Southern Nuclear

Cheryl A. Gayheart
Regulatory Affairs Director

3535 Colonnade Parkway
Birmingham, AL 35243
205 992 5316 tel
205 992 7601 fax
cagayhea@southernco.com

August 19, 2022

Docket Nos.: 50-321
50-366

NL-22-0406
10 CFR 50.90

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

Edwin I. Hatch Nuclear Plant – Units 1 and 2
Request to Relax the Required Number of Fully Tensioned Reactor Pressure Vessel Head Closure Studs in Technical Specification Table 1.1-1, "MODES"

Ladies and Gentlemen:

Pursuant to the provisions of 10 CFR 50.90, "Application for amendment of license, construction permit or early site permit," Southern Nuclear Operating Company (SNC) hereby requests a proposed license amendment to the Technical Specifications (TS) for Edwin I. Hatch Nuclear Plant (HNP) Units 1 and 2 Renewed Facility Operating Licenses DPR-57 and NPF-5, respectively. The proposed amendment would revise TS Table 1.1-1, "MODES."

The amendment is considered a permanent change to allow operation of HNP Units 1 and 2 with the required reactor pressure vessel head closure studs fully tensioned. The required number of fully tensioned closure studs, which may be less than the total number, has been established by calculation that demonstrates operation of HNP Units 1 and 2 reactor pressure vessels with the required studs fully tensioned does not result in any component of the reactor pressure vessel closure flange exceeding the design basis ASME Code allowables. The calculation for HNP Unit 1 determined that any one closure stud may be less than fully tensioned. The calculation for HNP Unit 2 determined that any two closure studs may be less than fully tensioned as long as the two studs are separated by nine or more studs. Prudent operating and engineering principles are applied to maintaining all the head closure studs in service. Circumstances may arise that result in the need to safely operate HNP Units 1 and 2 with a head closure stud(s) not fully tensioned.

SNC has made several attempts to remove HNP Unit 2 reactor pressure vessel head closure stud #33 due to the identification of a circumferential flaw indication. Removal is necessary to perform an ASME Section V, Mandatory Appendix 6 (Liquid Penetrant) or Mandatory Appendix 7 (Magnetic Particle) Surface Examination. SNC is proposing changes to TS Table 1.1-1 to address the increased possibility that a reactor pressure vessel head closure stud may not be able to be fully tensioned and avert the possible need for an exigent or emergency license amendment during the Spring 2023 Refueling Outage. Therefore, SNC requests approval of the proposed license amendment by February 25, 2023. The amendment, if approved, will be implemented within 30 days of issuance.

Enclosure 1 provides a description and assessment of the proposed change, including a no significant hazards considerations analysis, regulatory requirements, and environmental considerations. Attachment 1 to Enclosure 1 provides the existing TS pages marked to show the proposed change. Attachment 2 to Enclosure 1 provides the revised (clean) TS pages. Enclosure 2 provides the HNP Unit 1 calculation for operation with one closure stud out of service. Enclosure 3 provides the HNP Unit 2 calculation for operation with two closure studs out of service.

In accordance with 10 CFR 50.91, “Notice for public comment, State consultation,” paragraph (b), a copy of this application, with enclosures and attachments, is being provided to the designated Georgia Officials.

This letter contains no regulatory commitments. If you have any questions regarding this submittal, please contact Amy Chamberlain at 205.992.6361.

I declare under penalty of perjury that the foregoing is true and correct. Executed on the 19th day of August 2022.

Respectfully submitted,

Cheryl A. Gayheart
Regulatory Affairs Director
Southern Nuclear Operating Company

CAG/agq

Enclosures:
1. Evaluation of the Proposed Change
2. Calculation C-037-2201-00-01, “Hatch Unit 1 Operation with One Stud Out of Service Evaluation”
3. Calculation C-037-2201-00-02, “Hatch Unit 2 Operation with Two Studs Out of Service Evaluation”

cc: NRC Regional Administrator, Region II
NRC NRR Project Manager – Hatch
NRC Senior Resident Inspector – Hatch
Director, Environmental Protection Division – State of Georgia
RType: CHA02.004

Edwin I. Hatch Nuclear Plant – Units 1 and 2
Request to Relax the Required Number of Fully Tensioned Reactor Pressure Vessel Head Closure Studs in Technical Specification Table 1.1-1, "MODES"

NL-22-0406

Enclosure 1

Evaluation of the Proposed Change

ENCLOSURE

Evaluation of the Proposed Change

Subject: Request to Relax the Required Number of Fully Tensioned Reactor Pressure Vessel Head Closure Studs in Technical Specification Table 1.1-1, “MODES”

1. SUMMARY DESCRIPTION

Southern Nuclear Operating Company (SNC) is proposing to revise the Technical Specifications (TS) Table 1.1-1, “MODES,” for Hatch Nuclear Plant (HNP) Units 1 and 2.

The amendment is considered a permanent change to the Technical Specifications allowing operation of HNP Units 1 and 2 with the required reactor pressure vessel head closure studs fully tensioned. The required number of fully tensioned closure studs, which may be less than the total number, has been established by calculation that demonstrates operation of HNP Units 1 and 2 reactor pressure vessels (RPVs) with the required studs fully tensioned does not result in any component of the reactor pressure vessel closure flange exceeding the design basis ASME Code allowables. The calculation for HNP Unit 1 determined that any one closure stud may be less than fully tensioned. The calculation for HNP Unit 2 determined that any two closure studs may be less than fully tensioned as long as the two studs are separated by nine or more studs.

2. DETAILED DESCRIPTION

2.1 System Design and Operation

The HNP Unit 1 reactor pressure vessel is designed, fabricated, inspected, and tested in accordance with ASME Boiler and Pressure Vessel Code, Section III, Nuclear Vessels, 1965 Edition and addenda to and including winter 1966 addenda, and the following additions:

- Low-alloy steel plate for pressure parts in accordance with ASME SA-533, Grade B, Class 1 material and Code Cases 133B-3 and 1339-2.

- Low-alloy steel forgings to pressure parts in accordance with ASME SA-508, Class 2 material, Code Case 1332-4.

- Inconel nozzles in accordance with SB-166 material, Code classes 1336 and 1359-1.

- Nozzle ends for austenitic pipe and flange ends for low-allow steel nozzles in accordance with SA-105 Grade II material, Code Case 1332-4.

- Studs, nuts, bushings, and washers in accordance with American Society of Testing Materials A-540, Grade 24 material and Code Case 1335.

- Shroud support legs, baffle plate, and ring in accordance with SB-168 material, Code Case 1336.

The HNP Unit 2 reactor pressure vessel is designed, fabricated, tested, inspected, and stamped in accordance with the ASME Boiler and Pressure Vessel Code, Section III, Class A (1968 edition plus summer 1970 addendum). The HNP Unit 2 reactor pressure vessel closure studs were examined in accordance with the requirements of ASME Section III, N-325. Bored blank nuts were ultrasonically examined by both the longitudinal

and shear wave methods. Shear wave examination of the nuts was performed in both the axial and circumferential directions.

The cylindrical shell and bottom head of the HNP Units 1 and 2 reactor pressure vessels are fabricated of low-alloy steel, the interior of which is clad with stainless steel weld overlay. Internal surfaces of nozzles that connect to stainless steel pipe are also clad with stainless steel weld overlay.

Each reactor pressure vessel top head is secured to the reactor pressure vessel by studs and nuts. These nuts are tightened with a stud tensioner. The reactor pressure vessel flanges are sealed with two concentric metal seal-rings designed to permit no detectable leakage through the inner or outer seal at any operating condition, including heating to operating pressure and temperature at a maximum rate of 100°F/h and cold hydrostatic pressure testing at the pressure specified in the ASME Code. The reactor pressure vessel is described in the HNP Unit 1 Final Safety Analysis Report (FSAR) Section 4.2.4.1 (Reference 1) and Appendix I (Reference 2) and in the HNP Unit 2 FSAR Section 5.4.6.3.1. (Reference 3).

Reactor vessel top head flange leakage detection is provided for both HNP Units 1 and 2. A connection is provided on the reactor vessel flange into the annulus between the two metallic seal rings used to seal the reactor vessel and top head flanges. This connection permits detection of leakage from the inside of the reactor vessel past the inner seal ring. The connection is piped to a pressure switch having an associated alarm in the main control room. The reactor vessel top head flange leakage detection is described in the HNP Unit 1 FSAR Section 7.8.5.5 (Reference 4) and in the HNP Unit 2 FSAR Sections 5.6.2.5 and 5.2.7.2.2.1 (Reference 5).

A Class 1 system leakage test in accordance with ASME Code IWB-5220 is conducted prior to each plant startup following a reactor refueling outage at a test pressure of 1045 psig.

Plant procedures provide the methodology for tensioning the reactor pressure vessel closure studs, and the studs at HNP Units 1 and 2 are typically tensioned four studs at a time in a four-fold symmetric pattern. If the reactor pressure vessel head is to be installed with an untensioned stud(s), the tensioning pattern will be reviewed to ensure that the sealing o-rings are fully compressed before the stud(s) not being tensioned is encountered in the pattern. The final tensioned condition of the studs is verified by an elongation measurement when all required studs have been tensioned. Elongations must be within acceptance criteria. The acceptance criteria for the final stud elongations are established to ensure that ASME Code stress limits are met for specified service loads for the worst-case flange and stud bending that result from various tensioning patterns, including an untensioned stud(s). The ASME Code examination requirements would also be reviewed to verify the requirements are being met or if relief is necessary.

2.2 Current Technical Specification Requirements

HNP Units 1 and 2 TS Table 1.1-1, “MODES,” is provided below:

Table 1.1-1 (page 1 of 1)
MODES

MODE	TITLE	REACTOR MODE SWITCH POSITION	AVERAGE REACTOR COOLANT TEMPERATURE (°F)
1	Power Operation	Run	NA
2	Startup	Refuel[(a)] or Startup/Hot Standby	NA
3	Hot Shutdown[(a)]	Shutdown	> 212
4	Cold Shutdown[(a)]	Shutdown	≤ 212
5	Refueling[(b)]	Shutdown or Refuel	NA

(a) All reactor vessel head closure bolts fully tensioned.

(b) One or more reactor vessel head closure bolts less than fully tensioned.

Footnotes (a) and (b) specify the reactor head closure bolt requirements. For the purposes of this amendment request, reactor vessel head closure bolts as specified in the TSs, are equivalent to reactor pressure vessel head closure studs or studs.

2.3 Reason for the Proposed Change

A flaw indication was found on HNP Unit 2 reactor pressure vessel head closure stud #33 during a code required volumetric examination during the spring 2017 refueling outage (2R24). The examination was completed in accordance with ASME Section XI Table IWB-2500-1, examination category B-G-1, Item B6.20, and met the examination volume requirements of Figure IWB-2500-12. During the Inservice Inspection (ISI) of the HNP Unit 2 closure studs (#1 through #56), a circumferential flaw indication was identified in the stud at location #33. The indication is located at a distance of 41.7 inches from the top of the closure stud. This correlates to just below or at the surface of the reactor vessel flange. The indication is approximately one inch (1") in length.

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 reactor pressure vessel head closure 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 of the indication, various attempts were made to remove the closure stud prior to flooding the reactor cavity for fuel movement and after draindown for vessel reassembly in refueling outage 2R24. Two different methodologies (Basic Removal and Advanced Removal) were pursued to remove the stud. The first attempt to remove the 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.

SNC submitted a Relief Request (Reference 6) from the surface examination requirement in the event reactor pressure vessel head closure stud #33 could not be removed for a code compliant surface examination. The Relief Request was subsequently approved by the NRC in Reference 7. Both of the attempts to remove the stud were unsuccessful.

During the HNP Unit 2 Spring 2019 refueling outage (2R25), several additional more aggressive attempts were made to remove the reactor pressure vessel head closure stud #33. These attempts were also unsuccessful. SNC submitted a Relief Request (Reference 8) to continue operation with a flaw indication on the reactor pressure vessel head closure stud #33. The Relief Request was subsequently approved by the NRC in Reference 9. There were no attempts to remove the stud during the 2021 refueling outage (2R26).

Since the attempts to remove reactor pressure vessel head closure stud #33 were unsuccessful, the stud remains in place, and is approved in a Code relief (Reference 9) to remain for the duration of the current 5th ISI Interval which is scheduled to end on December 31, 2025. This Code relief does not provide relief from the TS Table 1.1-1, “MODES,” which requires all reactor vessel head bolts to be fully tensioned. Reactor pressure vessel head closure stud #33 is fully tensioned at this time. However, if the indication on stud #33 becomes worse, or indication is found on another stud, there is a possibility that a stud(s) might be incapable of full tension.

The indication at HNP Unit 2 stud #33 is atypical of industry experience. Review of industry operating experience for degradation of reactor vessel closure studs was performed in support of Electric Power Research Institute (EPRI) Report 30020114589, “Technical Basis for Optimization of the Volumetric Examination Frequency for Reactor Vessel Studs,” (Reference 10). The review identified only one confirmed case of closure stud cracking, which occurred in 1989 and was traced to poor material conditions. Given this broader operating experience and the inspection history at HNP Units 1 and 2, there is no common cause associated with the examination indication.

As such, SNC is proposing changes to TS Table 1.1-1 to address the increased possibility that a reactor pressure vessel head closure stud may not be able to be fully tensioned and avert the possible need for an exigent or emergency license amendment during the

Spring 2023 Refueling Outage. During that refueling outage, stud #33 will be detensioned for reactor pressure vessel head removal and retensioned for operation, thereby increasing the possibility of its failure.

2.4 <u>Description of Proposed Change</u>

HNP Unit 1 TS Table 1.1-1 defines the criteria for MODES 1 through 5. Reactor MODE Switch Position “Refuel” for MODE 2, MODE 3, “Hot Shutdown,” and MODE 4, “Cold Shutdown,” is annotated with footnote (a) which currently states:

(a) All reactor vessel head closure bolts fully tensioned.

The proposed change would revise the footnote to state:

(a) All required reactor vessel head closure bolts fully tensioned. The required number of head closure bolts is at least 51 of 52 bolts.

In addition, MODE 5, “Refueling,” is annotated with footnote (b) which currently states:

(b) One or more reactor vessel head closure bolts less than fully tensioned.

The proposed change would revise the footnote to state:

(b) One or more required reactor vessel head closure bolts less than fully tensioned.

HNP Unit 2 TS Table 1.1-1 defines the criteria for MODES 1 through 5. Reactor MODE Switch Position “Refuel” for MODE 2, MODE 3, “Hot Shutdown,” and MODE 4, “Cold Shutdown,” are annotated with footnote (a) which currently states:

(b) All reactor vessel head closure bolts fully tensioned.

The proposed change would revise the footnote to state:

(b) All required reactor vessel head closure bolts fully tensioned. The required number of head closure bolts is at least 54 of 56 bolts, with a minimum of nine bolts between the two out of service bolts.

In addition, MODE 5, “Refueling,” is annotated with footnote (b) which currently states:

(b) One or more reactor vessel head closure bolts less than fully tensioned.

The proposed change would revise the footnote to state:

(b) One or more required reactor vessel head closure bolts less than fully tensioned.

The addition of the word “required” and specifying the required number of reactor pressure vessel head closure studs in footnote (a) will avoid any confusion regarding the state of a closure stud(s) that may be out of service.

For HNP Unit 1, the “required” number of fully tensioned closure studs is 51 of the 52 closure studs based on Calculation C-037-2201-00-01, “Hatch Unit 1 Operation with One Stud Out of Service Evaluation,” (see Enclosure 2).

For HNP Unit 2, the “required” number of fully tensioned closure studs is 54 of the 56 closure bolts, with a minimum of nine studs between the two out of service studs, based on Calculation C-037-2201-00-02, “Hatch Unit 2 Operation with One Stud Out of Service Evaluation,” (see Enclosure 3).

3. TECHNICAL EVALUATION

Separate calculations were performed for HNP Units 1 and 2. The calculations analyzed reactor pressure vessel closure stresses, stud stresses, closure flange separation and fatigue. The calculations demonstrated that applicable ASME Code allowable stresses are met. The calculations were performed using the design pressure of 1,250 psia. At HNP Units 1 and 2, the design pressure bounds the pressure for all Normal and Upset transients established in the design basis analysis. Stresses resulting from Emergency and Faulted transients were also considered.

<u>HNP Unit 1 Calculation Results</u>

Enclosure 2 provides the Dominion Engineering, Inc. calculation supporting continued operation of the HNP Unit 1 reactor pressure vessel with one closure stud out of service. The average stresses in the studs due to primary load conditions were calculated with all studs meeting the ASME Code requirements for primary loads with one stud out of service. The maximum primary stud stress is calculated to be 35.48 ksi, which is less than the design stress-intensity value (S_m) allowable of 36.30 ksi.

Operation of the HNP Unit 1 reactor pressure vessel with any one stud out of service does not result in any component of the reactor pressure vessel closure flange exceeding the design basis ASME Code allowables. The closure 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.

The closure stud out of service has a modest impact 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.

The closure stud out of service causes an additional flange separation at the inner o-ring of 0.0079 inch. The flange separation is less than the o-ring minimum springback of 0.010 inch. Due to rotation of the flanges under stud loading, the flange separation at the outer ring is less than the inner o-ring. Therefore, compression on the gasket is maintained, and the flange separation will not result in additional risk of leakage.

The closure stud out of service increases the maximum stress at: (1) the head flange/shell by 1.02 ksi, (2) the vessel flange/shell by 0.40 ksi and (3) the stud by 0.23 ksi; each of these increases are approximately 1-2% of the previous design basis stress. The fatigue usage values were calculated for the full service life of the component. The impact of a 2% increase in

stress for a single cycle of operation on these components is negligible. The calculation 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 $1.02^2 = 1.04$ (4% increase). Increasing the fatigue usage by 4% results in fatigue usage that is well below the Code allowable of 1.0.

HNP Unit 2 Calculation Results

Enclosure 3 provides the Dominion Engineering, Inc. calculation supporting continued operation of the HNP Unit 2 reactor pressure vessel with any two closure studs out of service. The average stresses in the studs due to primary load conditions were calculated with all studs meeting the ASME Code requirements for primary loads with two studs out of service. The maximum primary stud stress is calculated to be 34.74 ksi, which is less than the S_m allowable of 36.30 ksi.

Operation of the HNP Unit 2 reactor pressure vessel with two studs out of service, with a minimum of nine studs between them, does not result in any component of the reactor pressure vessel closure flange exceeding the design basis ASME Code allowables. The condition with two closure studs 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.

The condition with two closure studs out of service has a modest impact 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.

The condition with two closure studs out of service causes an additional flange separation at the inner o-ring of 0.0066 inch. The total flange separation is less than the o-ring minimum springback of 0.010 inch. Due to rotation of the flanges under stud loading, the flange separation at the outer ring is less than the inner o-ring. Therefore, compression on the gasket is maintained, and the flange separation will not result in additional risk of leakage.

The condition with two closure studs out of service increases the maximum stress at: (1) the head flange/shell by 1.48 ksi, (2) the vessel flange/shell by 0.42 ksi and (3) the stud by 0.31 ksi; each of these increases are approximately 1-2% of the previous design basis stress. The fatigue usage values were calculated for the full service life of the component. The impact of a 2% increase in stress for a single cycle of operation on these components is negligible. The calculation 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 two studs out of service, the increase in fatigue usage would be the square of the increase in stress, or $1.02^2 = 1.04$ (4% increase). Increasing the fatigue usage by 4% results in fatigue usage that is below the Code allowable of 1.0.

4. REGULATORY EVALUATION

4.1 Applicable Regulatory Requirements/Criteria

- 10 CFR Part 50, Appendix A, General Design Criterion (GDC) 14, "Reactor coolant pressure boundary," requires that:

  The reactor coolant pressure boundary shall be designed, fabricated, erected, and tested so as to have an extremely low probability of abnormal leakage, of rapidly propagating failure, and of gross rupture.

  The HNP design, fabrication, erection, and testing of the reactor coolant pressure boundary (RCPB) assure an extremely low probability of failure or abnormal leakage. Allowing the required pressure vessel closure stud(s) to be fully tensioned during operation will still satisfy the requirements of GDC 14.

- 10 CFR Part 50, Appendix A, General Design Criterion (GDC) 30, "Quality of reactor coolant pressure boundary," requires that:

  Components which are part of the reactor coolant pressure boundary shall be designed, fabricated, erected, and tested to the highest quality standards practical. Means shall be provided for detecting and, to the extent practical, identifying the location of the source of reactor coolant leakage.

  By utilizing conservative design practices and detailed quality control procedures, the pressure retaining components of the RCPB are designed and fabricated to retain their integrity during normal and postulated accident conditions. Accordingly, components which comprise the RCPB are designed, fabricated, erected, and tested in accordance with recognized industry codes and standards. Further product and process quality planning is provided to assure conformance with the applicable codes and standards and to retain appropriate documented evidence verifying compliance. The RCPB and the leak detection system are designed to meet the requirements of GDC 30. Allowing the required pressure vessel closure stud(s) to be fully tensioned during operation will still satisfy the requirements of GDC 30.

It is noted that HNP Unit 1 was not licensed to the 10 CFR 50, Appendix A, GDC. HNP Unit 1 was licensed to the applicable Atomic Energy Commission preliminary general design criteria identified in Federal Register 32 FR 10213, published July 11, 1967 (ADAMS Accession No. ML043310029). The applicable AEC proposed criteria were compared to the 10 CFR 50, Appendix A, General Design Criteria, as documented in the Hatch Updated Final Safety Analysis Report (UFSAR), Appendix F, "Conformance to the Atomic Energy Commission (AEC) Criteria."

- U. S. NRC Regulatory Guide 1.65, "Materials and Inspections for Reactor Vessel Closure Studs," is NRC guidance which defines materials and testing procedures acceptable for implementing these criteria for reactor vessel closure stud bolting. (Reference 11)

This regulatory guide is applicable only to HNP Unit 2. HNP Unit 2 design and inspection procedures are in conformance with the requirements of this regulatory guide except those in Regulatory Positions 2b, 2e, and 3.

Studs were examined in accordance with the requirements of American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, N-325; (1968 Edition plus Summer 1970 Addendum in effect at the time of the contract). Bored blank nuts were ultrasonically examined by both the longitudinal and shear wave methods. Shear wave examination of the nuts was performed in both the axial and circumferential directions.

Regulatory Position 3 recommends provision for adequate corrosion protection during venting and filling of the vessel, and while the head is removed. General Electric (GE) supplies thread protectors which prevent stud damage, but stud holes are not plugged, and neither stud nor flange threads are protected from exposure to water. In practice, this has been found to be adequate, as exposure to applied loads and operating and servicing environments has not required the replacement of any boiling water reactor (BWR) studs or flange threads. No corrosion protection for studs is provided.

4.2 Precedent

The proposed changes are similar to NRC-approved license amendment issued to:

- Braidwood Station Units 1 and 2 and Byron Station Units 1 and 2 on October 28, 2015, in Amendment Nos. 186 and 192, respectively (ADAMS Accession No. ML15232A441). These amendments approved the use of the methodology for developing the pressure and temperature limits reports and changed TS Table 1.1-1, “MODES,” footnote (b) to state: “All *required* reactor vessel head closure bolts fully tensioned” and footnote (c) to state: “One or more *required* reactor vessel head closure bolts less than fully tensioned” (emphasis added). The proposed license amendment request for HNP Units 1 and 2 is not requesting changes to the pressure and temperature limits methodology.

- Callaway Plant Unit 1 on May 28, 1999, in Amendment No. 133 (ADAMS Accession No. ML021640446). Amendment No. 133 converted the current TSs to the improved TSs. The amendment approved changes to TS Table 1.1-1 based on an NRC Safety Evaluation issued on May 26, 1988 (ADAMS Accession Nos. ML20155J379 and ML20155J490) associated with the operation of the Callaway Plant with stud #2 untensioned. Amendment No. 133 revised footnote (b) to state: “At least 53 of 54 reactor vessel head closure bolts fully tensioned and footnote (c) to state: “Two or more reactor vessel head closure bolts less than fully tensioned”.

The approved TS changes are similar to the changes proposed in this amendment request.

4.3 No Significant Hazards Consideration Determination Analysis

Southern Nuclear Operating Company (SNC) is proposing to revise the Technical Specifications (TS) Table 1.1-1, "MODES," for Hatch Nuclear Plant (HNP) Units 1 and 2.

The amendment would allow operation of HNP Units 1 and 2 with the required pressure vessel head closure studs fully tensioned. The required number of closure studs, which may be less than the total number, has been established by calculation that demonstrates operation of HNP Units 1 and 2 reactor pressure vessels with the required studs fully tensioned does not result in any component of the reactor pressure vessel closure flange exceeding the design basis ASME Code allowables. The calculation for HNP Unit 1 determined that any one closure stud may be less than fully tensioned. The required closure studs continue to meet ASME Code requirements for primary loads with one stud out of service. The calculation for HNP Unit 2 determined that any two closure studs may be less than fully tensioned as long as the two studs are separated by nine or more studs. The required closure studs continue to meet ASME Code requirements for primary loads with two studs out of service.

SNC has evaluated whether or not a significant hazards consideration is involved with the proposed amendment(s) by focusing on the three standards set forth in 10 CFR 50.92, "Issuance of amendment," as discussed below:

1. Does the proposed change involve a significant increase in the probability or consequences of an accident previously evaluated?

   Response: No.

   Overall protection system performance will remain within the bounds of the accident analyses, since no hardware changes are proposed. Since the stresses remain within ASME Code allowables, the proposed change will not affect the probability of any event initiators nor will the proposed change affect the ability of any safety related equipment to perform its intended function. There will be no degradation in the performance of nor an increase in the number of challenges imposed on safety related equipment assumed to function during an accident situation.

   Therefore, the proposed change does not involve a significant increase in the probability or consequences of an accident previously evaluated.

2. Does the proposed change create the possibility of a new or different kind of accident from any accident previously evaluated?

   Response: No.

   There are no hardware changes nor are there any changes in the method by which any safety related plant system performs its safety function. The method of plant operation is unaffected. Leakage would be precluded since adequate compression remains. Analysis demonstrates that any gap opening remains less than the springback recovery of the inner closure o-ring. Since stresses remain within ASME Code allowables, no

new accident scenarios, transient precursors, failure mechanisms, or limiting single failures are introduced as a result of this change.

Therefore, the proposed change does not create the possibility of a new or different kind of accident from any previously evaluated.

3. Does the proposed change involve a significant reduction in a margin of safety?

   Response: No.

   The proposed change does not affect any Safety Limits or controlling numerical values for a parameter established in the updated final safety analysis report or any specific values that define margin that are established in the plant's licensing basis. ASME Section III stress limits for affected components are not exceeded. Plant specific evaluations indicate that the reactor vessels will continue to meet ASME Code allowable stress criteria with the required reactor pressure vessel closure studs fully tensioned. The proposed change does not alter nor exceed the acceptance criteria for any analyzed event. There will be no effect on the manner in which safety limits or limiting safety system settings are determined nor will there be any effect on those plant systems necessary to assure the accomplishment of protection functions.

   Therefore, the proposed change does not involve a significant reduction in a margin of safety.

4.4 Conclusions

In conclusion, based on the considerations discussed above, (1) there is reasonable assurance that the health and safety of the public will not be endangered by operation in the proposed manner, (2) such activities will be conducted in compliance with the Commission's regulations, and (3) the issuance of the amendment will not be inimical to the common defense and security or to the health and safety of the public.

5. ENVIRONMENTAL CONSIDERATION

SNC has determined that the proposed amendment would change a requirement with respect to installation or use of a facility component located within the restricted area, as defined in 10 CFR 20, "Standards for protection against radiation," or would change an inspection or surveillance requirement. However, the proposed amendment does not involve (i) a significant hazards consideration, (ii) a significant change in the types or a significant increase in the amounts of any effluents that may be released offsite, or (iii) a significant increase in individual or cumulative occupational radiation exposure. Accordingly, the proposed amendment meets the eligibility criterion for categorical exclusion set forth in paragraph (c)(9) of 10 CFR 51.22, "Criterion for categorical exclusion, identification of licensing and regulatory actions eligible for categorical exclusion or otherwise not requiring an environmental review." Therefore, pursuant to 10 CFR 51.22(b), no environmental impact statement or environmental assessment need be prepared in connection with the proposed amendment.

6. REFERENCES

1. HNP-1-FSAR, Edwin I. Hatch Nuclear Plant Final Safety Analysis Report, Revision 38, September 2020, Section 4.2.1.4, "Reactor Vessel."

2. HNP-1-FSAR, Edwin I. Hatch Nuclear Plant Final Safety Analysis Report, Revision 38, September 2020, Appendix I, "Reactor Pressure Vessel Design Information."

3. HNP-2-FSAR, Edwin I. Hatch Nuclear Plant Final Safety Analysis Report, Revision 38, September 2020, Section 5.4.6.3.1, "Reactor Pressure Vessel."

4. HNP-1-FSAR, Edwin I. Hatch Nuclear Plant Final Safety Analysis Report, Revision 38, September 2020, Section 7.8.5.5, "Reactor Vessel Top Head Flange Leakage Detection."

5. HNP-2-FSAR, Edwin I. Hatch Nuclear Plant Final Safety Analysis Report, Revision 38, September 2020, Section 5.6.2.5, "RPV Top Head Flange Leakage Detection," and 5.2.7.2.2.1, "Reactor Vessel Head Seal Leak Detection."

6. Letter from C. R. Pierce (SNC) to the Document Control Desk (NRC), "Edwin I. Hatch Nuclear Plant – Unit 2 Relief Request Reactor Pressure Vessel Stud Inspection," dated February 17, 2017 (NRC ADAMS Accession No. ML17048A090).

7. Letter from M. T. Markley (NRC) to J. J. Hutto (SNC), "Edwin I Hatch Nuclear Plant, Unit 2 – Relief Request HNP-ISI-RR-05-01 Regarding Reactor Pressure Vessel Head Stud Inservice Inspection Requirements (CAC NO. MF9271)," dated August 10, 2017 (NRC ADAMS Accession No. ML17205A345).

8. Letter from C. A. Gayheart (SNC) to the Document Control Desk (NRC), "Edwin I. Hatch Nuclear Plant – Unit 2 Relief Request Reactor Pressure Vessel Stud HNP-ISI-RR-05-02," dated November 5, 2018 (NRC ADAMS Accession No. ML18309A272).

9. Letter from M. T. Markley (NRC) to C. A. Gayheart (SNC), "Edwin I Hatch Nuclear Plant, Unit 2 – Relief Request HNP-ISI-RR-05-02 Regarding Reactor Pressure Vessel Head Stud Inservice Inspection Requirements (EPID L-2018-LLR-0137)," dated February 6, 2019 (NRC ADAMS Accession No. ML19035A550).

10. EPRI Report 30020114589, "Technical Basis for Optimization of the Volumetric Examination Frequency for Reactor Vessel Studs," November 2018.

11. U. S. NRC Regulatory Guide 1.65, "Materials and Inspections for Reactor Vessel Closure Studs," October 1973.

Edwin I. Hatch Nuclear Plant – Units 1 and 2
Request to Relax the Required Number of Fully Tensioned Reactor Pressure Vessel Head
Closure Studs in Technical Specification Table 1.1-1, "MODES"

NL-22-0406

Attachment 1

HNP Units 1 and 2 Technical Specifications Marked-up Pages

Table 1.1-1 (page 1 of 1)
MODES

MODE	TITLE	REACTOR MODE SWITCH POSITION	AVERAGE REACTOR COOLANT TEMPERATURE (°F)
1	Power Operation	Run	NA
2	Startup	Refuel[(a)] or Startup/Hot Standby	NA
3	Hot Shutdown[(a)]	Shutdown	> 212
4	Cold Shutdown[(a)]	Shutdown	≤ 212
5	Refueling[(b)]	Shutdown or Refuel	NA

(a) All required reactor vessel head closure bolts fully tensioned. The required number of head closure bolts is at least 51 of 52 bolts.

(b) One or more required reactor vessel head closure bolts less than fully tensioned.

Table 1.1-1 (page 1 of 1)
MODES

MODE	TITLE	REACTOR MODE SWITCH POSITION	AVERAGE REACTOR COOLANT TEMPERATURE (°F)
1	Power Operation	Run	NA
2	Startup	Refuel[a] or Startup/Hot Standby	NA
3	Hot Shutdown[a]	Shutdown	> 212
4	Cold Shutdown[a]	Shutdown	≤ 212
5	Refueling[b]	Shutdown or Refuel	NA

(a) All required reactor vessel head closure bolts fully tensioned. The required number of head closure bolts is at least 54 of 56 bolts, with a minimum of nine bolts between the two out of service bolts.

(b) One or more required reactor vessel head closure bolts less than fully tensioned.

Edwin I. Hatch Nuclear Plant – Units 1 and 2
Request to Relax the Required Number of Fully Tensioned Reactor Pressure Vessel Head
Closure Studs in Technical Specification Table 1.1-1, "MODES"

NL-22-0406

Attachment 2

HNP Units 1 and 2 Technical Specifications Revised Pages

Table 1.1-1 (page 1 of 1)
MODES

MODE	TITLE	REACTOR MODE SWITCH POSITION	AVERAGE REACTOR COOLANT TEMPERATURE (˚F)
1	Power Operation	Run	NA
2	Startup	Refuel[(a)] or Startup/Hot Standby	NA
3	Hot Shutdown[(a)]	Shutdown	> 212
4	Cold Shutdown[(a)]	Shutdown	≤ 212
5	Refueling[(b)]	Shutdown or Refuel	NA

(a) All required reactor vessel head closure bolts fully tensioned. The required number of head closure bolts is at least 51 of 52 bolts.

(b) One or more required reactor vessel head closure bolts less than fully tensioned.

Table 1.1-1 (page 1 of 1)
MODES

MODE	TITLE	REACTOR MODE SWITCH POSITION	AVERAGE REACTOR COOLANT TEMPERATURE (°F)
1	Power Operation	Run	NA
2	Startup	Refuel[(a)] or Startup/Hot Standby	NA
3	Hot Shutdown[(a)]	Shutdown	> 212
4	Cold Shutdown[(a)]	Shutdown	≤ 212
5	Refueling[(b)]	Shutdown or Refuel	NA

(a) All required reactor vessel head closure bolts fully tensioned. The required number of head closure bolts is at least 54 of 56 bolts, with a minimum of nine bolts between the two out of service bolts.

(b) One or more required reactor vessel head closure bolts less than fully tensioned.

Edwin I. Hatch Nuclear Plant – Units 1 and 2
Request to Relax the Required Number of Fully Tensioned Reactor Pressure Vessel Head
Closure Studs in Technical Specification Table 1.1-1, “MODES”

NL-22-0406

Enclosure 2

Calculation C-037-2201-00-01, “Hatch Unit 1 Operation with One Stud Out of Service Evaluation”

RECORD OF REVISIONS

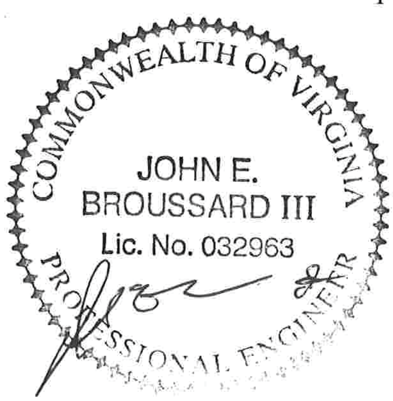
Rev.	Description	Prepared by Date	Checked by Date	Reviewed by Date	Approved by Date
0	Original Issue	J.E. Broussard 7/11/22 J.E. Broussard Principal Engineer	CR Casarez 7/11/2022 C.R. Casarez Senior Engineer	CR Casarez 7/11/2022 C.R. Casarez Senior Engineer	G.A. White 7/11/2022 G.A. White Principal Engineer

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.

TABLE OF CONTENTS

CERTIFICATION

The original Edwin I. Hatch Nuclear Plant Unit 1 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 1965 Edition of Section III of the ASME Boiler and Pressure Vessel Code, with Addenda through Winter 1966. All requirements of applicable Code revisions are satisfied. This evaluation was performed under Purchase Order number SNG10283093.



John E. Broussard, III, PE. 7/11/2022
Virginia Certificate No. 032963 Date

LIST OF TABLES

LIST OF FIGURES

1 PURPOSE

Dominion Engineering, Inc. (DEI) originally provided optimized tensioning and detensioning procedures for Plant Hatch in April 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-3937-00-02 [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 1 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

3.1 Analysis Inputs

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 1 RPV is 52 [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].

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

6. 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; this table is identical to Table A-1 from Reference [1].
7. 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].
8. 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]. Table 2-1 includes the updated stress values applicable to the conditions evaluated in the report. The following values from Table 2-1 are used in this calculation:
    a. Closure head / head flange maximum stress intensity range: 66.5 ksi [1, Table 2-1]
    b. Vessel closure shell / flange maximum stress intensity range: 50.1 ksi [1, Table 2-1]
    c. Closure stud membrane stress, maximum service load: 46.2 ksi [1, Table 2-1]
    d. Closure stud maximum stress, maximum service load: 101.5 ksi [1, Table 2-1]
    e. Closure stud fatigue usage: 0.454 [1, Table 2-1]
    f. Closure head / head flange fatigue usage: 0.080 [1, Table 2-1]
    g. Vessel closure shell / flange fatigue usage: 0.268 [1, Table 2-1]
9. 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: 21.9 ksi [2, p. A-7]
    b. Vessel closure shell / flange general membrane stress: 25.5 ksi [2, p. A-7]
    c. Closure head / head flange local membrane + bending stress: 26.9 ksi [2, p. A-7]
    d. Vessel closure shell / flange local membrane + bending stress: 35.0 ksi [2, p. A-7]

3.2 Acceptance Criteria

The following acceptance criteria are applicable to this calculation:

1. The RPV closure components were designed according to the 1965 Edition with Winter 1966 Addenda of Section III of the ASME Boiler and Pressure Vessel Code [7].
2. The stresses in the closure studs are subject to the following requirements and allowable stresses:

a. Primary stress at 575°F design temperature: 36.3 ksi (S_m) [1, Table 3-3].

b. Maximum allowable average stress, evaluated at 550°F: 73.5 ksi ($2S_m$) [1, Table 2-1]

c. Maximum allowable stress, evaluated at 550°F: 110.3 ksi ($3S_m$) [1, Table 2-1]

3. The stresses in the closure head and vessel are subject to the following requirements and allowable stresses:

   a. Closure head / head flange and vessel closure shell / flange [7, Paragraph N-414.1] general membrane allowable stress at 575°F design temperature: 26.7 ksi (S_m) [1, Table 3-3]

   b. Closure head / head flange and vessel closure shell / flange [7, Paragraph N-414.3] primary local membrane + bending allowable stress at 575°F design temperature: 40.05 ksi ($1.5S_m$) [1, Table 3-3]

   c. Closure head / head flange and vessel closure shell /flange [7, Paragraph N-414.4] maximum allowable stress intensity range, evaluated at 575°F design temperature: 80.10 ksi ($3S_m$) [1, Table 2-1]

4. The maximum allowable fatigue usage factor is 1.0 [7, Paragraph N-415.2(d)(6)].

5. The minimum o-ring springback is 0.010 inch [1, Table 3-2]. Although this is not an ASME Code criterion, it is a condition evaluated to demonstrate the flange opening will not result in additional risk of leakage. The design basis report does not calculate any o-ring opening at operating conditions [1, Table 3-2].

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. This assumption is appropriate given the small bending stiffness of the studs relative to the overall head cross section.

4. The design pressure is assumed to act out to the radius of the inner o-ring of the vessel. This is an appropriate assumption because leakage past the inner o-ring is not a normal operating condition.

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 ν = 0.3. All stud elements were assigned material properties appropriate for low alloy steel at ambient temperature: E = 29.9E6 psi and ν = 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 in Reference [1] from the correlation between the model predictions and the actual stud elongation data using the original plant tensioning procedure.
10. All studs are assumed to be initially uniformly tensioned to the target stud elongation of 0.0432 inch, equivalent to a stud stress of 40.403 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 51 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:

$$\bar{F} = \frac{PA_h}{51} = \frac{P(\pi R_i^{\,2})}{51} = \frac{(1235\text{ psig})(\pi \times 111.0^2\text{ in}^2)}{51} = 937.3\text{ kips} \qquad [5\text{-}1]$$

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 (51/52)×937.3 = 919.3 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

$$\sum F_z = \sum_i F_i - PA_h = 0$$

$$\sum M_n = \sum_i F_i(x_i - \delta) - PA_h(-\delta) = 0 \qquad [5\text{-}2]$$

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.

$$x_i = R_o \cos\theta_i\,, \text{ where } \theta_i = \left(\frac{i-27}{52}\right) \times 2\pi \qquad [5\text{-}3]$$

At this point, we assume per Assumption 1 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

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

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

$$\sum_i \left(\bar{F} + f(x_i - \delta)\right) - PA_h = 0 \;\rightarrow\; \sum_i f(x_i - \delta) = 0 \;\rightarrow$$
$$\delta = \frac{1}{51}\sum_i x_i = \frac{R_o}{51}\sum_i \cos\theta_i \qquad [5\text{-}5]$$

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

$$\sum_i \left(\bar{F} + f(x_i - \delta)\right)(x_i - \delta) - PA_h(-\delta) = 0 \;\rightarrow$$
$$\sum_i \left(\bar{F} + f(R_o \cos\theta_i - \delta)\right)(R_o \cos\theta_i - \delta) + PA_h\delta = 0 \;\rightarrow \qquad [5\text{-}6]$$
$$f = \left(\frac{-PA_h\delta - \sum_i \bar{F} R_o \cos\theta_i + 51\bar{F}\delta}{\sum_i {R_o}^2 \cos^2\theta_i - \sum_i 2R_o\delta\cos\theta_i + 51\delta^2}\right)$$

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 52, 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 35.48 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) compare the calculated single stud out of service condition stresses to 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. The current design basis conditions for the closure flange and closure studs are defined in Inputs 8 and 9, and the associated ASME Code comparisons and allowables are defined in Section 3.2. 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 impact 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 0.0079 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 per Section 3.2.

5.2.4.4 Fatigue

Per Table 3, the stud out of service increases the maximum stress at: (1) the head flange/shell by 1.02 ksi, (2) the vessel flange/shell by 0.40 ksi and (3) the stud by 0.23 ksi; each of these increases are approximately 1-2% of the previous design basis stress. As noted in Input 8, the fatigue usage values in these components are as follows: (1) the head is 0.080, (2) the vessel is 0.268, and (3) the stud is 0.454. These fatigue usage values were calculated for the full service life of the component.

The impact of a 2% 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 $1.02^2 = 1.04$ (4% increase). Increasing the fatigue usage by 4% results in fatigue usage that is well 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 the design basis transients considered as part of the nominal analysis for normal and upset conditions included transients associated with emergency and faulted conditions (although not

specified as such). Therefore, the analyses performed here include consideration of emergency and faulted conditions.

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 _HATCH1.RUNS, _MACROS.HATCH1, and _MACROS.DEI. The _HATCH1.RUNS input listing defines parameters that are used by _MACROS.HATCH1 and _MACROS.DEI to generate the geometry and run the stud out of service analysis cases. The input listings _HATCH1.RUNS and _MACROS.HATCH1 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 037-2201) 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 19.0 which was verified on March 13, 2022, 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

[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).

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 365 on a Dell 5530 Precision Mobile Workstation with an Intel Core i7 processor and running Microsoft Windows 10. The one-time-use Microsoft Excel spreadsheet "Hatch 1 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-3937-00-02, Rev. 0, "Reactor Vessel Tensioning Optimization Stress Report – Hatch Nuclear Plant Unit 1," April 2015.
2. "Analytical Report for Hatch No. 1 Reactor Vessel for Georgia Power Company," Combustion Engineering Report No. CENC-1160, August 1971.
3. Dominion Engineering, Inc. Software Test Report No. STR-9898-00-31, "ANSYS 19.0 Re-Verification on ANSYS-A.DOMENG.COM Software Test Report." Revision 0, March 2022.
4. *Dominion Engineering, Inc. Quality Assurance Manual for Safety-Related Nuclear Work*, DEI-002. Revision 18, November 2010.
5. Dominion Engineering, Inc. Memorandum M-037-2201-00-01, Revision 0, "ANSYS Confirmatory Analysis and Review of Error Reports / QA Notices for C-037-2201-00-01, Rev. 0," June 2022.
6. Dominion Engineering, Inc. Data Disk D-037-2201-00-01, Revision 0, July 2022.
7. ASME Boiler and Pressure Vessel Code, Section III – Rules for Construction of Nuclear Vessels, 1965 Edition with Addenda through Winter 1966.

[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.

Table 1. FEA Model Inputs

Parameter	Units	Hatch Unit 1
Stud and Vessel Parameters		
– Number of Studs	---	52
– 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	40.59
- Corresponding Elongation	in	0.0434
– Design Pressure	psia	1,250
– Stud Effective Length	in	31.972
Tensioning Parameters		
– Max Tensioner Pressure (new)	psi	n/a
– Optimized Sequence Final Pressure (new)	psi	7,250
– Resulting Stud Stress	ksi	40.403
– Tensioner Coefficient, Kt	psi/in	5.573
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	---	0.63
Vessel Flange Dimensions		
– Flange IR	in	109.690
– Inner O-ring Mean Radius	in	111.000
– Reaction Radius	in	112.750
– 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	110.373
– Shell thickness	in	5.875
– Z dim to Bottom of Transition	in	-20.048
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	937.3 kips
Studs Out of Service	1	Neutral axis off: d	2.300 in.
Stud Stress Area, A	27.489	Coefficient f	-319.9 lb/in
Number of Studs	52		

Stud	theta (deg)	cos(theta)	cos^2 (theta)	Fi (kip)	Stress (ksi)
1	-180	untensioned	untensioned	untensioned	untensioned
2	-173	-0.9927	0.99	975.3	35.48
3	-166	-0.9709	0.94	974.5	35.45
4	-159	-0.9350	0.87	973.2	35.40
5	-152	-0.8855	0.78	971.3	35.33
6	-145	-0.8230	0.68	968.9	35.25
7	-138	-0.7485	0.56	966.2	35.15
8	-132	-0.6631	0.44	962.9	35.03
9	-125	-0.5681	0.32	959.4	34.90
10	-118	-0.4647	0.22	955.5	34.76
11	-111	-0.3546	0.13	951.4	34.61
12	-104	-0.2393	0.06	947.0	34.45
13	-97	-0.1205	0.01	942.6	34.29
14	-90	0.0000	0.00	938.1	34.13
15	-83	0.1205	0.01	933.5	33.96
16	-76	0.2393	0.06	929.1	33.80
17	-69	0.3546	0.13	924.8	33.64
18	-62	0.4647	0.22	920.6	33.49
19	-55	0.5681	0.32	916.8	33.35
20	-48	0.6631	0.44	913.2	33.22
21	-42	0.7485	0.56	910.0	33.10
22	-35	0.8230	0.68	907.2	33.00
23	-28	0.8855	0.78	904.8	32.92
24	-21	0.9350	0.87	903.0	32.85
25	-14	0.9709	0.94	901.6	32.80
26	-7	0.9927	0.99	900.8	32.77
27	0	1.0000	1.00	900.5	32.76
28	7	0.9927	0.99	900.8	32.77
29	14	0.9709	0.94	901.6	32.80
30	21	0.9350	0.87	903.0	32.85
31	28	0.8855	0.78	904.8	32.92
32	35	0.8230	0.68	907.2	33.00
33	42	0.7485	0.56	910.0	33.10
34	48	0.6631	0.44	913.2	33.22
35	55	0.5681	0.32	916.8	33.35
36	62	0.4647	0.22	920.6	33.49
37	69	0.3546	0.13	924.8	33.64
38	76	0.2393	0.06	929.1	33.80
39	83	0.1205	0.01	933.5	33.96
40	90	0.0000	0.00	938.1	34.13
41	97	-0.1205	0.01	942.6	34.29
42	104	-0.2393	0.06	947.0	34.45
43	111	-0.3546	0.13	951.4	34.61
44	118	-0.4647	0.22	955.5	34.76
45	125	-0.5681	0.32	959.4	34.90
46	132	-0.6631	0.44	962.9	35.03
47	138	-0.7485	0.56	966.2	35.15
48	145	-0.8230	0.68	968.9	35.25
49	152	-0.8855	0.78	971.3	35.33
50	159	-0.9350	0.87	973.2	35.40
51	166	-0.9709	0.94	974.5	35.45
52	173	-0.9927	0.99	975.3	35.48

Table 3. Stress Increase Due to Stud Out of Service

Load Condition	Stud Condition	Load Case	Shell Stresses (ksi) (1) Gen. Membrane Head	Gen. Membrane Vessel	Local Memb.+Bend. Head	Local Memb.+Bend. Vessel	Maximum SI Head	Maximum SI Vessel	Stud Stresses (ksi) Max Membrane	Memb+ Bending	Flange Separation (10^-3 in)
Preload Only	Normal	A1	0.08	0.33	27.00	22.12	27.89	22.41	40.41	93.02	13.9
Preload Only	1 Untensioned	B1	0.11	0.34	27.02	22.13	27.90	22.42	40.41	93.05	14.0
Preload Only	1 Failed	C1	0.10	0.33	27.01	22.13	27.90	22.42	43.77	93.04	14.0
Preload+Pressure	Normal	A2	22.12	23.36	37.70	36.89	37.53	36.39	37.79	104.94	17.6
Preload+Pressure	1 Untensioned	B2	22.13	23.37	38.47	36.92	38.55	36.44	40.13	105.02	25.5
Preload+Pressure	1 Failed	C2	22.12	23.37	37.97	37.28	38.06	36.79	42.77	105.17	23.3
Max. Increase from A2 (Cases B2 & C2)			0.01	0.00	0.77	0.39	1.02	0.40	4.98	0.23	7.9
Limiting Vessel Report Value			21.9	25.5	26.9	35.0	66.5	50.1	46.2	101.5	--
New Maximum Value			**21.9**	**25.5**	**27.7**	**35.4**	**67.5**	**50.5**	**51.2**	**101.7**	**7.9**
Code Stress Limit			Sm = **26.7**	Sm = **26.7**	1.5 Sm = **40.1**	1.5 Sm = **40.1**	3 Sm = **80.1**	3 Sm = **80.1**	2 Sm = **73.5**	3 Sm = **110.3**	

(1) 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).

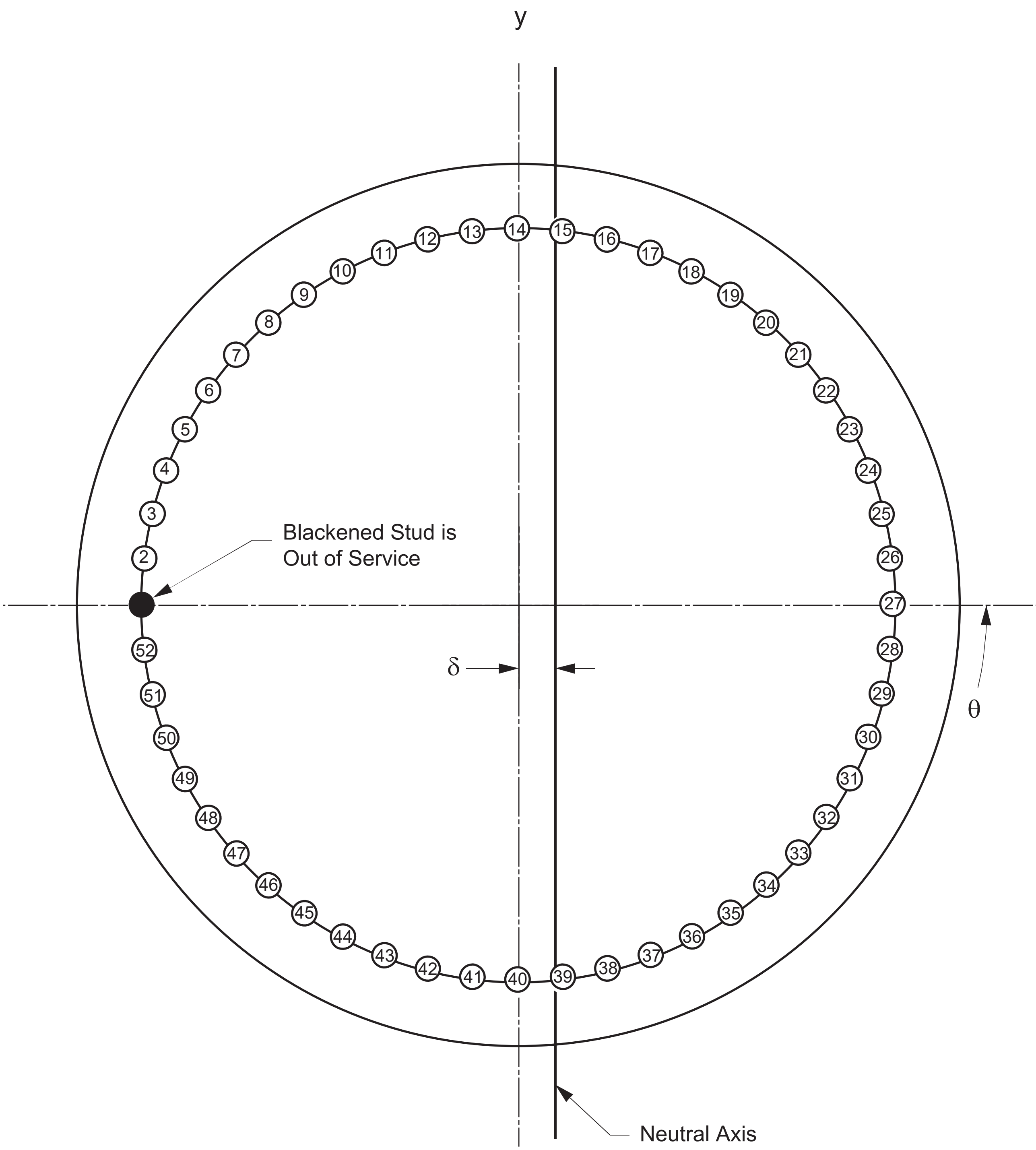


Figure 1. Reactor Vessel Head Stud Geometry, One Stud Out of Service

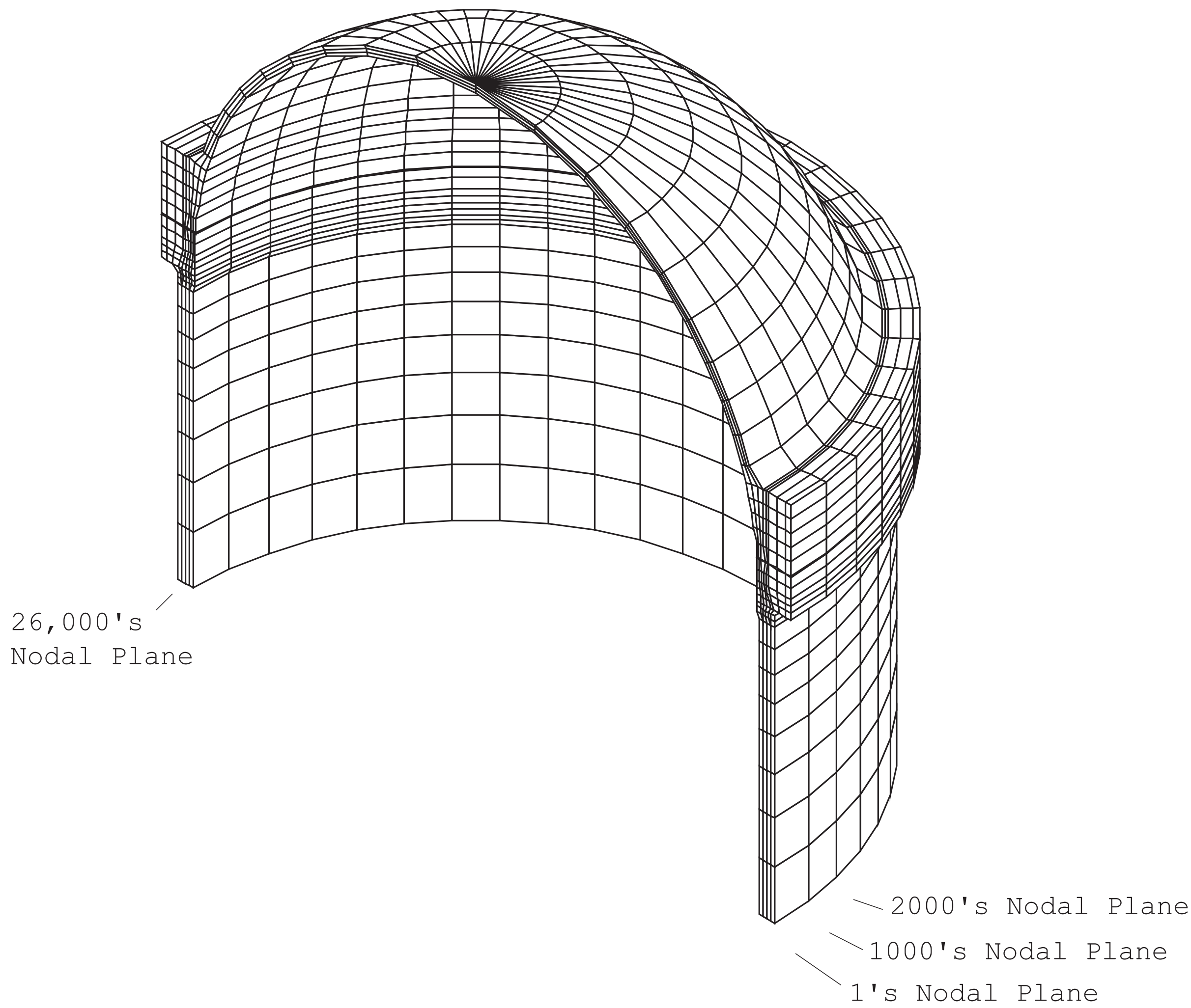


Figure 2. Hatch Unit 1 RPV Closure Flange FEA Model Overall View [1]

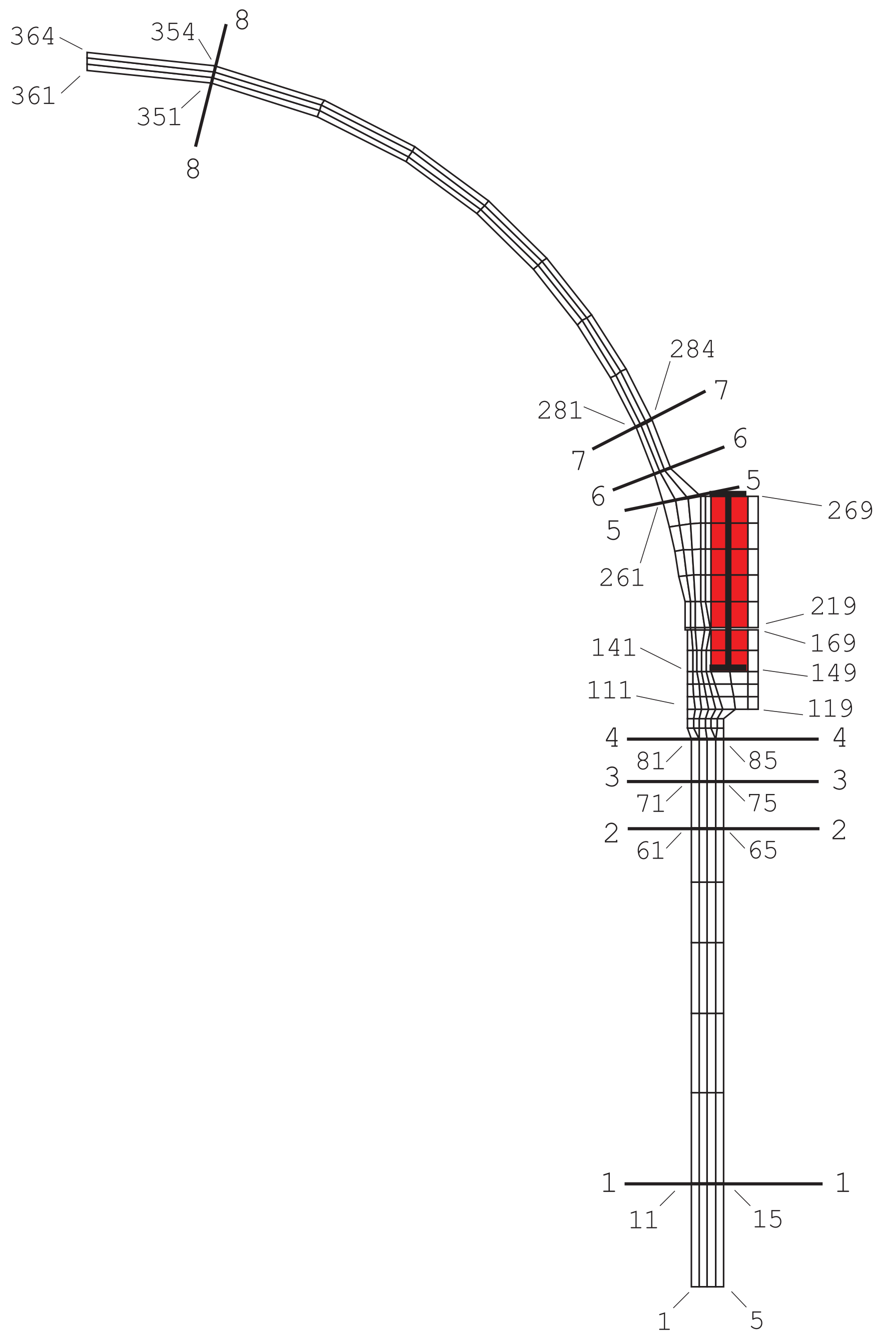


Figure 3. FEA Model Node Numbering and Section Cut Line Locations [1]

A FINITE ELEMENT ANALYSIS INPUT LISTINGS

A.1 File: _HATCH1.runs

```
/BATCH,LIST
/COM,
/COM, ********************************************************************************
/COM,     Hatch Unit 1 Stud Out of Service Evaluation
/COM, ********************************************************************************
/COM,
/INP,_MACROS,HATCH1
/INP,_MACROS,DEI
/COM,
/COM, ********************************************************************************
/COM,     PRE-RUN SETUP
/COM, ********************************************************************************
/COM,
/FILNAM,Tens-1
/SHOW,plots,grph
/TYPE,1,4
/PREP7
/TITLE, Hatch1 Reactor Vessel Tensioning
/COM, Define run parameters
NT = 52                              ! Total number of studs in model
NV = 52                              ! Total number of studs in real vessel
NPMAX = 52*3                         ! Max number of studs any sequence
TENSMX = 7                           ! Max number of Tens-* routines
XS = 40403                           ! Final stud stress target for old tensioner
XP = 7250                            ! Corresponding tensioner pressure
Pmax = 8600                          ! Tensioner pressure cap
X1 = 0.98                            ! Empirical correction factor (init guess)
X2 = 0.95                            ! Empirical correction factor (init guess)
Kt = XS*X2/XP                        ! Relate tensioner pressure to stud stress
RLMAX = 54                           ! 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, Hatch1 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                                    ! FIGURE A-1
ESEL,S,ELEM,,41,290
ESEL,A,ELEM,,1041,1290
NSLE
/PNUM,MAT,1
/NUM,1
/AUTO
EPLO                                    ! FIGURE A-2
ESEL,S,TYPE,,1
ESEL,R,ELEM,,1,1000
NSEL,S,NODE,,1,1000
/VIEW
EPLO                                    ! FIGURE A-3
*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                                    ! FIGURE A-4
/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                                    ! FIGURE A-5
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,'Hatch1','Tens-1',1      ! Solve model
   X1 = X2*XS/RLIST(10,3)               ! X1 is ref. stress/av. stud stress - single stud
   X2 = X2*XS/RLIST(1,3)                ! X2 is ref. stress/av. stud stress - all studs
```

```
   Kt = XS*X2/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,'Hatch1','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,'Hatch1','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, Hatch1 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,'Hatch1','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,'Hatch1','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
   *USE,GEOMCLUP
   *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,'Hatch1','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,'Hatch1','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,'Hatch1','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,'Hatch1','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
/COM,
/TITLE, Hatch1 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.HATCH1

```
/COM, --------------- MACROS.HATCH1, Revision 1, Created May 2022  ----------------
/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     = 31.972                    ! 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  = 0.63*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     = 112.75                    ! >>> 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   = 110.373                    ! Vessel shell inside radius
VSTH   =  5.875                    ! Vessel shell thickness
ZVTR   =-20.048                    ! 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,ZVTR                      ! SHELL I.R. AT BOTTOM OF FLANGE
N,85,VSIR+VSTH,ZVTR                 ! 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
*DO,I,1,NT
   CP,I,UX,164+(I-1)*1000,204+(I-1)*1000
   CP,100+I,UY,164+(I-1)*1000,204+(I-1)*1000
*ENDDO
/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,,164,99164,1000
      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, Include nodes in core barrel groove and up to 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
   CMDELE,NHEAD
   CMDELE,EHEAD
   CMDELE,NVESSEL
   CMDELE,EVESSEL
   CMDELE,NHEADR
   CMDELE,EHEADR
   EDELE,ALL
   NDELE,ALL
*END
/COM,
/COM, ----------------------------------------------------------------------------------
/COM,     END GEOMCLUP 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 Z 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+151                      ! Node 151
   NNUM2 = (J-1)*1000+159                      ! Node 159
   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,
```

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-037-2201-00-01 [6] in their native electronic formats. This data disk is retained with the Task 037-2201 project file and is available for on-site review by Southern Nuclear personnel.

File Name	Description
_HATCH1.RUNS	Input file which sets run parameters and performs the closure flange evaluation cases.
_MACROS.HATCH1	Input file which sets the finite element model geometry and boundary conditions specific to the Hatch Unit 1 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.
HATCH1.out	Full output file generated automatically which includes every ANSYS operation performed throughout the analysis.
HATCH1.err	Automatically generated error file which includes all warnings generated during the analysis.
Hatch 1 Stud Primary Stress Calc v0.xlsx	Microsoft Excel spreadsheet used to perform stud primary stress calculations.

Edwin I. Hatch Nuclear Plant – Units 1 and 2
Request to Relax the Required Number of Fully Tensioned Reactor Pressure Vessel Head
Closure Studs in Technical Specification Table 1.1-1, "MODES"

NL-22-0406

Enclosure 3

Calculation C-037-2201-00-02, "Hatch Unit 2 Operation with Two Studs Out of Service Evaluation"

Title: Hatch Unit 2 Operation with Two Studs Out of Service Evaluation

Calculation No.: C-037-2201-00-02 Revision No.: 0

RECORD OF REVISIONS

Rev.	Description	Prepared by Date	Checked by Date	Reviewed by Date	Approved by Date
0	Original Issue	J.E. Broussard 7/11/2022 J.E. Broussard Principal Engineer	D.J. Gross 7/11/2022 D.J. Gross Principal Engineer	D.J. Gross 7/11/2022 D.J. Gross Principal Engineer	G.A. White 7/11/2022 G.A. White 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.

TABLE OF CONTENTS

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 SNG10283093.

COMMONWEALTH OF VIRGINIA
JOHN E. BROUSSARD III
Lic. No. 032963
PROFESSIONAL ENGINEER

7/11/22

John E. Broussard, III, PE. Date
Virginia Certificate No. 032963

List of Tables

List of Figures

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. A subsequent calculation performed for Hatch Unit 2 in February 2017 [3] demonstrated the acceptability of operating Unit 2 with one stud out of service. The purpose of this calculation is to provide an update to these evaluations that considers the effect of two studs out of service. This analysis considers the stresses resulting from two conditions which bound the effects of studs out of service: (1) operating with two studs left untensioned, and (2) the unlikely condition of two studs that are tensioned then fail in service. The analysis of record for operating with one stud out of service should remain the original analysis performed in February 2017 [3].

2 SUMMARY OF RESULTS

The average stresses in the studs due to primary load conditions with two studs 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 two studs out of service.

The FEA model which was used to develop the current stud tensioning evaluations in DEI Report R-3937-00-01 [1] and DEI Calculation C-3944-00-01 [3] was used to perform an analysis of the closure flange with two studs out of service, as summarized in Section 5.2. **A further restriction is placed on operating with two studs out of service: the two studs must be separated by nine or more studs (e.g., studs 1 and 10 out of service would meet this restriction).** The analysis results are summarized in Table 3. As demonstrated by the results in Table 3, operation of the Hatch Unit 2 RPV with two studs out of service, with a minimum of nine studs between them, does not result in any component of the RPV closure flange to exceed the design basis ASME Code allowables.

3 INPUT REQUIREMENTS

3.1 Analysis Inputs

The following inputs are required to calculate the average stresses in the studs due to primary load conditions with two studs 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].

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

6. 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, which is reproduced from Table A-1 of Reference [1].
7. 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].
8. 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. The following values from Table 2-1 are used in this calculation:
   a. Closure head / head flange maximum stress intensity range: 64.0 ksi [1, Table 2-1]
   b. Vessel closure shell / flange maximum stress intensity range: 47.4 ksi [1, Table 2-1]
   c. Closure stud membrane stress, maximum service load: 45.3 ksi [1, Table 2-1]
   d. Closure stud maximum stress, maximum service load: 95.4 ksi [1, Table 2-1]
   e. Closure stud fatigue usage: 0.846 [1, Table 2-1]
   f. Closure head / head flange fatigue usage: 0.178 [1, Table 2-1]
   g. Vessel closure shell / flange fatigue usage: 0.679 [1, Table 2-1]
9. 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 [2, p. A-16]
   b. Vessel closure shell / flange general membrane stress: 23.8 ksi [2, p. A-16]
   c. Closure head / head flange local membrane + bending stress: 37.9 ksi [2, p. A-7]
   d. Vessel closure shell / flange local membrane + bending stress: 37.5 ksi [2, p. A-7]

3.2 Acceptance Criteria

The following acceptance criteria are applicable to this calculation:

1. The RPV closure components were designed according to the 1968 Edition with Summer 1970 Addenda of Section III of the ASME Boiler and Pressure Vessel Code [8].
2. The stresses in the closure studs are subject to the following requirements and allowable stresses:
    a. Primary stress at 575°F design temperature: 36.3 ksi (S_m) [1, Table 3-3].
    b. Maximum allowable average stress, evaluated at 550°F: 73.5 ksi ($2S_m$) [1, Table 2-1]
    c. Maximum allowable stress, evaluated at 550°F: 99.2 ksi ($2.7S_m$) [1, Table 2-1]
3. The stresses in the closure head and vessel are subject to the following requirements and allowable stresses:
    a. Closure head / head flange and vessel closure shell / flange [8, Paragraph N-414.1] general membrane allowable stress at 575°F design temperature: 26.7 ksi (S_m) [1, Table 3-3]
    b. Closure head / head flange and vessel closure shell / flange [8, Paragraph N-414.3] local membrane + bending allowable stress at 575°F design temperature: 40.05 ksi ($1.5S_m$) [1, Table 3-3]
    c. Closure head / head flange and vessel closure shell /flange [8, Paragraph N-414.4] maximum allowable stress intensity range, evaluated at 575°F design temperature: 80.10 ksi ($3S_m$) [1, Table 2-1]
4. The maximum allowable fatigue usage factor is 1.0 [8, Paragraph N-415.2(e)(6)].
5. The minimum o-ring springback is 0.010 inch [1, Table 3-2]. Although this is not an ASME Code criterion, it is a condition evaluated to demonstrate the flange opening will not result in additional risk of leakage. The design basis report maximum o-ring opening is 0.0015 inch [1, Table 3-2].

4 ASSUMPTIONS

The following assumptions are used to calculate the average stresses in the studs due to primary load conditions with two studs 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. This assumption is appropriate given the small bending stiffness of the studs relative to the overall head cross section.
4. The design pressure is assumed to act out to the radius of the inner o-ring of the vessel. This is an appropriate assumption because leakage past the inner o-ring is not a normal operating condition.
5. Stud primary membrane stress is calculated by conservatively assuming the two out-of-service studs to be adjacent to each other.

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

6. 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.
7. 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.
8. 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.
9. 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 with all studs active, 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.
10. 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.
11. 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 Two studs Out of Service*

The effect of two studs 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 studs will tend to create a larger primary load in the studs adjacent to the inactive studs.

We treat the studs as a single cross section loaded in bending by the pressure on the reactor head. Assuming two adjacent studs are 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 54 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:

$$\bar{F} = \frac{PA_h}{54} = \frac{P\left(\pi {R_i}^2\right)}{54} = \frac{(1235\ \text{psig})(\pi \times 111.0^2\ \text{in}^2)}{54} = 885.3\ \text{kips} \qquad [5\text{-}1]$$

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 (54/56)•885.3 = 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

$$\sum F_z = \sum_i F_i - PA_h = 0$$
$$\sum M_n = \sum_i F_i(x_i - \delta) - PA_h(-\delta) = 0 \qquad [5\text{-}2]$$

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. Note that the axes are arranged to split the gap between two studs that are out of service, accounting for an additional one-half stud pitch in the coordinate calculation.

$$x_i = R_o \cos\theta_i \text{, where } \theta_i = \left(\frac{i - (28 + 0.5)}{56}\right) \times 2\pi \qquad [5\text{-}3]$$

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

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

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

$$\sum_i \left(\bar{F} + f(x_i - \delta)\right) - PA_h = 0 \;\rightarrow\; \sum_i f(x_i - \delta) = 0 \;\rightarrow$$
$$\delta = \frac{1}{54}\sum_i x_i = \frac{R_o}{54}\sum_i \cos\theta_i \qquad [5\text{-}5]$$

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

$$\sum_i \left(\bar{F} + f(x_i - \delta)\right)(x_i - \delta) - PA_h(-\delta) = 0 \;\rightarrow$$
$$\sum_i \left(\bar{F} + f(R_o \cos\theta_i - \delta)\right)(R_o \cos\theta_i - \delta) + PA_h\delta = 0 \;\rightarrow \qquad [5\text{-}6]$$
$$f = \left(\frac{-PA_h\delta - \sum_i \bar{F}R_o \cos\theta_i + 54\bar{F}\delta}{\sum_i {R_o}^2 \cos^2\theta_i - \sum_i 2R_o\delta\cos\theta_i + 54\delta^2}\right)$$

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 55, as might be expected since these are adjacent to the untensioneds stud (Nos. 1 and 56).

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 34.74 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 Two Studs Out of Service

5.2.1 Evaluation Methodology

The effect of two studs 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 two studs out of service under preload plus design pressure conditions, (2) determine the increase in the stresses when going from the intact to the two studs 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) compare the calculated two studs out of service condition stresses to ASME Code requirements.

The two studs out of service are not adjacent to each other in this evaluation. In order to meet all defined acceptance criteria, the two out of service studs must be separated by at least nine tensioned and in service studs.

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 2 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.

Untensioned studs are 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. The condition for two studs out of service is simulating by considering stud number 6 in the model as out of service; because of model symmetry (see Section 5.2.2.2), this condition represents both stud 6 and stud 54 being out of service.

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 two studs untensioned and with all other studs preloaded to the specified initial stress. The two untensioned studs are separated by nine tensioned studs.

- 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 two studs assumed to fail in service. The two studs are separated by nine tensioned studs.
- 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 studs are summarized, and the stresses are compared to the appropriate ASME Code allowables. The current design basis conditions for the closure flange and closure studs are defined in Inputs 8 and 9, and the associated ASME Code comparisons and allowables are defined in Section 3.2. The following evaluations are considered:

5.2.4.1 RPV Closure Stresses

As shown in Table 3, the condition with two studs 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 condition with two studs 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 condition with two studs out of service causes an additional flange separation at the o-ring of 0.0066 inch. This increase does not impact an ASME Code allowable. The resulting total flange separation in Table 3 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 condition with two studs out of service increases the maximum stress at: (1) the head flange/shell by 1.48 ksi, (2) the vessel flange/shell by 0.42 ksi and (3) the stud by 0.31 ksi; each of these increases are approximately 1-2% 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 2% increase in stress for a single cycle of operation on these components is negligible. Referring to the fatigue curves in the design basis Code [8], 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 two studs out of service, the increase in fatigue usage would be the square of the increase in stress, or $1.02^2 = 1.04$ (4%. increase). Increasing the fatigue usage by 4% results in fatigue usage that is well 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 at least 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 [7] along with other software usage QA records required by the DEI QA program [5]. The contents of this data disk are listed in Appendix B. This data disk is retained with the project file for this task (Task 037-2201) 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 19.0 which was verified on March 13, 2022, as documented in Reference [4]. 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 [5].[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 [6].

---

[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 other nuclear industry vendors.

[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.

The stud primary stress calculations performed in Table 2 were generated using Microsoft Excel 365 on a Dell 5530 Precision Mobile Workstation with an Intel Core i7 processor and running Microsoft Windows 10. 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 [5] and is archived on the data disk associated with this calculation [7].

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. DEI Calculation C-3944-00-01, Rev. 0, "Hatch Unit 2 Operation with One Stud Out of Service Evaluation," February 2017.
4. Dominion Engineering, Inc. Software Test Report No. STR-9898-00-31, "ANSYS 19.0 Re-Verification Software Test Report." Revision 0, March 2022.
5. *Dominion Engineering, Inc. Quality Assurance Manual for Safety-Related Nuclear Work*, DEI-002. Revision 18, November 2010.
6. Dominion Engineering, Inc. Memorandum M-037-2201-00-02, Revision 0, "ANSYS Confirmatory Analysis and Review of Error Reports / QA Notices for C-037-2201-00-02, Rev. 0," June 2022.
7. Dominion Engineering, Inc. Data Disk D-037-2201-00-02, Revision 0, July 2022.
8. 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, Two Studs 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	885.3 kips
Studs Out of Service	2	Neutral axis off:d	4.338 in.
Stud Stress Area, A	27.489	Coefficient f	-581.1 lb/in
Number of Studs	56		

Stud	theta (deg)	cos(theta)	cos^2 (theta)	Fi (kip)	Stress (ksi)
1	-177	untensioned	untensioned	untensioned	untensioned
2	-170	-0.9859	0.97	955.0	34.74
3	-164	-0.9609	0.92	953.3	34.68
4	-158	-0.9239	0.85	950.8	34.59
5	-151	-0.8752	0.77	947.4	34.47
6	-145	-0.8156	0.67	943.4	34.32
7	-138	-0.7456	0.56	938.6	34.14
8	-132	-0.6663	0.44	933.2	33.95
9	-125	-0.5787	0.33	927.2	33.73
10	-119	-0.4837	0.23	920.8	33.50
11	-113	-0.3827	0.15	913.9	33.24
12	-106	-0.2768	0.08	906.6	32.98
13	-100	-0.1675	0.03	899.2	32.71
14	-93	-0.0561	0.00	891.6	32.43
15	-87	0.0561	0.00	884.0	32.16
16	-80	0.1675	0.03	876.4	31.88
17	-74	0.2768	0.08	868.9	31.61
18	-68	0.3827	0.15	861.7	31.35
19	-61	0.4837	0.23	854.8	31.10
20	-55	0.5787	0.33	848.3	30.86
21	-48	0.6663	0.44	842.4	30.64
22	-42	0.7456	0.56	836.9	30.45
23	-35	0.8156	0.67	832.2	30.27
24	-29	0.8752	0.77	828.1	30.13
25	-23	0.9239	0.85	824.8	30.00
26	-16	0.9609	0.92	822.3	29.91
27	-10	0.9859	0.97	820.6	29.85
28	-3	0.9984	1.00	819.7	29.82
29	3	0.9984	1.00	819.7	29.82
30	10	0.9859	0.97	820.6	29.85
31	16	0.9609	0.92	822.3	29.91
32	23	0.9239	0.85	824.8	30.00
33	29	0.8752	0.77	828.1	30.13
34	35	0.8156	0.67	832.2	30.27
35	42	0.7456	0.56	836.9	30.45
36	48	0.6663	0.44	842.4	30.64
37	55	0.5787	0.33	848.3	30.86
38	61	0.4837	0.23	854.8	31.10
39	68	0.3827	0.15	861.7	31.35
40	74	0.2768	0.08	868.9	31.61
41	80	0.1675	0.03	876.4	31.88
42	87	0.0561	0.00	884.0	32.16
43	93	-0.0561	0.00	891.6	32.43
44	100	-0.1675	0.03	899.2	32.71
45	106	-0.2768	0.08	906.6	32.98
46	113	-0.3827	0.15	913.9	33.24
47	119	-0.4837	0.23	920.8	33.50
48	125	-0.5787	0.33	927.2	33.73
49	132	-0.6663	0.44	933.2	33.95
50	138	-0.7456	0.56	938.6	34.14
51	145	-0.8156	0.67	943.4	34.32
52	151	-0.8752	0.77	947.4	34.47
53	158	-0.9239	0.85	950.8	34.59
54	164	-0.9609	0.92	953.3	34.68
55	170	-0.9859	0.97	955.0	34.74
56	177	untensioned	untensioned	untensioned	untensioned

Table 3. Stress Increase Due to Two Studs Out of Service

Load Condition	Stud Condition	Load Case	Shell Stresses (ksi) (1) Gen. Membrane Head	Shell Stresses (ksi) (1) Gen. Membrane Vessel	Shell Stresses (ksi) (1) Local Memb.+Bend. Head	Shell Stresses (ksi) (1) Local Memb.+Bend. Vessel	Shell Stresses (ksi) (1) Maximum SI Head	Shell Stresses (ksi) (1) Maximum SI Vessel	Stud Stresses (ksi) Max Membrane	Stud Stresses (ksi) Memb+ Bending	Flange Separation (10^-3 in)
Preload Only	Normal	A1	0.07	0.28	23.85	18.14	24.63	18.50	37.15	81.68	15.2
Preload Only	1 Untensioned	B1	0.09	0.28	23.87	18.12	24.65	18.52	37.15	81.72	15.2
Preload Only	1 Failed	C1	0.08	0.28	23.86	18.12	24.64	18.51	40.13	81.70	15.2
Preload+Pressure	Normal	A2	22.13	23.49	36.94	34.20	37.03	33.97	34.96	98.04	21.4
Preload+Pressure	1 Untensioned	B2	22.13	23.50	38.40	34.30	38.51	34.07	36.93	98.22	28.0
Preload+Pressure	1 Failed	C2	22.13	23.49	37.61	34.62	37.70	34.39	39.27	98.35	26.1
Max. Increase from A2 (Cases B2 & C2)			0.00	0.01	1.46	0.42	1.48	0.42	4.31	0.31	6.6
Limiting Vessel Report Value			22.50	23.80	37.90	37.50	64.00	47.40	45.30	95.40	1.5
New Maximum Value			**22.50**	**23.81**	**39.36**	**37.92**	**65.48**	**47.82**	**49.61**	**95.71**	**8.1**
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) 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).

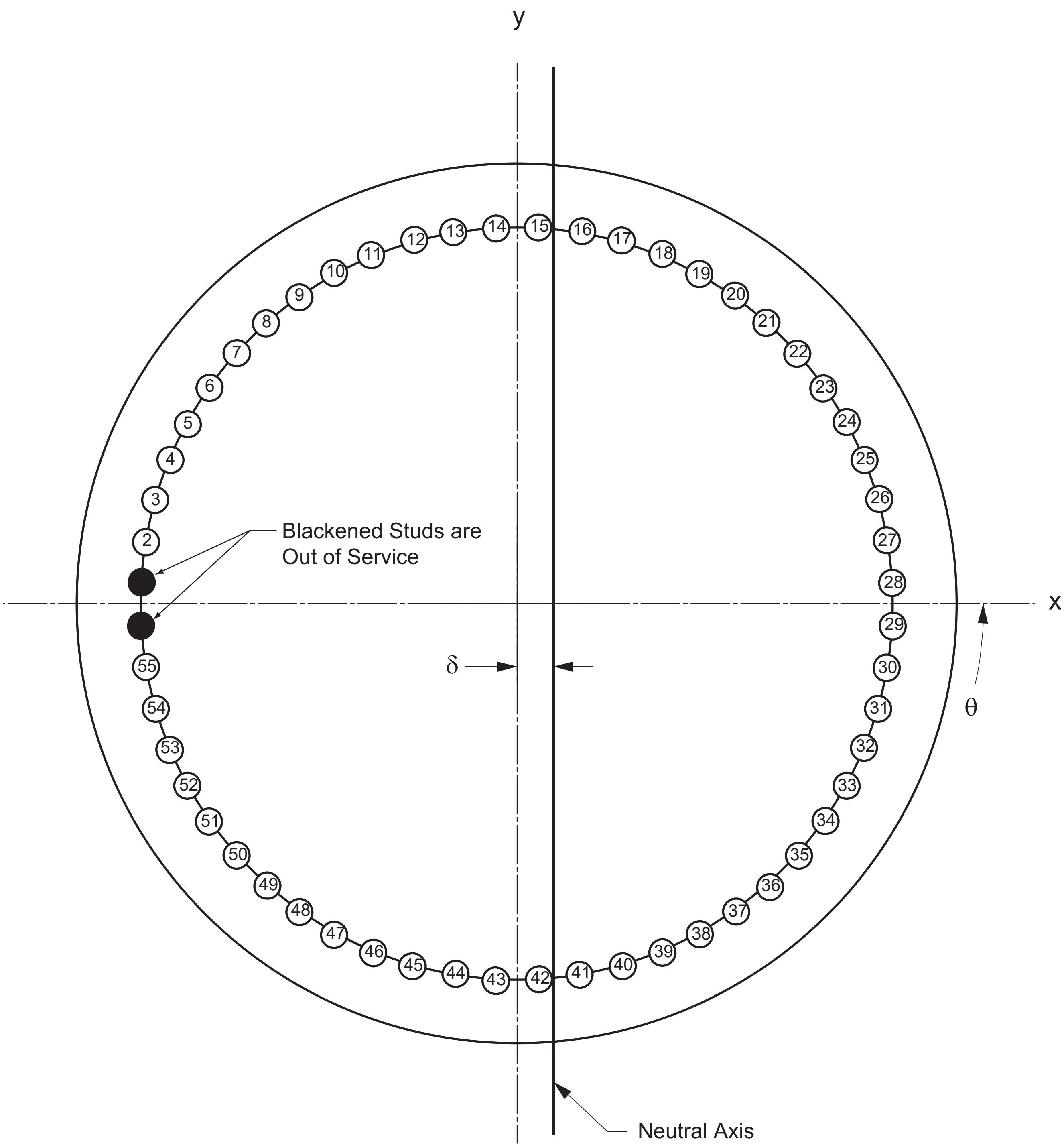


Figure 1. Reactor Vessel Head Stud Geometry, Two Studs Out of Service

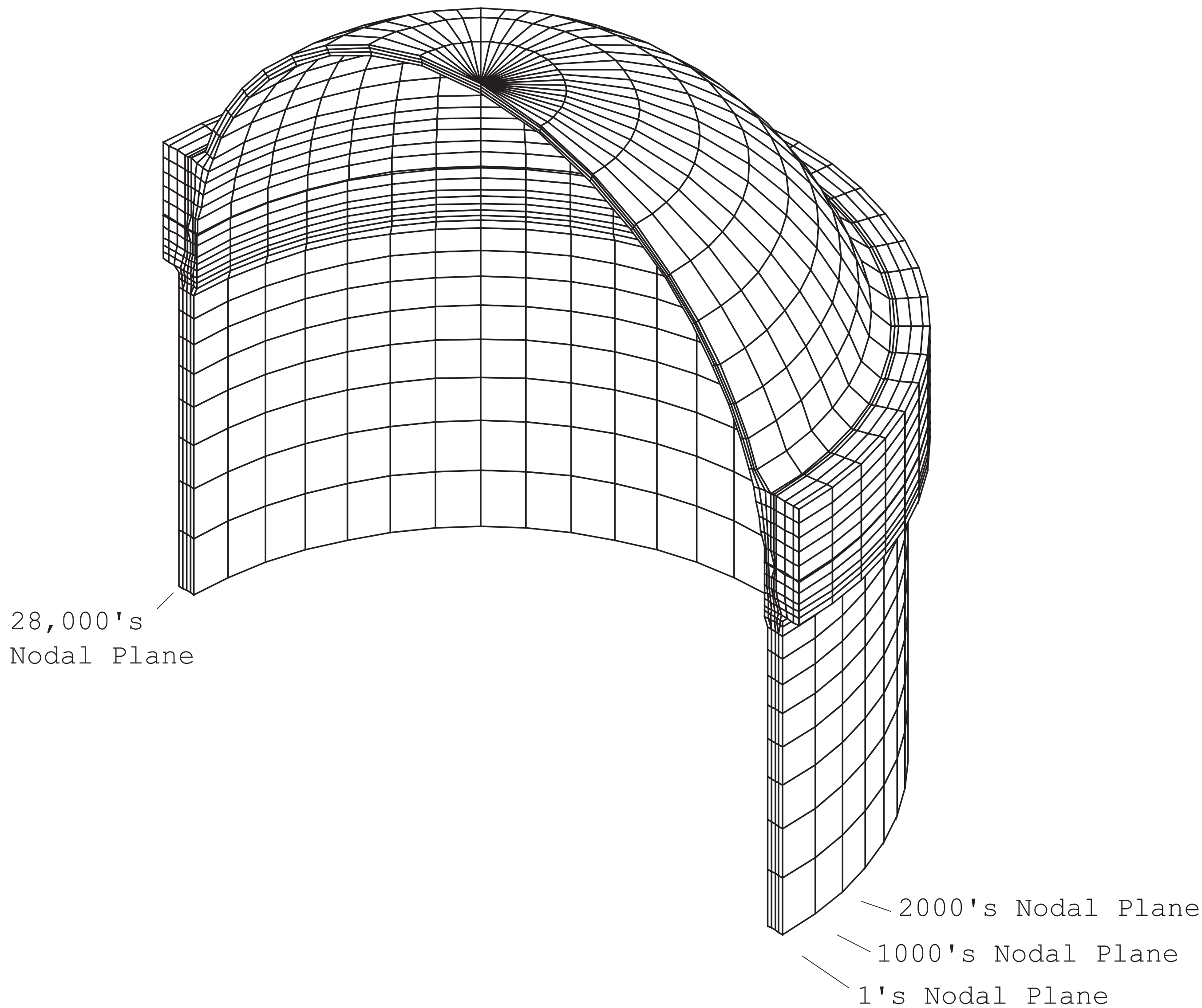


Figure 2. Hatch Unit 2 RPV Closure Flange FEA Model Overall View [1]

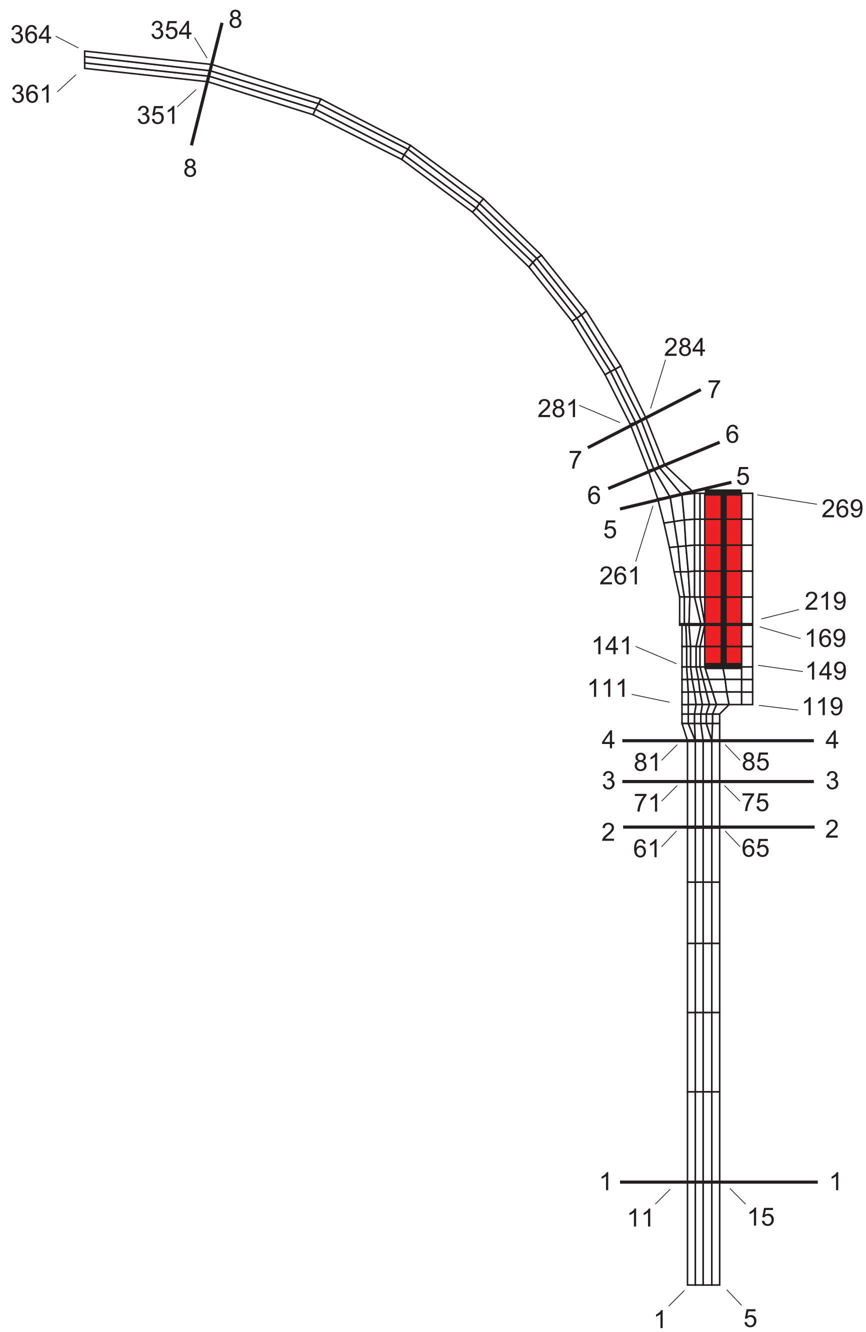


Figure 3. FEA Model Node Numbering and Section Cut Line Locations [1]

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 = 0.98                            ! Empirical correction factor (init guess)
X2 = 0.95                            ! Empirical correction factor (init guess)
Kt = XS*X2/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 = X2*XS/RLIST(10,3)           ! X1 is ref. stress/av. stud stress - single stud
   X2 = X2*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,5502
/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
EDELE,ALL
NDELE,ALL
*USE,GEOM,0                           ! Create geometry
FINISH
/FILN,Tens-10B
/COM, Tension all studs in one pass except stud 6
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,1,5
   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,6,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
/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',5.0,1235    ! Re-Solve model - Case B2
   SAVE,,B2C
   *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',6.0,1235    ! Re-Solve model - Case B2
   SAVE,,B2D
   *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 2, Created May 2022  ----------------
/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,ZVTR                     ! SHELL I.R. AT BOTTOM OF FLANGE
N,85,VSIR+VSTH,ZVTR                ! 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
*DO,I,1,NT
   CP,I,UX,164+(I-1)*1000,204+(I-1)*1000
   CP,100+I,UY,164+(I-1)*1000,204+(I-1)*1000
*ENDDO
/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,,164,99164,1000
      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 GEOMCLUP 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 Z 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+151                       ! Node 151
   NNUM2 = (J-1)*1000+159                       ! Node 159
   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,
```

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-037-2201-00-02 [7] in their native electronic formats. This data disk is retained with the Task 037-2201 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 Two-Stud Primary Stress Calc v0.xlsx	Microsoft Excel spreadsheet used to perform stud primary stress calculations.