud Primary Stress Calc v0.xlsx" was prepared, checked, and reviewed in accordance with DEI's nuclear QA program manual [4] and is archived on the data disk associated with this calculation [6].

6 REFERENCES

1. DEI Report R-3937-00-1, Rev. 0, "Reactor Vessel Tensioning Optimization Stress Report – Hatch Nuclear Plant Unit 2," January 2015.
2. "Analytical Report for Hatch No. 2 Reactor Vessel for Georgia Power Company," Combustion Engineering Report No. CENC-1232, April 1975.
3. Dominion Engineering, Inc. Software Test Report No. STR-9898-00-19, "ANSYS 15.0 Re-Verification Software Test Report." Revision 0, February 2017.
4. *Dominion Engineering, Inc. Quality Assurance Manual for Safety-Related Nuclear Work*, DEI-002. Revision 18, November 2010.
5. Dominion Engineering, Inc. Memorandum M-3944-00-01, Revision 0, "ANSYS Confirmatory Analysis and Review of Error Reports / QA Notices for C-3944-00-01, Rev. 0." February 2017.
6. Dominion Engineering, Inc. Data Disk D-3944-00-01, Revision 0, dated February 2017.

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[1] DEI's quality assurance program for safety-related work (DEI-002) commits to applicable requirements of 10 CFR 21, Appendix B of 10 CFR 50, and ASME/ANSI NQA-1. This QA program is independently audited periodically by both NUPIC (the Nuclear Procurement Issues Committee) and NIAC (the Nuclear Industry Assessment Committee).

[2] Confirmatory analyses for a given project may include comparison of model-computed stresses to theoretical closed-form solutions and other checks on model results.

7. ASME Boiler and Pressure Vessel Code, Section III – Rules for Construction of Nuclear Vessels, 1968 Edition with Addenda through Summer 1970.

Table 1. FEA Model Inputs

Parameter	Units	Hatch Unit 2
Stud and Vessel Parameters		
– Number of Studs	---	56
– Stud Shank OD	in	6.000
– Design Stud Stress Area in Shank	in^2	27.489
– Calculated Stud Moment of Inertia	in^4	63.568
– Membrane Stress, Preload Only	ksi	35.58
- Corresponding Elongation	in	0.038
– Design Pressure	psia	1,250
– Stud Effective Length	in	31.937
Tensioning Parameters		
– Max Tensioner Pressure (new)	psi	n/a
– Optimized Sequence Final Pressure (new)	psi	7,100
– Resulting Stud Stress	ksi	37.15
– Tensioner Coefficient, Kt	psi/in	5.232
Bolting Dimensions		
– Stud Circle Radius	in	117.313
– Stud Hole Diameter	in	6.750
– Spherical Washer Radius of Curvature	in	27.000
– Modulus Ratio in Hole Region	---	0.60
Vessel Flange Dimensions		
– Flange IR	in	109.690
– Inner O-ring Mean Radius	in	111.000
– Reaction Radius	in	113.250
– Seating Surface Outer Radius	in	113.750
– Flange OR	in	122.625
– Z dim to ID Transition	in	-18.000
– Z dim to OD transition	in	-14.500
Vessel Shell Dimensions		
– Shell IR	in	110.720
– Shell thickness	in	5.875
– Z dim to Bottom of Transition	in	-21.090
Head Flange Dimensions		
– Flange IR	in	109.250
– Flange OR	in	122.625
– Flange Top Fillet Radius	in	2.750
– Z dim to Top of Flange	in	24.375
– Z dim to Recess (inner)	in	0.375
– Z dim to Recess (outer)	in	0.375
Head Shell Dimensions		
– Shell IR	in	109.500
– Shell thickness	in	3.188
– Z dim to Head Coord. Sys.	in	-7.250

Table 2. Calculation of Primary Stresses in Reactor Vessel Studs, One Stud Out of Service

Design Pressure, P, psig	1,235	Bolt Circle Radius, Ro	117.313 in.
Inner o-ring Radius, Ri	111.000	Average force, Fbar	869.2 kips
Studs Out of Service	1	Neutral axis offset, d	2.133 in.
Stud Stress Area, A	27.489	Coefficient f	-274.6 psi/in
Number of Studs	56		

Stud	theta (deg)	cos(theta)	cos^2 (theta)	Fi (kip)	Stress (ksi)
1	-180	untensioned	untensioned	untensioned	untensioned
2	-174	-0.9937	0.99	901.8	32.80
3	-167	-0.9749	0.95	901.2	32.78
4	-161	-0.9439	0.89	900.2	32.75
5	-154	-0.9010	0.81	898.8	32.70
6	-148	-0.8467	0.72	897.0	32.63
7	-141	-0.7818	0.61	894.9	32.56
8	-135	-0.7071	0.50	892.5	32.47
9	-129	-0.6235	0.39	889.8	32.37
10	-122	-0.5320	0.28	886.9	32.26
11	-116	-0.4339	0.19	883.7	32.15
12	-109	-0.3303	0.11	880.4	32.03
13	-103	-0.2225	0.05	876.9	31.90
14	-96	-0.1120	0.01	873.4	31.77
15	-90	0.0000	0.00	869.7	31.64
16	-84	0.1120	0.01	866.1	31.51
17	-77	0.2225	0.05	862.6	31.38
18	-71	0.3303	0.11	859.1	31.25
19	-64	0.4339	0.19	855.8	31.13
20	-58	0.5320	0.28	852.6	31.02
21	-51	0.6235	0.39	849.7	30.91
22	-45	0.7071	0.50	847.0	30.81
23	-39	0.7818	0.61	844.6	30.72
24	-32	0.8467	0.72	842.5	30.65
25	-26	0.9010	0.81	840.7	30.58
26	-19	0.9439	0.89	839.3	30.53
27	-13	0.9749	0.95	838.3	30.50
28	-6	0.9937	0.99	837.7	30.48
29	0	1.0000	1.00	837.5	30.47
30	6	0.9937	0.99	837.7	30.48
31	13	0.9749	0.95	838.3	30.50
32	19	0.9439	0.89	839.3	30.53
33	26	0.9010	0.81	840.7	30.58
34	32	0.8467	0.72	842.5	30.65
35	39	0.7818	0.61	844.6	30.72
36	45	0.7071	0.50	847.0	30.81
37	51	0.6235	0.39	849.7	30.91
38	58	0.5320	0.28	852.6	31.02
39	64	0.4339	0.19	855.8	31.13
40	71	0.3303	0.11	859.1	31.25
41	77	0.2225	0.05	862.6	31.38
42	84	0.1120	0.01	866.1	31.51
43	90	0.0000	0.00	869.7	31.64
44	96	-0.1120	0.01	873.4	31.77
45	103	-0.2225	0.05	876.9	31.90
46	109	-0.3303	0.11	880.4	32.03
47	116	-0.4339	0.19	883.7	32.15
48	122	-0.5320	0.28	886.9	32.26
49	129	-0.6235	0.39	889.8	32.37
50	135	-0.7071	0.50	892.5	32.47
51	141	-0.7818	0.61	894.9	32.56
52	148	-0.8467	0.72	897.0	32.63
53	154	-0.9010	0.81	898.8	32.70
54	161	-0.9439	0.89	900.2	32.75
55	167	-0.9749	0.95	901.2	32.78
56	174	-0.9937	0.99	901.8	32.80

Table 3. Stress Increase Due to Stud Out of Service

			Shell Stresses (ksi) (2)						Stud Stresses (ksi)		Flange
	Stud	Load	Gen. Membrane		Local Memb.+Bend.		Maximum SI		Max	Memb+	Separation
Load Condition	Condition	Case	Head	Vessel	Head	Vessel	Head	Vessel	Membrane	Bending	(10^-3 in)
Preload Only	Normal	A1	0.07	0.28	23.82	18.11	24.60	18.48	37.10	81.56	14.7
Preload Only	1 Untensioned	B1	0.09	0.28	23.83	18.10	24.61	18.49	37.10	81.59	14.7
Preload Only	1 Failed	C1	0.09	0.28	23.82	18.11	24.60	18.48	40.06	81.58	14.7
Preload+Pressure	Normal	A2	22.13	23.49	36.93	34.17	37.02	33.94	34.91	97.92	21.2
Preload+Pressure	1 Untensioned	B2	22.13	23.49	37.12	34.52	37.21	34.31	37.34	97.98	29.1
Preload+Pressure	1 Failed	C2	22.13	23.49	37.17	34.63	37.26	34.41	39.30	98.89	26.6
Max. Increase from A2 (Cases B2 & C2)			0.00	0.00	0.24	0.46	0.24	0.47	4.40	0.97	7.8
Limiting Vessel Report Value (1)			22.50	23.80	28.10	28.20	64.00	47.40	45.30	95.40	--
New Maximum Value			**22.50**	**23.80**	**28.34**	**28.66**	**64.24**	**47.87**	**49.70**	**96.37**	–
Code Stress Limit			Sm = **26.7**	Sm = **26.7**	1.5 Sm = **40.1**	1.5 Sm = **40.1**	3.0 Sm = **80.1**	3.0 Sm = **80.1**	2 Sm = **73.5**	2.7 Sm = **99.2**	

(1) Value taken from R-3937-00-01 Rev 0 [1] or from Reference [2] as listed in Input 10.

(2) Local Membrane + Bending and Maximum SI taken at cut lines 2, 3, 4, 5, 6, and 7. General Membrane SI taken at cut lines 1 and 8. (See Figure 3).

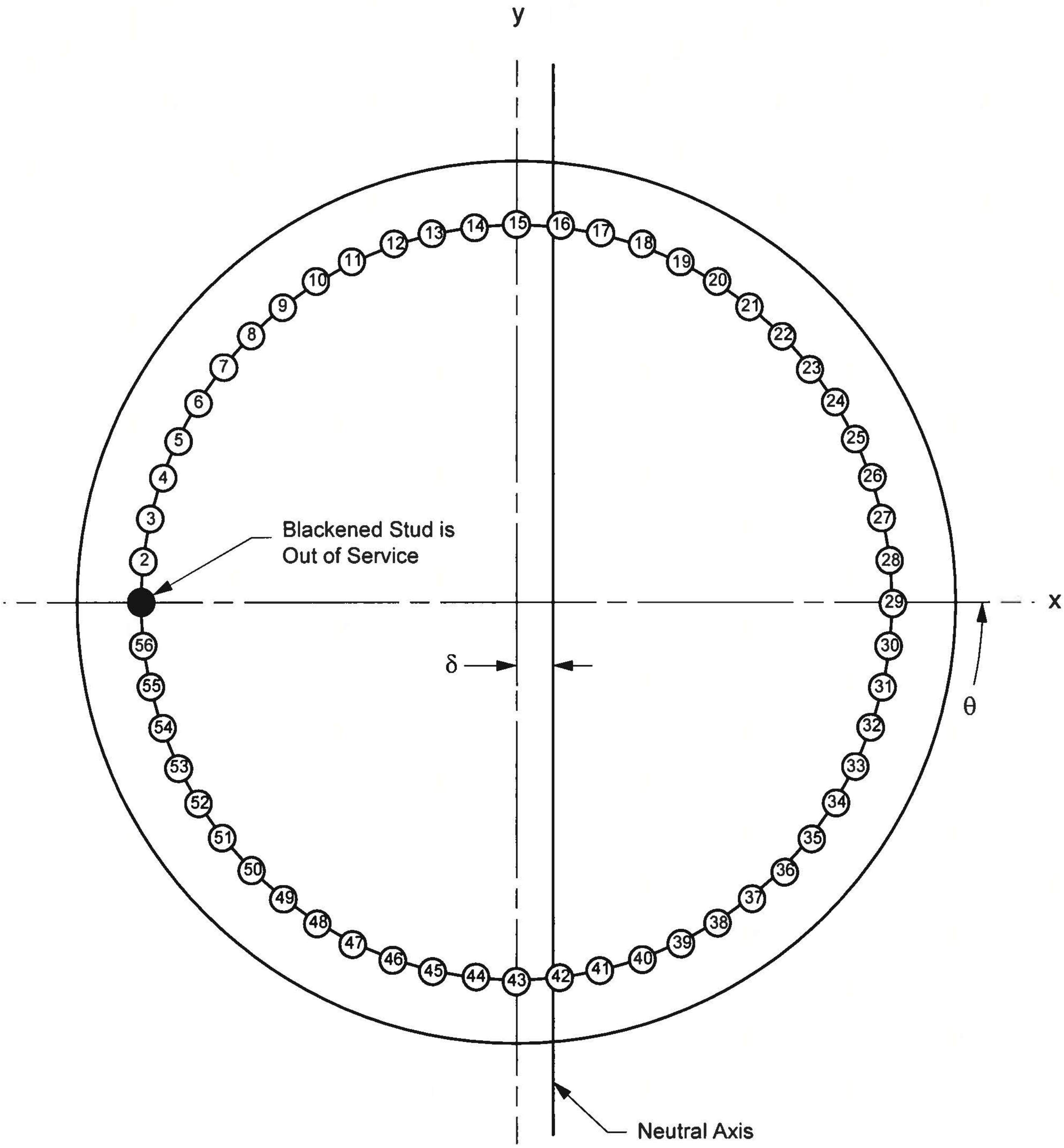

Figure 1. Reactor Vessel Head Stud Geometry, One Stud Out of Service

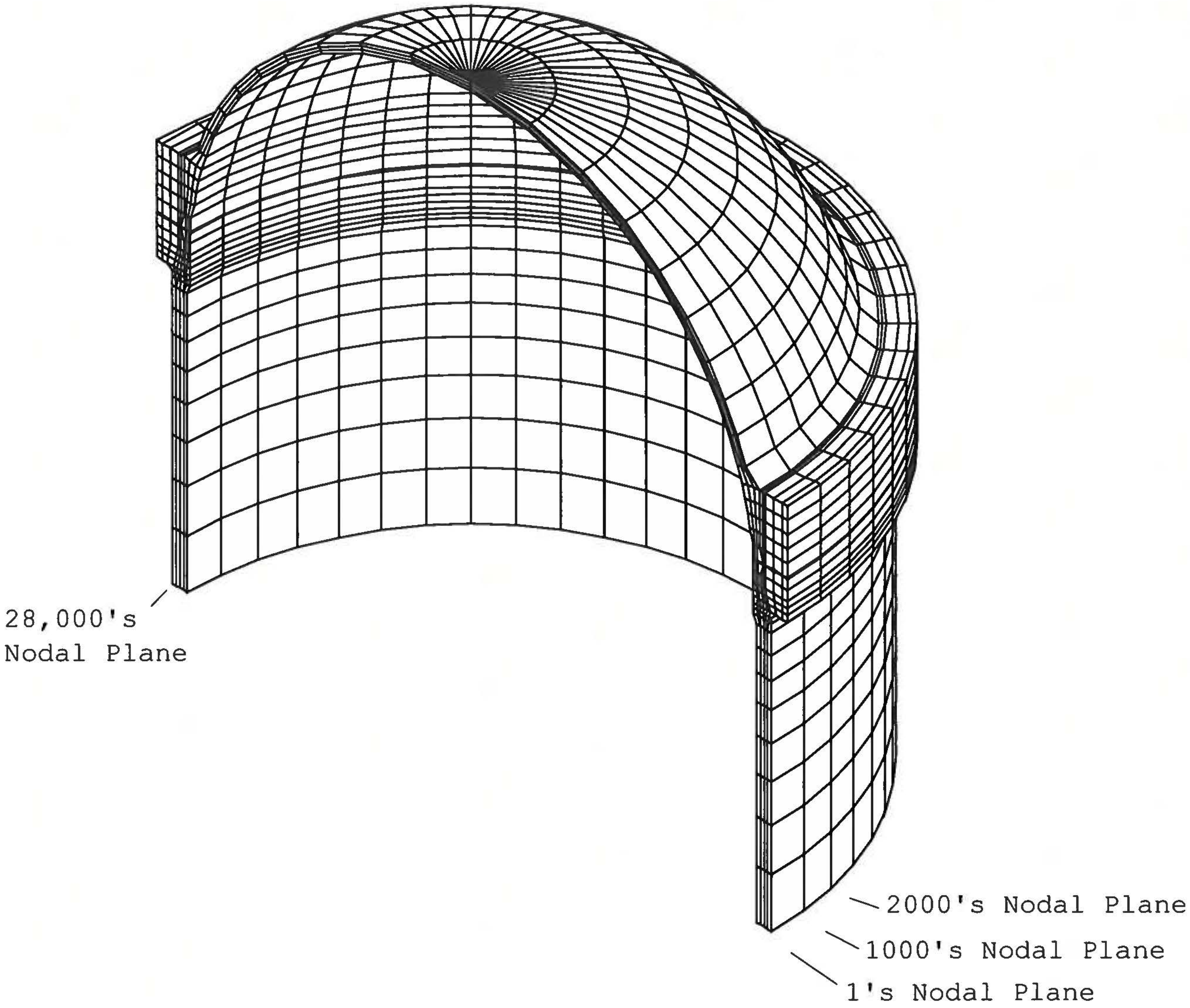

Figure 2. Hatch Unit 2 RPV Closure Flange FEA Model Overall View [1]

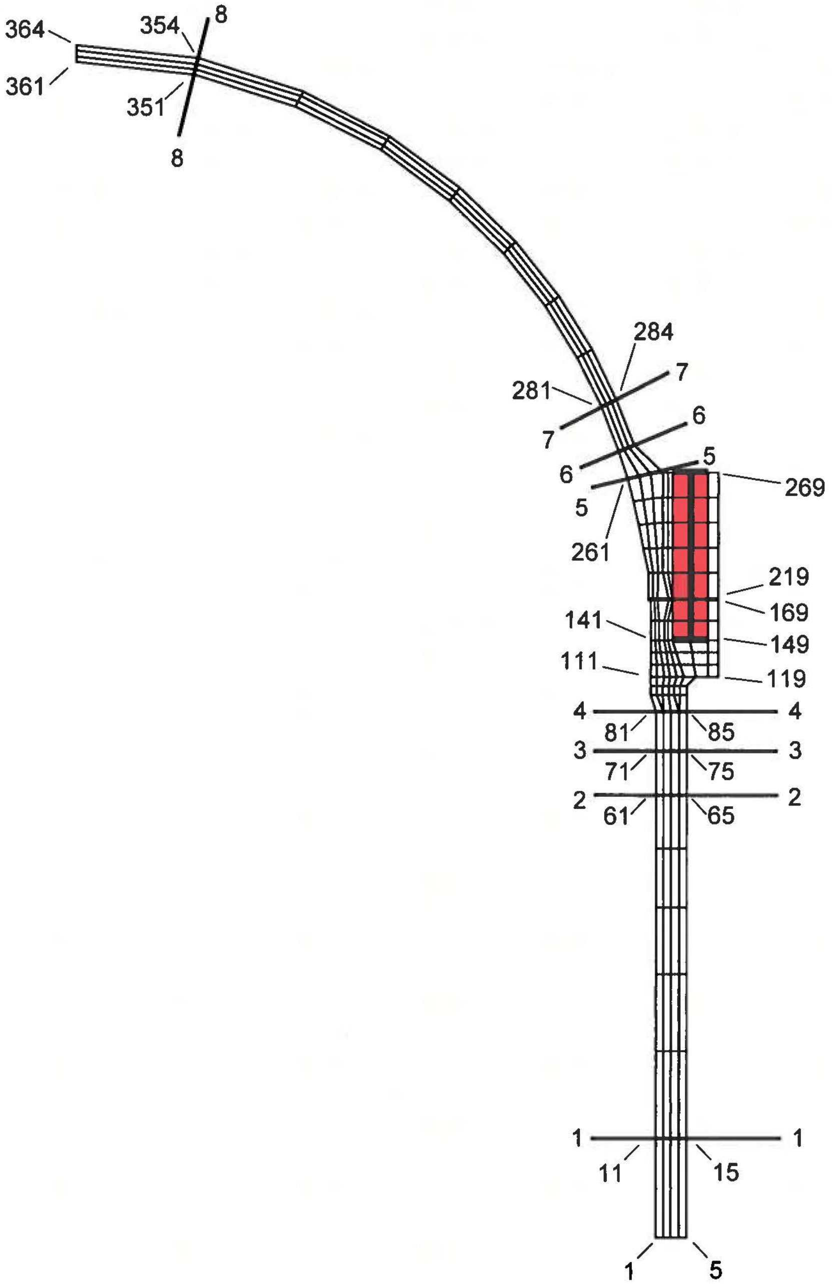

Figure 3. FEA Model Node Numbering and Section Cut Line Locations [1]

A FINITE ELEMENT ANALYSIS INPUT LISTINGS

A.1 File: _HATCH2.runs

```
/BATCH,LIST
/COM,
/COM, **********************************************************************************
/COM,     Hatch Unit 2 Stud Out of Service Evaluation
/COM, **********************************************************************************
/COM,
/INP,_MACROS,HATCH2
/INP,_MACROS,DEI
/COM,
/COM, **********************************************************************************
/COM,     PRE-RUN SETUP
/COM, **********************************************************************************
/COM,
/FILNAM,Tens-1
/SHOW,plots,grph
/TYPE,1,4
/PREP7
/TITLE, Hatch2 Reactor Vessel Tensioning
/COM, Define run parameters
NT = 56                              ! Total number of studs in model
NV = 56                              ! Total number of studs in real vessel
NPMAX = 56*3                         ! Max number of studs any sequence
TENSMX = 7                           ! Max number of Tens-* routines
XS = 37146                           ! Final stud stress target for old tensioner
XP = 7100                            ! Corresponding tensioner pressure
Pmax = 8500                          ! Tensioner pressure cap
X1 = 0.9994                          ! Empirical correction factor (init guess)
X2 = 0.9854                          ! Empirical correction factor (init guess)
Kt = XS*X1/XP                        ! Relate tensioner pressure to stud stress
RLMAX = NT+1                         ! Number of data items in RLIST (from ENDPOST macro)
*DIM,TENSAR,ARRAY,TENSMX,3
/COM,
*DIM,MPBTMPI,ARRAY,5
*DIM,MPBTMPC,ARRAY,5
*DIM,MPBTMPO,ARRAY,5
*DIM,TOTTMPI,ARRAY,5
*DIM,TOTTMPO,ARRAY,5
/COM,
/COM,  *** TOGGLE TENSIONING ROUTINES ***
/COM,
/COM,  To set tensioning routine I (Tens-I) to RUN, toggle TENSAR(I,1)=1
/COM   To set tensioning routine I (Tens-I) to OFF, toggle TENSAR(I,1)=0
/COM,  TENSAR(I,2) is number of cyclic symmetry slices (=1 for full model) for Tens-I
/COM,  TENSAR(I,3) is number of passes thru OPTLOOP for Tens-I (max of 7)
/COM,
TENSAR(1,1)=1             $TENSAR(1,2)=1           $TENSAR(1,3)=1
RUNMORF   = 1             ! RUNMORF=1 to run out of service stud cases
!
/COM,
*DIM,PLIST,ARRAY,NPMAX,4
*DIM,RLIST,ARRAY,NT,RLMAX
*DIM,RSAVE10,ARRAY,NV/2+1,RLMAX,6
/COM,
/COM,
/COM, **********************************************************************************
/COM,     GEOMETRY FIGURES
/COM, **********************************************************************************
/COM,
/COM, Make 1/2 model to lay down 'Appendix A' plots
NT = NV/2+1                         ! Total number of studs in model
/COM, Clear the boundary conditions and re-do the geometry.
/PREP7
```

```
*USE,GEOM,0                         ! Create geometry
/TITLE, Hatch2 Reactor Vessel Tensioning
/VIEW,1,1,1,1
ESEL,S,TYPE,,1
NSLE
/COLOR,NUM,BLAC,1
/TRIAD,OFF
/DIST,1,1.5*HFOR
/FOCUS,1,-HFOR/4,-65,-HFOR/2.1
EPLO
ESEL,S,ELEM,,41,290
ESEL,A,ELEM,,1041,1290
NSLE
/PNUM,MAT,1
/NUM,1
/AUTO
EPLO
ESEL,S,TYPE,,1
ESEL,R,ELEM,,1,1000
NSEL,S,NODE,,1,1000
/VIEW
EPLO
*DO,I,1,11
   /COLOR,NUM,WHIT,I
*ENDDO
/NUM
/PNUM,ELEM,1
ESEL,S,ELEM,,502,506
ESEL,A,ELEM,,1502,1506
*REPEAT,4,,,,1000,1000
NSLE
NSEL,U,NODE,,361,4361,1000
/VIEW,1,1,1,1
/AUTO
EPLO
/VIEW,1,-1,1,5
/NUM,2
ESEL,S,ELEM,,501
NSLE
EPLO
/USER
/DIST,1,5.75
ESEL,S,TYPE,,1
ESEL,A,ELEM,,501
NSLE
EPLO
ALLSEL
/AUTO
/COLOR,DEFA
/NUM
FINISH
/COM,
/COM,
/COM, *********************************************************************************
/COM,     TENSIONING ROUTINE 1: INITIALIZE MODEL
/COM, *********************************************************************************
/COM,
/COM,
/PREP7
NT = 10                             ! Total number of studs in model
*USE,GEOMCLUP
*USE,GEOM,0                         ! Create geometry
FINISH
/COM,
/COM, Do initial sets at final pressure to solve for X1 and X2
/COM, Tension all studs except in one set and then retension stud 10
PP = NT                             ! Number of studs in each set
NP = 2                              ! Number of sets in this sequence
TT = 1                              ! Number of sets to achieve one-pass tens.
*USE,ZEROIT
*DO,I,1,NT
   PLIST(I,1) = I                   ! Load PLIST column 1 with stud numbers
   PLIST(I,2) = XP                  ! Load PLIST column 2 with ref. tens. press.
*ENDDO
```

```
*DO,I,NT+1,NT*2
   PLIST(I,1) = 10                  ! Load PLIST column 1 with stud numbers
   PLIST(I,2) = XP                  ! Load PLIST column 2 with ref. tens. press.
   PLIST(I,4) = 1.0                 ! Load PLIST column 4 with retens. flag
*ENDDO
*IF,TENSAR(1,1),GT,0.5,THEN
   *USE,GOSOLV,'Hatch2','Tens-1',1  ! Solve model
   X1 = X1*XS/RLIST(10,3)           ! X1 is ref. stress/av. stud stress - single stud
   X2 = X1*XS/RLIST(1,3)            ! X2 is ref. stress/av. stud stress - all studs
   Kt = XS*X1/XP                    ! Relate tensioner pressure to stud stress
*ENDIF
/COM,
/COM,
/COM, ***********************************************************************************
/COM,     TENSIONING ROUTINE 10: RUN MISSING OR FAILED STUD CASES
/COM, ***********************************************************************************
/COM,
/COM,
/FILNAM,Tens-10
/COM, Change over to a half model for missing stud runs
/PREP7
*USE,GEOMCLUP
NT = NV/2+1                          ! Total number of studs in model
*USE,GEOM,0                          ! Create geometry
FINISH
Kt = XS*X2/XP                        ! Relate tensioner pressure to stud stress
/COM, Tension all studs in one pass
PP = NT                              ! Number of studs in each pass
NP = 1                               ! Number of passes
TT = 1                               ! Number of passes to achieve one-pass tens.
*USE,ZEROIT
*DO,I,1,PP
   PLIST(I,1) = I                    ! Load PLIST column 1 with stud numbers
   PLIST(I,2) = XP                   ! Load PLIST column 2 with ref. tens. press.
*ENDDO
*USE,GOSOLV,'Hatch2','Tens-10',1       ! Solve model - Case A1
SAVE,,A1
*DO,I,1,NT
   *DO,J,1,RLMAX
      RSAVE10(I,J,1) = RLIST(I,J)
   *ENDDO
*ENDDO
*USE,ZEROIT
I=1
*USE,PSOLV,'Hatch2','A2',2.0,1235      ! Solve model - Case A2
SAVE,,A2
*DO,I,1,NT
   *DO,J,1,RLMAX
      RSAVE10(I,J,2) = RLIST(I,J)
   *ENDDO
*ENDDO
*USE,ZEROIT
I=1
/COM, BEGIN SOLUTION PHASE
/SOLU
ANTYPE,STATIC,REST
SFDELE,ALL,ALL
EKILL,502
/TITLE, Hatch2 Reactor Vessel - Case C1 - Preload Only
TIME,3.0
SOLVE
FINISH
/POST1
SET,,,,,3.0
*USE,POSTER
*USE,ENDPOST
FINISH
SAVE,,C1
*DO,I,1,NT
   *DO,J,1,RLMAX
      RSAVE10(I,J,5) = RLIST(I,J)
   *ENDDO
*ENDDO
*USE,ZEROIT
```

```
I=1
*USE,PSOLV,'Hatch2','C2',4.0,1235       ! Solve model - Case C2
SAVE,,C2
*DO,I,1,NT
   *DO,J,1,RLMAX
      RSAVE10(I,J,6) = RLIST(I,J)
   *ENDDO
*ENDDO
/COM, Check for flange contact links which came out of compression
LCHG = 0
*DO,I,1,NT
   *IF,RLIST(I,10),GT,0,THEN
      LCHG = 1.0
      /PREP7
      EKILL,I*1000-499                ! EKILL 501 El. in row
      CPDELE,I
      CPDELE,100+I
      FINISH
   *ENDIF
*ENDDO
*IF,LCHG,EQ,1.0,THEN
   *USE,ZEROIT
   I=1
   *USE,PSOLV,'Hatch2','C2',5.0,1235   ! Re-Solve model - Case C2
   SAVE,,C2A
   *DO,I,1,NT
      *DO,J,1,RLMAX
         RSAVE10(I,J,6) = RLIST(I,J)
      *ENDDO
   *ENDDO
*ENDIF
/COM, Clear the boundary conditions and re-do the geom.
/PREP7
SFDELE,ALL,ALL
CPDELE,ALL,ALL
EDELE,ALL
NDELE,ALL
*USE,GEOM,0                           ! Create geometry
FINISH
/FILN,Tens-10B
/COM, Tension all studs in one pass except stud 1
PP = NT-1                             ! Number of studs in each pass
NP = 1                                ! Number of passes
TT = 1                                ! Number of passes to achieve one-pass tens.
*USE,ZEROIT
*DO,I,1,PP
   PLIST(I,1) = I+1                   ! Load PLIST column 1 with stud numbers
   PLIST(I,2) = XP                    ! Load PLIST column 2 with ref. tens. press.
*ENDDO
*USE,GOSOLV,'Hatch2','Tens-10B',1         ! Solve model - Case B1
SAVE,,B1
*DO,I,1,NT
   *DO,J,1,RLMAX
      RSAVE10(I,J,3) = RLIST(I,J)
   *ENDDO
*ENDDO
*USE,ZEROIT
I=1
*USE,PSOLV,'Hatch2','B2',2.0,1235       ! Solve model - Case B2
SAVE,,B2
*DO,I,1,NT
   *DO,J,1,RLMAX
      RSAVE10(I,J,4) = RLIST(I,J)
   *ENDDO
*ENDDO
/COM, Check for flange contact links which came out of compression
LCHG = 0
*DO,I,1,NT
   *IF,RLIST(I,10),GT,0,THEN
      LCHG = 1.0
      /PREP7
      EKILL,I*1000-499                ! EKILL 501 El. in row
      CPDELE,I
      CPDELE,100+I
```

```
         FINISH
      *ENDIF
   *ENDDO
   *IF,LCHG,EQ,1.0,THEN
      *USE,ZEROIT
      I=1
      *USE,PSOLV,'Hatch2','B2',3.0,1235    ! Re-Solve model - Case B2
      SAVE,,B2A
      *DO,I,1,NT
         *DO,J,1,RLMAX
            RSAVE10(I,J,4) = RLIST(I,J)
         *ENDDO
      *ENDDO
   *ENDIF
   /COM, Check again for flange contact links which came out of compression
   LCHG = 0
   *DO,I,1,NT
      *IF,RLIST(I,10),GT,0,THEN
         LCHG = 1.0
         /PREP7
         EKILL,I*1000-499               ! EKILL 501 El. in row
         CPDELE,I
         CPDELE,100+I
         FINISH
      *ENDIF
   *ENDDO
   *IF,LCHG,EQ,1.0,THEN
      *USE,ZEROIT
      I=1
      *USE,PSOLV,'Hatch2','B2',4.0,1235    ! Re-Solve model - Case B2
      SAVE,,B2B
      *DO,I,1,NT
         *DO,J,1,RLMAX
            RSAVE10(I,J,4) = RLIST(I,J)
         *ENDDO
      *ENDDO
   *ENDIF
   FINISH
   /COM, Clear the pressure boundary conditions
   /PREP7
   SFDELE,ALL,ALL
   FINISH
   *USE,ZEROIT
   *ENDIF
   /COM,
   /TITLE, Hatch2 Reactor Vessel Tensioning
   FINISH
   SAVE
   /COM,
   /COM, ***********************************************************************************
   /COM,     PRINT RESULTS
   /COM, ***********************************************************************************
   /COM,
   /COM, Print contents of PSAVE and RSAVE arrays
   /OUT,RESULTS,OUT
   /NOPR
   *IF,RUNMORF,EQ,1,THEN
      *USE,PRINTENS,'PSAVE10','RSAVE10',6,'Stud OOS',0
   *ENDIF
   /OUT
   /GOPR
   !
   FINISH
   /COM,
   /COM, ***********************************************************************************
   /COM,     RUN COMPLETE
   /COM, ***********************************************************************************
   /COM,
   /FILN,Tens-0
   PARSAV,ALL
   /COM, Do some file cleanup
   /SYS, del CMMAKER
   /SYS, del ENDPOST
   /SYS, del GEOM
```

```
/SYS, del GEOMCLUP
/SYS, del GODETEN
/SYS, del GOSOLV
/SYS, del OPTLOOP
/SYS, del POSTER
/SYS, del POSTER2
/SYS, del POSTER3
/SYS, del PRINTOLR
/SYS, del PRINTENS
/SYS, del PSOLV
/SYS, del READSI
/SYS, del ZEROIT
/SYS, del NPL
/SYS, del linrept
/SYS, del *.dbs
/SYS, del *.stat
/SYS, del *.osav
/SYS, del *.PCS
/SYS, del *.PVTS
/SYS, del *.BCS
/SYS, del *.full
/SYS, del file.log
/SYS, del Tens-1.*
/SYS, del Tens-10.e???
/EXIT
```

A.2 File: _MACROS.HATCH2

```
/COM, --------------- MACROS.HATCH2, Revision 1, Created February 2017  ----------------
/COM, ***********************************************************************************
/COM,
/COM,
/COM,
/COM, ***********************************************************************************
/COM, ***********************************************************************************
/COM,     CREATE GEOMETRY MACRO
/COM, -----------------------------------------------------------------------------------
/COM,
*CREATE,GEOM
/COM, -----------------------------------------------------------------
/COM,     GEOMETRY AND RUN PARAMETERS
/COM, -----------------------------------------------------------------
/COM, Loads and Material Properties
Esteel = 27.9E6                     ! Young's modulus (psi)
Ds     =  6.000                     ! Stud shank diameter (in)
As     = 27.489                     ! Stud area (in^2)
Is     = 63.568                     ! Stud mom. of I (in^4)
Ls     = 31.937                     ! Stud effective length (in)
Estud  = 29.9E6                     ! Tune Estud or Ls to get right effective L
/COM,
/COM, Bolting Dimensions
SCR    = 117.313                    ! Stud Circle Radius (in)
NDs    = 6.750                      ! Stud Hole diameter (in)
SWRC   = 27.00                      ! Spherical Washer Rad. of Curvature (in)
Ehole  = 0.60*Esteel                ! Derate in stud hole regions
/COM,
/COM, Vessel Flange Dimensions
VFIR   = 109.690                    ! Vessel flange inner radius (in)
! CBIR   = 0.000                     ! Core Barrel groove inner radius (in)
IORR   = 111.00                     ! Inner O-Ring radius (in)
SSOR   = 113.75                     ! Seating Surface outer radius (in)
RR     = 113.25                     ! >>> TUNE REACTION RADIUS <<<
VFOR   = 122.625                    ! Vessel flange outer radius (in)
! ZVFS   =  0.000                     ! Z dimension to vessel flange surface (in)
! ZBCB   =--0.000                     ! Z dimension to bottom of Core Barrel groove
ZVIT   =-18.00                      ! Z dim to vessel inside trans. (120's row)
ZVOT   =-14.50                      ! Z dim to vessel outside trans. (130's row)
/COM,
/COM, Vessel Shell Dimensions
VSIR   = 110.72                     ! Vessel shell inside radius
VSTH   =  5.875                     ! Vessel shell thickness
ZVTR   =-21.090                     ! Z dimension to bottom of vessel transition
/COM,
/COM, Head Flange Dimensions
HFIR   = 109.25                     ! Head flange inner radius
HFOR   = 122.625                    ! Head flange outer radius
HFFR   =  2.750                     ! Head flange top fillet radius
ZTHF   = 24.375                     ! Z dimension to top of head flange
ZHFRI  =  0.375                     ! Z dimension to head flange recess - inner
ZHFRO  =  0.375                     ! Z dimension to head flange recess - outer
! /COM,
! /COM, Head Shell Flange Transition
! RTCS   = 0.000                      ! Radial dimension to Transition Coordinate System
! ZTCS   = 0.000                      ! Z dimension to Transition Coordinate System
! IRTR   = 0.000                      ! Inner radius of transition area
! ZUIC   = 0.000                      ! Vertical rise of OD Transition
/COM,
/COM, Head Shell Dimensions
HSIR   = 109.50                     ! Head shell inner radius
HSTH   =  3.188                     ! Head shell thickness
ZHCS   = -7.250                     ! Z dimension to Head Coordinate System
AHT    = 19.0                       ! Approximate start of head shell region
/COM,
/COM,
/COM,
/COM,
At     = As/100                     ! Arbitrarily small tie bar area (in^2)
It     = Is*100                     ! Arbitrarily large tie bar mom. Of i (in^4)
```

```
Dt     = Ds*100                     ! Arbitrarily large tie bar diameter (in)
RLTH   = 0.005                      ! Reaction link thickness (in Z direction)
Ar     = As*100*(RLTH/Ls)           ! Reaction link area tuned for stiffness
!                                     100 times greater than stud (in^2)
/COM,
/COM,
/COM, -----------------------------------------------------------------
/COM,     MATERIAL PROPERTIES
/COM, -----------------------------------------------------------------
/COM, Set types, mats, and reals
/COM, Element types
ET,1,SOLID45                        ! Solids - vessel (no associated real props)
ET,2,LINK8                          ! Links - for reaction (REALS: AREA,ISTRN)
ET,3,BEAM4                          ! Beams - studs (A,IZZ,IYY,TKZ,TKY,THETA,ISTRN)
/COM,
/COM, Material properties
/COM, Material 1 for GENERAL USE
MP,EX,1,Esteel
MP,NUXY,1,0.30
/COM,
/COM, Material 2 for STUD ELEMENTS
MP,EX,2,Estud
MP,NUXY,2,0.30
/COM,
/COM, Material 3 for STUD HOLES
MP,EX,3,Ehole
MP,NUXY,3,0.30
/COM,
/COM, REAL PROPERTIES
/COM,
R,1,0                               ! Real 1: Dummy real for solid elements
R,2,Ar                              ! Real 2: Reaction links
R,3,Ar/2                            ! Real 3: Cutting plane reaction links
R,4,At,It,It,Dt,Dt,0                ! Real 4: Tie bars
R,5,At/2,It/2,It/2,Dt,Dt,0          ! Real 5: Cutting plane tie bars
R,11,As,Is,Is,Ds,Ds,0               ! Real 11:Stud elements
*REPEAT,NT,1                        ! Assign different reals to each stud
/COM,
/COM,
/COM, -----------------------------------------------------------------
/COM,     NODE DEFINITION
/COM, -----------------------------------------------------------------
/COM,
*AFUN,DEG
/COM, Establish coordinate systems
LOCAL,20,0,0,0                      ! Cartesian on lower mating surface
LOCAL,21,1,0,0,0,0,-90,0            ! Cylindrical on lower mating surface (z up)
! LOCAL,22,1,RTCS,ZTCS                ! Cylindrical system 1 for head curvature
LOCAL,23,1,0,ZHCS                   ! Cylindrical system 2 for head curvature
LOCAL,24,2,0,ZHCS                   ! Spherical system for head stresses
/COM,
/COM, Define keypoints on theta = 0 plane
CSYS,20
BOTZ=-100+ZVTR
N,1,VSIR,BOTZ                       ! SHELL I.R. AT BOTTOM OF MODEL
N,5,VSIR+VSTH,BOTZ                  ! SHELL O.R. AT BOTTOM OF MODEL
N,81,VSIR,BOTZ+100                  ! SHELL I.R. AT BOTTOM OF FLANGE
N,85,VSIR+VSTH,BOTZ+100             ! SHELL O.R. AT BOTTOM OF FLANGE
/COM,
/COM, DEFINE FEATURES ON MATING SURFACE
N,161,VFIR,0                        ! Flange inner surface
N,162,(VFIR+IORR)/2,0               ! "Core barrel groove inner surface"
N,163,IORR,0                        ! Inner o-ring radius
N,164,RR,0                          ! Reaction radius
N,165,SSOR,0                        ! Outer limit of seating surface
N,166,SCR-NDs/2,0                   ! Bolt hole inner edge
N,167,SCR,0                         ! Bolt circle
N,168,SCR+NDs/2,0                   ! Bolt hole outer edge
N,169,VFOR,0                        ! Flange outer surface
flwdth = HFOR-HFIR                  ! Flange width - head
flwdtv = VFOR-VFIR                  ! Flange width - vessel
iormo = RR-IORR                     ! Inner o-ring moment arm
/COM,
/COM, COPY FEATURES THROUGH VESSEL FLANGE
```

```
NGEN,2,-10,161,169,1,0,(ZTHF-Ls)/2  ! Copy mating surf. thru lower flange (150's)
NGEN,2,-20,161,169,1,0,ZTHF-Ls      ! Copy mating surf. thru lower flange (140's)
NGEN,2,-50,161,169,1,0,ZVOT         ! Make 110's row for O.D. feature
FILL,151,156,,,,2,-10               ! Even out 150's and 140's row
FILL,111,117
FILL,116,118
NGEN,2,-20,111,117,1,0,(ZVIT-ZVOT)  ! Make 90's row for I.D. feature
NMODIF,97,NX(85)
FILL,91,97
NGEN,2,10,91,97,1,0,-(ZVIT-ZVOT)/2  ! Make 100's row for transition
FILL,111,141,2,121,10,9,1
/COM,
/COM, FILL IN REST OF NODES IN VESSEL FLANGE
FILL,1,5
FILL,81,85
FILL,1,81,7,,,5,1,0.4               ! FILL IN VESSEL SHELL NODES
/COM,
/COM, ARRANGE HEAD FLANGE SURFACE NODES
CSYS,20
NGEN,2,40,161,169,1,0,RLTH          ! COPY LOWER MATING SURF. TO UPPER FLANGE
N,201,HFIR,RLTH                     ! HEAD FLANGE INNER SURFACE
FILL,201,203
NGEN,2,10,201,209,1,0,ZHFRI-RLTH    ! COPY UP THROUGH UPPER FLANGE
NGEN,6,10,211,219,1,0,((ZTHF-ZHFRI)/5)! COPY FIVE ROWS UP THROUGH UPPER FLANGE
FILL,221,226,,,,5,10                  ! ALIGN 220'S ROW
/COM,
/COM, MOVE HEAD SHELL IR NODES
CSYS,23
NMODIF,231,HSIR
*REPEAT,4,10
FILL,231,234,,,,4,10
/COM,
/COM, DEFINE NODES IN FREE HEAD
CSYS,23
N,361,HSIR,90                       ! TOP OF HEAD (INNER SURFACE)
N,364,HSIR+HSTH,90                  ! TOP OF HEAD (OUTER SURFACE)
N,271,HSIR,AHT                      ! LOCATE I.R. AT TOP OF FILLET RADIUS
N,274,HSIR+HSTH,AHT                 ! LOCATE O.R. AT TOP OF FILLET RADIUS
FILL,271,361,8,,,,,2.5              ! FILL IN HEAD INNER RADIUS
FILL,274,364,8,,,,,2.5              ! FILL IN HEAD OUTER RADIUS
FILL,251,254,,,,12,10               ! FILL IN INTERIOR HEAD NODES
/COM,
/COM, SWEEP OUT AROUND 360 DEGREES
CSYS,21
NGEN,NT+1,1000,ALL,,,0,360/NV,0     ! MAKE FULL SWEEP OF MODEL
NROTAT,ALL                          ! BRING CS'S INTO ACTIVE CS
/COM,
/COM, ------------------------------------------------------------------
/COM,     ELEMENT DEFINITION
/COM, ------------------------------------------------------------------
/COM,
/COM, _____________________________________
/COM, MAKE SOLID ELEMENTS
TYPE,1
MAT,1
REAL,1
EN,1,1,2,12,11,1001,1002,1012,1011
ENGEN,1,4,1,1,1,1                   ! SWEEP ACROSS BOTTOM ROW
ENGEN,10,8,10,1,4,1                 ! SWEEP UP TO BOTTOM OF FLANGE
SHPP,OFF                            ! TEMPORARILY TURN OFF SHAPE WARNINGS
EN,81,81,82,92,91,1081,1082,1092,1091
EN,82,82,93,92,92,1082,1093,1092,1092
EN,83,82,83,94,93,1082,1083,1094,1093
ENGEN,1,2,1,83
EN,85,84,96,95,95,1084,1096,1095,1095
EN,86,84,85,97,96,1084,1085,1097,1096
!
EN,91,91,92,102,101,1091,1092,1102,1101
ENGEN,1,6,1,91                      ! make 91 - 96
ENGEN,10,2,10,91,96,1               ! make 101 - 106
ENGEN,10,2,10,101                   ! MAKE 111
ENGEN,1,8,1,111,111,1               ! SWEEP RIGHT TO MAKE 112 - 118
ENGEN,10,5,10,111,118
/COM,
```

```
EN,201,201,202,212,211,1201,1202,1212,1211      ! MAKE 201
ENGEN,1,4,1,201,201,1               ! SWEEP RIGHT TO MAKE 202 TO 204
ENGEN,10,2,10,201,201,1             ! SWEEP UP TO MAKE 211
ENGEN,1,8,1,211,211,1               ! SWEET RIGHT TO MAKE 212 TO 218
ENGEN,10,5,10,211,218,1             ! SWEEP UP TO TOP OF FLANGE
ENGEN,10,10,10,251,253,1            ! SWEEP THROUGH SHELL
EN,351,351,1351,1361,361,352,1352,1362,362      ! MAKE 351
ENGEN,1,3,1,351,351,1               ! FIX UP LAST ROW
/COM,
/COM,
/COM, ASSIGN BOLT HOLE REGION
ESEL,S,ELEM,,146,500,10             ! SELECT INNER SIDE OF BOLT HOLE
ESEL,A,ELEM,,147,500,10             ! SELECT OUTER SIDE OF BOLT HOLE
EMODIF,ALL,MAT,3                    ! ASSIGN BOLT HOLE DIFFERENT MATERIAL
ESEL,ALL
ENGEN,1000,NT,1000,ALL              ! COPY AROUND CIRCLE
/COM,
/COM, _____________________________________
/COM, MAKE LINE ELEMENTS FOR STUD
TYPE,2
REAL,2
EN,501,164,204                      ! REACTION FORCE LINK
TYPE,3
REAL,11
MAT,2
EN,502,147,267,361                  ! STUD
/COM,
/COM, _____________________________________
/COM, MAKE LINE ELEMENTS FOR TIE BARS
REAL,4
MAT,1
EN,503,146,147,207
EN,504,147,148,207
EN,505,266,267,207
EN,506,267,268,207                  ! TIE BARS
EN,507,162,163,204
EN,508,163,164,204
EN,509,164,165,204
EN,510,202,203,164
EN,511,203,204,164
EN,512,204,205,164                  ! REACTION SURFACE
ENGEN,1000,NT,1000,501,512,1        ! COPY REST OF WAY THROUGH
/COM,
/COM, _____________________________________
/COM, ASSIGN INDIVIDUAL REAL PROPERTIES TO EACH STUD
/COM, STUD REAL IS STUD NO. + 10
*DO,I,1,NT
    ESEL,S,ELEM,,I*1000-498
    EMODIF,ALL,REAL,I+10
*ENDDO
ESEL,ALL
/COM,
/COM, _____________________________________
/COM, DO SOME NODAL CLEANUP
NSLE,U
NDELE,ALL                           ! DELETE UNUSED NODES
NSEL,ALL
NUMMRG,NODE,0.001                   ! MERGE OVERLAPPING NODES
/COM,
/COM,
/COM, -----------------------------------------------------------------
/COM,     APPLY BOUNDARY CONDITIONS
/COM, -----------------------------------------------------------------
/COM,
CSYS,21
/COM, _____________________________________
/COM, COUPLE UPPER AND LOWER FLANGE AT REACTION RADIUS
CP,1,UX,164,204                     ! COUPLE IN X AXIS
CPSGEN,NT,1000,1,1,1                ! SWEEP UX SET AROUND CIRCLE
CP,101,UY,164,204                   ! COUPLE IN Y AXIS
CPSGEN,NT,1000,101,101,1            ! SWEEP UY SET AROUND CIRCLE
/COM, APPLY DISPLACEMENT BOUNDARY CONDITIONS
NSEL,S,LOC,Z,BOTZ                   ! SELECT BOTTOM OF MODEL
D,ALL,UY                            ! APPLY ZERO VERT DISP
```

```
D,ALL,UZ                             ! APPLY ZERO VERT DISP
NSEL,ALL
ESEL,S,REAL,,4                       ! SELECT TIE BAR ELEMENTS
NSLE                                 ! SELECT TIE BAR NODES
NSEL,U,NODE,,207,99207,1000          ! DESELECT CENTER
NSEL,U,NODE,,361                     ! DESELECT TOP OF FLANGE
D,ALL,ROTX,0,0,,,ROTZ                ! HOLD ROTATIONS ON TIE BARS
ESEL,ALL
NSEL,ALL
/COM,
/COM, ______________________________________
/COM, APPLY PRYING FORCES DUE TO CORE BARREL SPRING AND CORE SUPPORT LOAD
*IF,Fspr+Fcsl,GT,1.0,THEN
*DO,I,1,NT
   F,131+(I-1)*1000,FZ,-(Fspr+Fcsl)/2
   F,132+(I-1)*1000,FZ,-(Fspr+Fcsl)/2
   F,201+(I-1)*1000,FZ,+Fspr/2
   F,202+(I-1)*1000,FZ,+Fspr/2
*ENDDO
*ENDIF
/COM,
/COM, ______________________________________
/COM, PUT SPECIAL BOUNDARY CONDITIONS ON VESSEL FOR PARTIAL MODELS
*IF,NT,LT,NV,THEN
   *IF,ARG1,LT,0.5,THEN          ! USE MIRROR SYMMETRY B.C.s
      /COM, DELETE EXTRA ELEMENTS AND NODES BEYOND LAST STUD
      EDELE,(NT-1)*1000+1,(NT-1)*1000+499
      /COM, DO SOME NODAL CLEANUP
      NSLE,U
      NDELE,ALL
      NSEL,ALL
      /COM, CHANGE REALS ON CUTTING PLANES
      ESEL,S,ELEM,,501
      ESEL,A,ELEM,,501+(NT-1)*1000
      EMODIF,ALL,REAL,3
      ESEL,S,ELEM,,503,512
      ESEL,A,ELEM,,503+(NT-1)*1000,512+(NT-1)*1000
      EMODIF,ALL,REAL,5
      ESEL,ALL
      NSEL,S,NODE,,1,1000
      NSEL,A,NODE,,1+(NT-1)*1000,NT*1000
      NSEL,U,NODE,,204,99204,1000
      D,ALL,UY
      NSEL,ALL
     *IF,Fspr+Fcsl,GT,1.0,THEN
      F,131,FZ,-(Fspr+Fcsl)/4
      F,132,FZ,-(Fspr+Fcsl)/4
      F,201,FZ,+Fspr/4
      F,202,FZ,+Fspr/4
      F,131+(NT-1)*1000,FZ,-(Fspr+Fcsl)/4
      F,132+(NT-1)*1000,FZ,-(Fspr+Fcsl)/4
      F,201+(NT-1)*1000,FZ,+Fspr/4
      F,202+(NT-1)*1000,FZ,+Fspr/4
      *ENDIF
   *ELSE                       ! USE CYCLIC SYMMETRY B.C.s
      /COM, GET RID OF EXCESS ELEMENTS
      EDELE,(NT-1)*1000+1,(NT-1)*1000+350
      /COM, SWING LAST PLANE AROUND TO 0 DEGREES
      NSEL,S,NODE,,NT*1000+1,(NT+1)*1000
      CSYS,21
      NMODIF,ALL,,0
      NSEL,A,NODE,,1,1000
      NSEL,U,NODE,,164,204,40
      NROTATE,ALL
      CPINTF,ALL,0.001
      NSEL,S,NODE,,NT*1000+1,(NT+1)*1000
      NMODIF,ALL,,NT*360/NV
      NSEL,ALL
      NROTATE,ALL
      /COM, BRING BACK LAST PLANE OF ELS.
      ENGEN,(NT-1)*1000,2,(NT-1)*1000,1,350,1                ! COPY AROUND CIRCLE
      /COM, FIX UP COUPLES ON EDGE PLANES
      CP,1,,NT*1000+164,NT*1000+204
      CP,101,,NT*1000+164,NT*1000+204
```

```
      CP,1501,UZ,164,NT*1000+164
      CP,1502,UZ,204,NT*1000+204
   *ENDIF
*ENDIF
/COM, Define a few components for later use
*USE,CMMAKER,201,500,'NHEAD','EHEAD'
*USE,CMMAKER,1,200,'NVESSEL','EVESSEL'
*USE,CMMAKER,221,500,'NHEADR','EHEADR'
!
/COM, Define pressure surfaces for PSOLV macro
NSEL,S,NODE,,1,99999,10
/COM, Select additional nodes which form crevice between flanges out to the
/COM,    inner o-ring
NSEL,A,NODE,,161,99999,1000
NSEL,A,NODE,,162,99999,1000
NSEL,A,NODE,,163,99999,1000
NSEL,A,NODE,,201,99999,1000
NSEL,A,NODE,,202,99999,1000
NSEL,A,NODE,,203,99999,1000
CM,PSURF,NODE
NSEL,ALL
!
SHPP
CHECK
*END
/COM,
/COM, ----------------------------------------------------------------------------------
/COM,     END GEOMETRY MACRO
/COM, **********************************************************************************
/COM, **********************************************************************************
/COM,
/COM,
/COM,
/COM, **********************************************************************************
/COM, **********************************************************************************
/COM,     CREATE CMMAKER MACRO
/COM, ----------------------------------------------------------------------------------
/COM,
*CREATE,CMMAKER
   NSEL,NONE
   ESEL,NONE
   *DO,I,0,(NT-1)*1000,1000
       NSEL,A,NODE,,ARG1+I,ARG2+I
       *IF,I,EQ,(NT-1)*1000,THEN
          *IF,NT,LT,NV,EXIT
       *ENDIF
       ESEL,A,ELEM,,ARG1+I,ARG2+I
   *ENDDO
   CM,ARG3,NODE
   CM,ARG4,ELEM
   NSEL,ALL
   ESEL,ALL
*END
/COM,
/COM, ----------------------------------------------------------------------------------
/COM,     END CMMAKER MACRO
/COM, **********************************************************************************
/COM, **********************************************************************************
/COM,
/COM,
/COM,
/COM, **********************************************************************************
/COM, **********************************************************************************
/COM,     CREATE GEOMCLUP MACRO
/COM, ----------------------------------------------------------------------------------
/COM,
*CREATE,GEOMCLUP
   CPDELE,ALL,ALL
   CMDELE,NHEAD
   CMDELE,EHEAD
   CMDELE,NVESSEL
   CMDELE,EVESSEL
   CMDELE,NHEADR
   CMDELE,EHEADR
```

```
   EDELE,ALL
   NDELE,ALL
*END
/COM,
/COM, ---------------------------------------------------------------------------------
/COM,     END CMMAKER MACRO
/COM, *********************************************************************************
/COM, *********************************************************************************
/COM,
/COM,
/COM,
/COM, *********************************************************************************
/COM, *********************************************************************************
/COM,     CREATE ENDPOST MACRO
/COM, ---------------------------------------------------------------------------------
/COM, RLIST columns as follows:
/COM,     RLIST(J,1) = Flange Displ. last pass
/COM,     RLIST(J,2) = Stud Initial Elongation Real Constant
/COM,     RLIST(J,3) = Stud Final Membrane Stress
/COM,     RLIST(J,4) = Stud Max. Membrane+Bending Stress
/COM,     RLIST(J,5) = Maximum Membrane Stress during any pass
/COM,     RLIST(J,6) = Pass Number at which Max. Membrane Stress Occurs
/COM,
/COM,     RLIST(J,7) = Angular Rotation of Upper Flange (radians)
/COM,     RLIST(J,8) = Angular Rotation of Lower Flange (radians)
/COM,     RLIST(J,9) = Inner O-ring separation
/COM,
/COM,     RLIST(J,10) = Force on Contact Link Element
/COM,     RLIST(J,11) = Global X Shear Force on Coupled Set
/COM,     RLIST(J,12) = Global Y Shear Force on Coupled Set
/COM,
/COM,     RLIST(J,13) = Mu Required to Prevent Flange Mating Surf. Slide
/COM,     RLIST(J,14) = Mu Required to Prevent Flange Stud Washer Slide
/COM,
/COM, Cut Plane Stress Intensities:
/COM,   Line 1 - Vessel Far Field Cut Plane (RLIST(J,15) to RLIST(J,19))
/COM,     RLIST(J,15) = Linearized SI at Inner Surface
/COM,     RLIST(J,16) = Linearized SI at Center of Surface (Membrane SI)
/COM,     RLIST(J,17) = Linearized SI at Outer Surface
/COM,     RLIST(J,18) = Total SI at Inner Surface
/COM,     RLIST(J,19) = Total SI at Outer Surface
/COM,
/COM,   Line 2 - Vessel Local Cut Plane - Lower   (RLIST(J,20) to RLIST(J,24))
/COM,   Line 3 - Vessel Local Cut Plane - Middle  (RLIST(J,25) to RLIST(J,29))
/COM,   Line 4 - Vessel Local Cut Plane - Upper   (RLIST(J,30) to RLIST(J,34))
/COM,   Line 5 - Head Local Cut Plane - Lower     (RLIST(J,35) to RLIST(J,39))
/COM,   Line 6 - Head Local Cut Plane - Middle    (RLIST(J,40) to RLIST(J,44))
/COM,   Line 7 - Head Local Cut Plane - Upper     (RLIST(J,45) to RLIST(J,49))
/COM,   Line 8 - Head Far Field Cut Plane         (RLIST(J,50) to RLIST(J,54))
/COM,
*CREATE,ENDPOST
/COM, Finish by loading results in RLIST
*DO,J,1,NT
   ENUMB = J*1000-498                            ! El. no. of subject element
   *GET,RLIST(J,3),ELEM,ENUMB,ETAB,MEMBSTRS      ! El. membrane stress
   *GET,DUMBOT,ELEM,ENUMB,ETAB,MAXM+BI           ! El. membrane+bend stress (I)
   *GET,DUMTOP,ELEM,ENUMB,ETAB,MAXM+BJ           ! El. membrane+bend stress (J)
   RLIST(J,4) = DUMBOT > DUMTOP
   /COM,
   RSYS,21
   NNUM1 = (J-1)*1000+131                        ! Node 131
   NNUM2 = (J-1)*1000+139                        ! Node 139
   NNUM3 = (J-1)*1000+211                        ! Node 211
   NNUM4 = (J-1)*1000+219                        ! Node 219
   RLIST(J,7) = (UZ(NNUM4)-UZ(NNUM3))/flwdth     ! Upper Flange Rotation (radians)
   RLIST(J,8) = (UZ(NNUM2)-UZ(NNUM1))/flwdtv     ! Lower Flange Rotation (radians)
   NNUM1 = (J-1)*1000+164
   NNUM2 = (J-1)*1000+204
   RLIST(J,9) = UZ(NNUM2)-UZ(NNUM1)+iormo*(RLIST(J,8)-RLIST(J,7))
   /COM,
   ENUMB = (J-1)*1000+501                        ! El. no. 501
   *GET,RLIST(J,10),ELEM,ENUMB,ETAB,FORCE        ! El. Force
   CMSEL,S,EHEAD
   NSEL,S,NODE,,(J-1)*1000+204
```

```
   FSUM
   ESEL,ALL
   NSEL,ALL
   *GET,RLIST(J,11),FSUM,,ITEM,FX                ! Global X-Shear Force
   *GET,RLIST(J,12),FSUM,,ITEM,FZ                ! Global Z-Shear Force
   ! RLIST(J,13) is resultant shear divided by link membrane force
   *IF,RLIST(J,10),LT,-1.0,THEN
      RLIST(J,13) = -SQRT(RLIST(J,11)**2+RLIST(J,12)**2)/RLIST(J,10)
   *ELSE
      RLIST(J,13) = -1                           ! Trap divide by zero
   *ENDIF
   SLIPCNST = 2*Is/(Ds*SWRC*As)                  ! Constants in washer slip calc
   *IF,RLIST(J,3),GT,1.0,THEN
      RLIST(J,14) = SLIPCNST*(RLIST(J,4)-RLIST(J,3))/RLIST(J,3)
   *ELSE
      RLIST(J,14) = -1                           ! Trap divide by zero
   *ENDIF
   /COM,
   /COM, Cut Lines:
   *USE,READSI,11,15,21,15,J                     ! Cut 1: Nodes 11 to 15 in CSYS 21
   *USE,READSI,61,65,21,20,J                     ! Cut 2: Nodes 61 to 65 in CSYS 21
   *USE,READSI,71,75,21,25,J                     ! Cut 3: Nodes 71 to 75 in CSYS 21
   *USE,READSI,81,85,21,30,J                     ! Cut 4: Nodes 81 to 85 in CSYS 21
   *USE,READSI,261,264,24,35,J                   ! Cut 5: Nodes 261 to 261 in CSYS 24
   *USE,READSI,271,274,24,40,J                   ! Cut 6: Nodes 271 to 274 in CSYS 24
   *USE,READSI,281,284,24,45,J                   ! Cut 7: Nodes 281 to 284 in CSYS 24
   *USE,READSI,351,354,24,50,J                   ! Cut 8: Nodes 351 to 354 in CSYS 24
*ENDDO
*END
/COM, -----------------------------------------------------------------------------------
/COM,     END ENDPOST MACRO
/COM, ***********************************************************************************
/COM, ***********************************************************************************
/COM,
/COM,
/COM,
/COM, ***********************************************************************************
/COM, ***********************************************************************************
/COM,     CREATE PRINTENS MACRO
/COM, -----------------------------------------------------------------------------------
/COM,
/COM, PRINTENS arguments as follows:
/COM,    ARG1 = PSAVE Text
/COM,    ARG2 = RSAVE Text
/COM,    ARG3 = Loop Ending No.
/COM,    ARG4 = Free Text Field (e.g., 'Existing')
/COM,    ARG5 = Sequence Print Flag (1 = Print Sequence)
/COM,
*CREATE,PRINTENS
*DO,K,1,ARG3
   !
   *VWRITE,K
   ('-----',/,'Tensioning Sequence Iteration ',F2.0)
   !
   *VWRITE,ARG4
   ('-----',/,A,' Procedure Results -')
   *VWRITE
   (2/,'Stud Stress Summary',/)
   *VSCFUN,MAXCOL1,MAX, %ARG2%(1, 3,K)
   *VSCFUN,MINCOL1,MIN, %ARG2%(1, 3,K)
   *VSCFUN,AVECOL1,MEAN,%ARG2%(1, 3,K)
   *VSCFUN,MAXCOL2,MAX, %ARG2%(1, 4,K)
   *VSCFUN,MINCOL2,MIN, %ARG2%(1, 4,K)
   *VSCFUN,AVECOL2,MEAN,%ARG2%(1, 4,K)
   *VSCFUN,MAXCOL3,MAX, %ARG2%(1, 5,K)
   *VSCFUN,MINCOL3,MIN, %ARG2%(1, 5,K)
   *VSCFUN,AVECOL3,MEAN,%ARG2%(1, 5,K)
   *VSCFUN,MAXCOL4,MAX, %ARG2%(1,14,K)
   *VSCFUN,MINCOL4,MIN, %ARG2%(1,14,K)
   *VSCFUN,AVECOL4,MEAN,%ARG2%(1,14,K)
   !
   /COM,            MEMBRANE   MEMB+BEND    MAX. MEM.     REQUIRED
   /COM,             STRESS      STRESS       STRESS      WASHER MU
   !
```

```
*VWRITE,'MAXIMUM',MAXCOL1,MAXCOL2,MAXCOL3,MAXCOL4
(A7,3X,3(F9.0,3X),3X,F7.4)
*VWRITE,'MINIMUM',MINCOL1,MINCOL2,MINCOL3,MINCOL4
(A7,3X,3(F9.0,3X),3X,F7.4)
*VWRITE,'AVERAGE',AVECOL1,AVECOL2,AVECOL3,AVECOL4
(A7,3X,3(F9.0,3X),3X,F7.4)
!
*VWRITE
(2/,'Head and Head Flange Cut Planes Stress Summary',/)
!
*VSCFUN,AVECOL1,MEAN,%ARG2%(1,51,K)
*VWRITE,AVECOL1
('General Membrane Stress Intensity             ',F6.0)
!
*VSCFUN,MAXCOL1,MAX,%ARG2%(1,36,K)
*VSCFUN,MAXCOL2,MAX,%ARG2%(1,41,K)
*VSCFUN,MAXCOL3,MAX,%ARG2%(1,46,K)
MAXCOL4 = MAXCOL1 > MAXCOL2 > MAXCOL3
*VWRITE,MAXCOL4
('Maximum Local Membrane Stress Intensity       ',F6.0)
!
*VSCFUN,MAXCOL1,MAX,%ARG2%(1,35,K)
*VSCFUN,MAXCOL2,MAX,%ARG2%(1,40,K)
*VSCFUN,MAXCOL3,MAX,%ARG2%(1,45,K)
MAXCOL4 = MAXCOL1 > MAXCOL2 > MAXCOL3
*VSCFUN,MINCOL1,MAX,%ARG2%(1,37,K)
*VSCFUN,MINCOL2,MAX,%ARG2%(1,42,K)
*VSCFUN,MINCOL3,MAX,%ARG2%(1,47,K)
MINCOL4 = MINCOL1 > MINCOL2 > MINCOL3
*VWRITE,MAXCOL4 > MINCOL4
('Maximum Local Mem + Bend Stress Intensity     ',F6.0)
!
*VSCFUN,MAXCOL1,MAX,%ARG2%(1,38,K)
*VSCFUN,MAXCOL2,MAX,%ARG2%(1,43,K)
*VSCFUN,MAXCOL3,MAX,%ARG2%(1,48,K)
MAXCOL4 = MAXCOL1 > MAXCOL2 > MAXCOL3
*VSCFUN,MINCOL1,MAX,%ARG2%(1,39,K)
*VSCFUN,MINCOL2,MAX,%ARG2%(1,44,K)
*VSCFUN,MINCOL3,MAX,%ARG2%(1,49,K)
MINCOL4 = MINCOL1 > MINCOL2 > MINCOL3
*VWRITE,MAXCOL4 > MINCOL4
('Maximum Local Stress Intensity                ',F6.0)
!
*VWRITE
(2/,'Vessel and Vessel Flange Cut Planes Stress Summary',/)
!
*VSCFUN,AVECOL1,MEAN,%ARG2%(1,16,K)
*VWRITE,AVECOL1
('General Membrane Stress Intensity             ',F6.0)
!
*VSCFUN,MAXCOL1,MAX,%ARG2%(1,21,K)
*VSCFUN,MAXCOL2,MAX,%ARG2%(1,26,K)
*VSCFUN,MAXCOL3,MAX,%ARG2%(1,31,K)
MAXCOL4 = MAXCOL1 > MAXCOL2 > MAXCOL3
*VWRITE,MAXCOL4
('Maximum Local Membrane Stress Intensity       ',F6.0)
!
*VSCFUN,MAXCOL1,MAX,%ARG2%(1,20,K)
*VSCFUN,MAXCOL2,MAX,%ARG2%(1,25,K)
*VSCFUN,MAXCOL3,MAX,%ARG2%(1,30,K)
MAXCOL4 = MAXCOL1 > MAXCOL2 > MAXCOL3
*VSCFUN,MINCOL1,MAX,%ARG2%(1,22,K)
*VSCFUN,MINCOL2,MAX,%ARG2%(1,27,K)
*VSCFUN,MINCOL3,MAX,%ARG2%(1,32,K)
MINCOL4 = MINCOL1 > MINCOL2 > MINCOL3
*VWRITE,MAXCOL4 > MINCOL4
('Maximum Local Mem + Bend Stress Intensity     ',F6.0)
!
*VSCFUN,MAXCOL1,MAX,%ARG2%(1,23,K)
*VSCFUN,MAXCOL2,MAX,%ARG2%(1,28,K)
*VSCFUN,MAXCOL3,MAX,%ARG2%(1,33,K)
MAXCOL4 = MAXCOL1 > MAXCOL2 > MAXCOL3
*VSCFUN,MINCOL1,MAX,%ARG2%(1,24,K)
*VSCFUN,MINCOL2,MAX,%ARG2%(1,29,K)
```

```
   *VSCFUN,MINCOL3,MAX,%ARG2%(1,34,K)
   MINCOL4 = MINCOL1 > MINCOL2 > MINCOL3
   *VWRITE,MAXCOL4 > MINCOL4
   ('Maximum Local Stress Intensity                ',F6.0)
   !
   *VSCFUN,MAXCOL1,MAX,%ARG2%(1,9,K)
   *VWRITE,MAXCOL1
   (2/,'Maximum Inner O-Ring Separation is ',F7.5,' inches.')
   !
   *VSCFUN,MAXCOL1,MAX,%ARG2%(1,13,K)
   *VWRITE,MAXCOL1
   ('Required Mating Surface Mu to Prevent Slip is ',F7.5,'.')
   !
   *IF,ARG5,EQ,1,THEN
      *VWRITE,ARG4
      ('-----',/,A,' Procedure - Sequence Listing',/)
      /COM, SET NO.     STUD NO.   PRESSURE    RETEN. FLAG
      *VWRITE,SEQU,%ARG1%(1,1,K),%ARG1%(1,2,K),%ARG1%(1,4,K)
      (4(F9.0,3X))
   *ENDIF
   !
   *VWRITE,ARG4
   ('-----',/,A,' Procedure Results - Stud Stresses',/)
   !
   /COM,           MEMBRANE   MEMB+BEND    MAX. MEM.   ACHIEVED    REQUIRED
   /COM,STUD #      STRESS      STRESS      STRESS     @ SET NO.   WASHER MU
   *VWRITE,SEQU,%ARG2%(1,3,K),%ARG2%(1,4,K),%ARG2%(1,5,K),%ARG2%(1,6,K),%ARG2%(1,14,K)
   (F5.0,5X,4(F9.0,3X),2X,F7.4)
   !
   *VWRITE,ARG4
   ('-----',/,A,' Procedure Results - Flange Contact Forces',/)
   /COM,                      GLOBAL       GLOBAL       REQUIRED
   /COM,STUD #  LINK FORCE    X SHEAR      Z SHEAR      FLANGE MU
   *VWRITE,SEQU,%ARG2%(1,10,K),%ARG2%(1,11,K),%ARG2%(1,12,K),%ARG2%(1,13,K)
   (F5.0,3X,3(E11.4,2X),2X,F7.4)
   *VWRITE,ARG4
   ('-----',/,A,' Procedure Results - Flange Deflections',/)
   /COM,        UPPER FLANGE   LOWER FLANGE      O-RING
   /COM,STUD #    ROTATION       ROTATION      SEPARATION
   *VWRITE,SEQU,%ARG2%(1,7,K),%ARG2%(1,8,K),%ARG2%(1,9,K)
   (F5.0,4X,3(E11.4,4X))
   !
   CLNO = 0
   *DO,L1,15,50,5
      CLNO = CLNO+1
      L2 = L1+1
      L3 = L1+2
      L4 = L1+3
      L5 = L1+4
      *VWRITE,ARG4,CLNO
      ('-----',/,A,' Procedure Results - Cut Line ',F2.0,/)
      /COM,         INNER       CENTER      OUTER      INNER        OUTER
      /COM,STUD #  LIN. S.I.   LIN. S.I.   LIN. S.I.  TOT. S.I.    TOT. S.I.
*VWRITE,SEQU,%ARG2%(1,L1,K),%ARG2%(1,L2,K),%ARG2%(1,L3,K),%ARG2%(1,L4,K),%ARG2%(1,L5,K)
      (F5.0,2X,5(F9.0,3X))
   *ENDDO
*ENDDO
*END
/COM, ----------------------------------------------------------------------------------
/COM,     END PRINTENS MACRO
/COM, **********************************************************************************
/COM, **********************************************************************************
/COM,
/COM,
/COM,
/COM, **********************************************************************************
/COM, **********************************************************************************
/COM,     CREATE PRINTOLR MACRO
/COM, ----------------------------------------------------------------------------------
/COM,
/COM, PRINTOLR arguments as follows:
/COM,    ARG1 = RSAVE ARRAY TEXT (e.g., 'RSAVE7')
/COM,    ARG2 = Case Type (e.g., 'II')
/COM,    ARG3 = Starting Case No.
```

```
/COM,    ARG4 = Ending Case No.
/COM,    ARG5 = Starting Vessel Cut Plane No.
/COM,    ARG6 = Ending Vessel Cut Plane No.
/COM,    ARG7 = Starting Head Cut Plane No.
/COM,    ARG8 = Ending Head Cut Plane No.
/COM,
*CREATE,PRINTOLR
/COM,
*IF,ARG2,EQ,'II',THEN
   INDADD = 5
*ELSE
   INDADD = 0
*ENDIF
*DO,K,ARG3,ARG4
   *VSCFUN,MAXCOL1,MAX,%ARG1%(1,3,K)        $TABLEC2(INDADD+K,2) = MAXCOL1/1000
   *VSCFUN,MINCOL1,MIN,%ARG1%(1,3,K)        $TABLEC2(INDADD+K,1) = MINCOL1/1000
   *VSCFUN,AVECOL1,MEAN,%ARG1%(1,3,K)
   *VSCFUN,MAXCOL2,MAX,%ARG1%(1,4,K)        $TABLEC2(INDADD+K,3) = MAXCOL2/1000
   *VSCFUN,MINCOL2,MIN,%ARG1%(1,4,K)
   *VSCFUN,AVECOL2,MEAN,%ARG1%(1,4,K)
   *VSCFUN,MAXCOL3,MAX,%ARG1%(1,5,K)
   *VSCFUN,MINCOL3,MIN,%ARG1%(1,5,K)
   *VSCFUN,AVECOL3,MEAN,%ARG1%(1,5,K)
   *VSCFUN,MAXCOL4,MAX,%ARG1%(1,14,K)
   *VSCFUN,MINCOL4,MIN,%ARG1%(1,14,K)
   *VSCFUN,AVECOL4,MEAN,%ARG1%(1,14,K)
   !
   *VWRITE,ARG2,K
   ('-----',/,'Elongation Tolerance Case C',A2,'-',F2.0,/)
   !
   *VWRITE,ARG2
   ('Level ',A2,' Elongation Tolerance Results - Stud Stresses',/)
   /COM,           MEMBRANE   MEMB+BEND    MAX. MEM.   ACHIEVED    REQUIRED
   /COM,STUD #      STRESS      STRESS      STRESS     @ SET NO.   WASHER MU
   *VWRITE,SEQU,%ARG1%(1,3,K),%ARG1%(1,4,K),%ARG1%(1,5,K),%ARG1%(1,6,K),%ARG1%(1,14,K)
   (F5.0,5X,4(F9.0,3X),2X,F7.4)
   !
   *VWRITE,ARG2
   ('-----',/,'Level ',A2,' Elongation Tolerance Results - Flange Contact Forces',/)
   /COM,                      GLOBAL       GLOBAL       REQUIRED
   /COM,STUD #  LINK FORCE    X SHEAR      Z SHEAR      FLANGE MU
   *VWRITE,SEQU,%ARG1%(1,10,K),%ARG1%(1,11,K),%ARG1%(1,12,K),%ARG1%(1,13,K)
   (F5.0,3X,3(E11.4,2X),2X,F7.4)
   *VWRITE,ARG2
   ('-----',/,'Level ',A2,' Elongation Tolerance Results - Flange Deflections',/)
   /COM,        UPPER FLANGE   LOWER FLANGE      O-RING
   /COM,STUD #    ROTATION       ROTATION      SEPARATION
   *VWRITE,SEQU,%ARG1%(1,7,K),%ARG1%(1,8,K),%ARG1%(1,9,K)
   (F5.0,4X,3(E11.4,4X))
   !
   CLNO = 0
   *DO,L1,15,50,5
      CLNO = CLNO+1
      L2 = L1+1
      L3 = L1+2
      L4 = L1+3
      L5 = L1+4
      *VWRITE,ARG2,CLNO
      ('-----',/,'Level ',A2,' Elongation Tolerance Results - Cut Line ',F2.0,/)
      /COM,         INNER       CENTER      OUTER      INNER        OUTER
      /COM,STUD #  LIN. S.I.   LIN. S.I.   LIN. S.I.  TOT. S.I.    TOT. S.I.
*VWRITE,SEQU,%ARG1%(1,L1,K),%ARG1%(1,L2,K),%ARG1%(1,L3,K),%ARG1%(1,L4,K),%ARG1%(1,L5,K)
      (F5.0,2X,5(F9.0,3X))
   *ENDDO
   *DO,L,ARG7,ARG8
      *VSCFUN,TMPMAXSI,MAX,%ARG1%(1,L*5+13,K)
      TABLEC2(INDADD+K,4) = TMPMAXSI > TABLEC2(INDADD+K,4)
      *VSCFUN,TMPMAXSI,MAX,%ARG1%(1,L*5+14,K)
      TABLEC2(INDADD+K,4) = TMPMAXSI > TABLEC2(INDADD+K,4)
   *ENDDO
   *DO,L,ARG5,ARG6
      *VSCFUN,TMPMAXSI,MAX,%ARG1%(1,L*5+13,K)
      TABLEC2(INDADD+K,5) = TMPMAXSI > TABLEC2(INDADD+K,5)
      *VSCFUN,TMPMAXSI,MAX,%ARG1%(1,L*5+14,K)
```

```
      TABLEC2(INDADD+K,5) = TMPMAXSI > TABLEC2(INDADD+K,5)
   *ENDDO
   TABLEC2(INDADD+K,4) = TABLEC2(INDADD+K,4)/1000
   TABLEC2(INDADD+K,5) = TABLEC2(INDADD+K,5)/1000
*ENDDO
*END
/COM, ----------------------------------------------------------------------------------
/COM,     END PRINTOLR MACRO
/COM, **********************************************************************************
/COM, **********************************************************************************
```

B SOFTWARE USAGE RECORDS

The following table lists the Software Usage Records for the ANSYS analyses performed in support of this calculation. These records are included on the Data Disk D-3944-00-01 [6] in their native electronic formats. This data disk is retained with the Task 3944 project file and is available for on-site review by Southern Nuclear personnel.

File Name	**Description**
_HATCH2.runs	Input file which sets run parameters and performs the closure flange evaluation cases.
_MACROS.HATCH2	Input file which sets the finite element model geometry and boundary conditions specific to the Hatch Unit 2 RPV model.
_MACROS.DEI	Input file which performs stud tensioning and closure flange analyses.
RESULTS.OUT	Formatted output file which contains the stud stress results for the closure flange analysis cases.
_HATCH2.out	Full output file generated automatically which includes every ANSYS operation performed throughout the analysis.
HATCH2 .err	Automatically generated error file which includes all warnings generated during the analysis.
Hatch 2 Stud Primary Stress Calc v0.xlsx	Microsoft Excel spreadsheet used to perform stud primary stress calculations.