ATTACHMENT 6

GE Non-Proprietary Report

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Pilgrim Nuclear Power Station, Shroud Repair Replacement Upper Support Assembly-Stress Analysis Report

(37 pages)

GE Energy, Nuclear

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Pilgrim Nuclear Power Station

Shroud Repair Replacement Upper Support Assembly - Stress Analysis Report

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Revision Control Sheet

Revision	**Date**	Description
Rev. 0 (Draft)	December 11, 2006	Draft Report for Customer Review
Rev 1	March 01, 2007	Incorporated Resolutions to various customer and third party comments.
Rev 2	March 09, 2007	• Incorporated additional customer and third party comments [[•]]
Rev. 3	March 12, 2007	Identical to Rev 2. However the pdf version of Rev 2 as loaded into the e-DRF was inadvertently missing a few pages at the end. This revision 3 was created to fix this problem. There is no change in the content of the report.
Rev 4	March 14, 2007	Added Proprietary Information identification

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1.0 INTRODUCTION AND BACKGROUND

GE Energy, Nuclear (GE) has provided core shroud repairs using tie rods to several BWR plants including Pilgrim Nuclear Power Station. In the spring of 2006, during an in-vessel visual inspection (IVVI) at a domestic plant, indications were observed in the shroud repair tie rod upper supports made of Alloy X-750 at two of the four shroud tie rod repair locations. The indications emanated from the close vicinity of the sharp corner between the horizontal and vertical legs of the upper support and ran outwardly, at approximately 30° to the horizontal. The cracking mechanism was determined by metallographic and Scanning Electron Microscope (SEM) techniques to be Inter-Granular Stress Corrosion Cracking (IGSCC). Alloy X-750 material is susceptible to IGSCC if subjected to sustained, peak stresses in excess of the BWRVIP-84 (Reference 4) recommended limits.

GE opened an internal evaluation under 10CFR Part 21 to determine if the potential for IGSCC exists in the Alloy X-750 shroud repair components (in the tie rod vertical load path) of other BWR shroud repairs designed by GE. GE used the criterion provided in the BWR Vessels & Internals Project (BWRVIP-84, Reference 4) for the IGSCC susceptibility assessment of the X-750 components. Based on this evaluation, GE determined that the BWRVIP-84 IGSCC criterion ($0.8S_y$) was exceeded for the Pilgrim upper supports. A follow-on evaluation was performed to assess if postulated cracking in the Pilgrim shroud repair upper support could lead to a substantial safety hazard (SSH) during operation till the end of the current operating cycle 16. Based on this evaluation, GE determined that a SSH does not exist for the current operating cycle. However, as a long-term solution to mitigate the potential for IGSCC, the upper supports of the shroud repair are being replaced with new replacement hardware that is more robust from the standpoint of IGSCC.

2.0 SCOPE

The objective of the stress analysis presented in this report is to demonstrate that the proposed shroud repair replacement hardware (upper supports, their associated components, and tie rod nut) depicted in the drawings (Reference 5) satisfies the IGSCC and ASME Code requirements of the design specification data sheet. The shroud repair replacement hardware design, criteria for qualification, analysis approach, results, and conclusions are presented in the following sections.

3.0 REPLACEMENT HARDWARE DESIGN FEATURES

The geometry of the replacement hardware (upper supports, their associated components and tie rod nut) is shown in the Reference 5 drawings. The key components of the replacement hardware are identified in Figure 1. The major load-bearing Alloy X-750 components in the replacement assembly are the upper supports and the tie rod nut. These newly designed components incorporate features that improve their ability to resist IGSCC. These features are (see also Figure 2) as follows:

<u>Generous fillet radius at the corner of the upper support</u>. The original upper support design had no stress relief specified at the 90° corner where the horizontal arm meets the vertical leg of the upper support, resulting in large peak stresses. In the replacement upper support, a generous

semi-elliptical stress-relief has been incorporated. [[
]]

Elimination of one Bolted Connection. The bolted connection between the upper support extension and the two upper support sections of the original design has been eliminated in the replacement upper support design. The elimination of this bolted connection resulted in the elimination of local connection stresses and a more uniform stress profile in the remaining components.

Reduction in the total number of hardware components. The total number of hardware components is reduced from 13 for the original design to 9 for the replacement upper support design. This reduction results in relative ease of installation, reduction of required maintenance and inspection, and a more uniform stress profile between interfacing components.

Sharp edges eliminated. Generous fillet radii are specified at interfaces between mating surfaces and cross section variations. This provision reduces the stress concentration, and in turn reduces maximum stresses at critical cross sections.

Generous root radius for the tie rod nut threads. A generous root radius of [[ ]] is provided for the replacement tie rod nut ACME threads. This helps mitigate peak stress in the threads and hence the susceptibility of the tie rod nut to IGSCC. The finite element analysis of the Tie Rod Nut threads considered a [[ ]] root radius based on the actual measurements by the nut fabricator.

4.0 REPLACEMENT HARDWARE MATERIALS

The materials used in the shroud repair replacement hardware (upper supports, their associated components, and tie rod nut) and their properties are provided in Table 4-1.

Table 4-1. Materials Properties for Replacement Upper Support Components

Component	Material	Properties[1] @ 550 °F (Reference 10)		
Replacement Upper Support Tie Rod Nut Retainer Spring Retainer Pin Top Support Bolt SHCS Screw Support Top Support Locking Nut	ASTM B637 UNS N07750 Type 3 (Alloy X-750)	S_m = 53,300 psi S_y = 92,800 psi S_u = 160,000 psi E = 28.85x106 psi Est = 577,000 psi		
Top Support Locking Pins	SA 479 Type 316 or 316L		316 L	316[2]
		S_m, psi	13,950	17,500
		S_y, psi	15,450	19,450
		S_u, psi	61,600	71,800
		E, psi	25.55×10^6	25.55×10^6
		Est, psi	511,000	511,000

(1) S_m = Design Stress Intensity, S_y = Yield Strength, S_u = Ultimate Strength, E = Young's Modulus, Est = Strain-hardening modulus, psi. = 0.2% of E. Est is used in the elastic-plastic material modeling.

(2) Tie Rod material used as a part of the replacement tie rod nut analysis is XM-19

5.0 STRUCTURAL ANALYSIS

5.1 Design Basis Loads

5.1.1 Effect of TPO RIPDs on the Tie Rod Loads

The applicable loads shown below are consistent with the original design basis of the shroud repair. The effects of thermal power optimization (TPO) Reactor Internal Pressure Differences (RIPDs) across the shroud head and core plate on the tie rod loads were considered. It was determined that the loads in Table 5-1 based on the original design basis remain bounding and applicable to the replacement hardware qualification. While there are several load combinations within each service level, the bounding load within each service level was used in the evaluation of the replacement upper support, for example, the tie rod faulted load combination based on Main Steam Line Break LOCA bounds the load combination based on Recirculation Line Break LOCA.

Table 5-1. Shroud Repair Tie Rod Design Basis Loads (lbs.)

Normal Cond. (Sustained Loads)	Upset Cond. (Seismic)	Upset Cond. (Thermal)	Emergency Cond.	Faulted Cond.
[[				]]

[*Upset thermal loads are very close to and less than Emergency condition loads. For this reason, the Upset thermal qualification of the upper support is based conservatively on Emergency condition stresses using Upset thermal allowables.]

5.1.2 Effect of the Stiffness of the Replacement Upper Support on the Tie Rod Loads

The vertical stiffness of the replacement upper support assembly was determined using finite element methods. Using the replacement upper support stiffness, the net combined stiffness of the tie rod assembly was calculated and compared to the original design basis tie rod assembly stiffness. [[

]]

5.1.3 Effect of the Replacement Upper Support on the Tie Rod Seismic Loads

The effect of the change in the net stiffness is deemed to have negligible effect on the seismic component of the tie rod load.

5.2 Qualification Criteria

5.2.1 IGSCC Criterion

In accordance with the requirement of the design specification data sheet, the maximum tensile principal stress ($P_m + P_b + Q + F$) in the sustained normal loading condition is compared to the IGSCC criterion [[

]] S_y is the ASME Code minimum S_y at the operating temperature (See Table 5-3).

5.2.2 ASME Code Allowable Stress Limits

Per the design specification data sheet, the Normal (Level A), Upset (Level B), Emergency (Level C), and Faulted (Level D) condition allowable stress limits used in this stress analysis are in accordance with the ASME Code (Reference 10). The generic allowable stress limits of ASME Code are summarized in Table 5-2.

Table 5-2. ASME Code Allowable Stress Limits

Service Level	Stress Category	Allowable Limit	
Components Other Than Threaded Fasteners (Ref. 10 NG-3220)			
Levels A & B	P_m	S_m	
	$P_m + P_b$	1.5 S_m	
	$P_m + P_b + Q$	3.0 S_m	
	Shear Stress	0.6 S_m	
	Bearing Stress	S_y	
		1.5 S_y (away from free edge)	
	Σ Fatigue Usage	1.0	
Level C	P_m	1.5 S_m	
	$P_m + P_b$	2.25 S_m	
	Shear Stress	0.9 S_m	
	Bearing Stress	1.5 S_y	
		2.25 S_y (away from free edge)	
Level D	P_m	(*) 2.0 S_m	(*)Conservatively original design basis values used.
	$P_m + P_b$	(*) 3.0 S_m	
	Shear Stress	1.2 S_m	
	Bearing Stress	2.0 S_y	
		3.0 S_y (away from free edge)	
Threaded Structural Fasteners (Ref. 10, NG-3230)			
Levels A & B	P_m (Mechanical Loads)	S_m	
	P_m (Installation Torque)	Min. (1.08 S_y, 0.8 S_u) at installation temperature.	
	$P_m + Q_m$	Min. (0.9 S_y, 2/3 S_u)	
	$P_m + P_b + Q_m + Q_b$	Min. (1.2 S_y, 8/9 S_u)	
	Threads Shear Stress (Primary)	0.6 S_m	

Service Level	Stress Category		Allowable Limit
		Shear Stress (Primary + Secondary)	0.6 S_y
	Under bolt head	Bearing Stress	2.7 S_y
	Shanks, Threads	Σ Fatigue Usage	1.0
Level C	P_m, and (P_m+P_b)		Same as for non-threaded components. If S_u > 100 ksi, then same as Level A/B limits for threaded components.
	Shear Stress		Same as for Level A/B limits for threaded components.
Level D	P_m		Smaller of (2.4 S_m, 0.7 S_u); If S_u>100 ksi, then $2S_m$
	P_m+P_b		Smaller of ($3.6S_m$, $1.05S_u$); If S_u > 100 Ksi, then $3S_m$
	Shear Stress		Smaller of ($0.42S_u$, $0.6S_y$)

Table 5-3. IGSCC Allowable Limit

Service Level	Stress Category	Allowable Limit
Normal Sustained Condition – IGSCC Criterion	$P_m + P_b + Q + F$	[[
		]]

5.3 Analysis Methods

5.3.1 Replacement Upper Support Stress Analysis

A finite element analysis (FEA) of the replacement upper support was performed using the ANSYS computer program (Reference 12). The components in the analysis are shown in Figure 3. As shown in Figure 4, only one-half of the upper support assembly is modeled due to symmetry about vertical plane. The model is composed of ANSYS SOLID 45 (8-node brick) elements. [[

]] The boundary conditions and the loads as shown below were applied to the finite element model.

Boundary Conditions (Figure 5):

- The bearing interface of the horizontal arm of the upper support with the shroud flange was modeled using contact elements with [[ ]]
- The maximum gap that exists in the EDM pocket above the top surface of the upper support was modeled using contact elements. [[ ]]
- The portions of the shroud flange and shroud head flange in contact with the upper support were modeled as supporting blocks.
- The stiffness of the upper stabilizer was represented as a linear spring in the radial direction.
- At the lower end of the upper support the support block contacts the shroud in the close vicinity of the H2 weld. This contact was modeled by treating the shroud as a block.
- Symmetry boundary conditions were also provided about the mid-plane of the upper support assembly.

Load Application:

The upper support load (one half of the tie rod loads shown in Table 5-1) was applied in the downward direction along the tie rod axis (which is slightly skewed away from the shroud bottom at an angle of 1.5 degree relative to the vertical axis), at the annular bearing area between the Support and the Tie Rod Nut. The maximum tensile principal stress due to normal condition sustained load was used for the IGSCC check. The stresses due to Normal, Upset, Emergency, and Faulted condition loads were used for the ASME Code stress evaluation.

The results of this analysis are presented in Section 6.0.

5.3.2 Replacement Tie Rod Nut

The replacement tie rod nut was analyzed using a FEM for the IGSCC check, and by hand calculations for ASME Code evaluations.

An FEA of the replacement tie rod nut ACME threads was performed using the ANSYS computer program (Reference 12). [[

]]

The axisymmetric FEA model of the Tie Rod Nut and Tie Rod threads interface is shown in Figure 15, with all the available threads in engagement. The model was composed of ANSYS PLANE 82 (8-node axisymmetric element with mid side nodes) elements. [[

]]

The boundary conditions are as described below, and the loads specified in Table 5-1 were applied to the finite element model.

Boundary Conditions:

The tie rod nut is supported in the vertical direction as shown in Figure 15.

The tie rod nut and the tie rod are engaged at all the threads. Therefore, contact elements were provided between the threads of the tie rod nut and the tie rod, [[

]] All the threads in engagement were so modeled in the FEA. The outer edge of the support block-to-nut bearing interface is restrained in the radial direction. It permits the entire nut surface free to slide except at the location where it is restrained radially.

Material Properties:

[[

]]

Load Application:

The Normal condition sustained load specified in Table 5-1 was used for the check against the IGSCC criterion, and evaluated based on the elastic-plastic finite element analysis.

The Normal, Upset, Emergency, and Faulted condition loads in Table 5-1 were used for the ASME Code stress evaluation. The ASME Code stresses were evaluated based on hand calculations using elastic analysis methods.

The stress results of this analysis are presented in Section 6.0. The ANSYS analysis results show that the Tie Rod Nut (X-750 material) remains elastic (i.e., there is no plastic deformation) under the sustained load. Figures 16 and 17 show plots of maximum tensile principal stress and maximum total principal strain, respectively.

5.3.3 Other Associated Replacement Upper Support Components

In addition to the above, the following associated replacement upper support components were evaluated for their susceptibility to IGSCC and ASME Code compliance using hand calculations. The results of the calculations are presented in Section 6.0.

Table 5-4. Associated Replacement Upper Support Components

Component Name
Top Support Bolt
Retainer Spring
Locking Nut
Locking Nut Pin
Retainer Pin
SHCS SCREW
Support
Tie Rod Nut (ASME Code evaluations only)

6.0 ANALYSES RESULTS

The replacement hardware components (upper support, tie rod nut and other associated upper support components) were evaluated for their susceptibility to IGSCC and ASME Code stresses, consistent with the acceptance criteria of the design specification data sheet. The total stress (P_m + P_b + Q + F) for all Alloy X-750 components except the replacement Tie Rod Nut satisfies the [[ ]] requirement for IGSCC.' The replacement Tie Rod Nut satisfies the [[ ]] requirement for IGSCC. The calculated membrane and bending stresses for all components meet the ASME Code (Reference 10) allowable stress limits. The results of the structural integrity evaluation are provided in Table 6-1 through Table 6-4.

Table 6-1. Maximum Tensile Principal Stress in X-750 Components in the Replacement Assembly Due to Sustained Normal Condition for IGSCC Evaluation.

Component		See Figure	Max Tensile Principal Stress S1, psi (P_m+P_b+Q+F)	S_y[1], psi	SR = S_1/S_y
Upper Support at Fillet radius (Upper End)	FEA	Fig 6	[[	92,800	[[
Upper Support (Lower End)	FEA			92,800	
Tie Rod Nut threads	FEA	Fig 17		92,800	
Replacement Support Block	FEA			92,800	
Retainer Spring	Hand Calculations			92,800	
Retainer Pin	Hand Calculations			92,800	
SHCS Screw	Hand Calculations			92,800	
Bolt, Top Support	Hand Calculations		]]	92,800	]]

(1) [[
]]

(2) The maximum tensile principal stress is conservatively estimated based on the assumption that the support block is rigid. This value will be reduced by considering the flexibility of the support block providing larger margin. [[
]]

Table 6-2. Stress Intensities for the Replacement Upper Support – ASME Code Compliance

(N -Normal, N(I) - Normal installation load, U1 - Upset Thermal, U2-Upset Seismic, E-Emergency, F-Faulted)

Component Name (Material)	Lvl*	Governing Stress Intensity (psi)				
		See Figure	Stress Type	Max. Stress Intensity, psi	Allowable Stress, psi	Stress Ratio
Replacement Upper Support, at upper end, large radius. (X-750)	N	7, 8	P_m	[[	53,300	[[
		7, 8	P_m+P_b		79,950	
	U2	9, 10	P_m		53,300	
		9, 10	P_m+P_b		79,950	
	U1	11, 12	$P_m+P_b+Q^{(1)}$		159,900	
	E	11, 12	P_m		79,950	
		11, 12	P_m+P_b		119,925	
	F	13, 14	P_m		106,600	
		13, 14	P_m+P_b		159,900	
Replacement Upper Support, at lower end, at bolt holes. (X-750)	N		P_m		53,300	
			P_m+P_b		79,950	
	U2		Pm		53,300	
			P_m+P_b		79,950	
	U1		$P_m+P_b+Q^{(1)}$		159,900	
	E		P_m		79,950	
			P_m+P_b		119,925	
	F		P_m		106,600	
			P_m+P_b		159,900	
Bearing Stress at the interface of the Tie Rod Nut on the Support block. (Good for both components, both X-750)	N		Bearing		92,800	
	U2		Bearing		92,800	
	E		Bearing		139,200	
	F		Bearing	]]	185,600	]]

(1)This stress is conservatively assumed to be the same as Emergency condition (P_m+P_b) stress.

Table 6-3. Stress Intensities for Other Components in the Replacement Assembly – ASME Code Compliance

Component Name (Material)	Lvl*	Governing Stress Intensity (psi)			
		Stress Type	Max. Stress Intensity, psi	Allowable Stress, psi	Stress Ratio
Tie Rod Nut	N	Shear	[[	55,680	[[
		P_m		83,520	
	U2	Shear		55,680	
		P_m		83,520	
	U1	Shear		55,680	
		P_m		83,520	
	E	Shear		55,680	
		P_m		83,520	
	F	Shear		55,680	
		P_m		106,600	
Retainer Spring (X-750)	N(I)	P_m+P_b		79,950	
Retainer Pin (X-750)	N(I)	Shear		31,980	
SHCS Screw (X-750)	N(I)	P_m+P_b		83,520	
Upper Support Bolt	N	P_m		53,300	
	U2	P_m		53,300	
	U1	P_m+P_b+Q		159,900	
	E	P_m		79,950	
	F	P_m		112,000	
Locking Nut Pin (316 L)	N(I)	Shear		8,370	
Locking Nut (316 L)	N(I)	Shear		8,370	
Support (X-750)	N	P_m		53,300	
		P_m+P_b		79,950	
	U2	P_m		53,300	
		P_m+P_b		79,950	
	U1	P_m+P_b+Q		159,900	
	E	P_m		79,950	
		P_m+P_b		119,925	
	F	P_m		106,600	
		P_m+P_b	]]	159,900	]]

6.1.1 Results of Fatigue Evaluation

Cumulative usage factor (CUF) was evaluated for the replacement components in accordance with the provisions of the Code, and using the cycles per Reference 11. The number of cycles considered are 212 cycles for plant start up and shut down (normal load combination), 20 cycles for seismic (upset-seismic load combination) and 78 cycles for thermal (upset-thermal load combination). Table 6-4 summarizes the Cumulative Usage Factors for different components.

Table 6-4. Cumulative Usage Factors

No	Component	CUF
1	Upper Support	[[
2	Tie Rod Nut	
3	Support Block	
4	Upper Support Bolts	]]

6.1.2 Effect of Replacement Upper Support on the Reactor Vessel Stresses

[[

]] The replacement Upper Support and Tie Rod Nut stress analyses are based on the original design basis loads. Hence the RPV loads remain unaffected.

6.1.3 Effect of Replacement Upper Support on the FIV Characteristics of the Tie Rods

[[

]] Hence there is no effect of the replacement hardware on the FIV characteristics of the tie rod assembly.

7.0 CONCLUSION

Based on the structural evaluation documented in the preceding sections, the shroud repair replacement hardware (upper support, their associated components and tie rod nut) as depicted in the referenced drawings are structurally qualified in accordance with the design specification data sheet for IGSCC and ASME Code requirements.

8.0 REFERENCES

1. GENE 0000-0057-1782, Rev 0, "Failure Analysis Report, Edwin I. Hatch Unit One Nuclear Power Station Tie Rod Upper Support Bracket", Sept. 2006.

2. - Not Used -

3. – Not Used -

4. BWR Vessels and Internals Project, TR 1000248, "Guidelines for Selection and Use of Materials for Repairs to BWR Internal Components - BWRVIP-84, Final Report", October 2000.

5. Replacement Hardware Drawings and Parts Lists:

   Reactor

   Tie Rod Nut

   Upper Support Stabilizer

   Upper Support

   Retainer Spring

   Top Support Nut & Locking Pin

   Top Support Bolt

   Retainer Pin

   Shch Screw

   Support

6. – Not Used -

7. – Not Used -

8. – Not Used -

9. – Not Used -

10. ASME Boiler and Pressure Vessel Code, Section III, Division I, Nuclear Power Plant Components,

    a) Subsection NG, Core Support Structure, 2001 Edition through and Including the 2003 Addenda.

    b) Code Case N-60-5, Material for Core Support Structures, Section III, Division 1.

11. M1A12-2, Rev E2, "Entergy" – Reactor Thermal Cycles (Diagram for Pilgrim).

12. ANSYS Finite Element Computer Code, Version 10.0, ANSYS Incorporated, 2005.

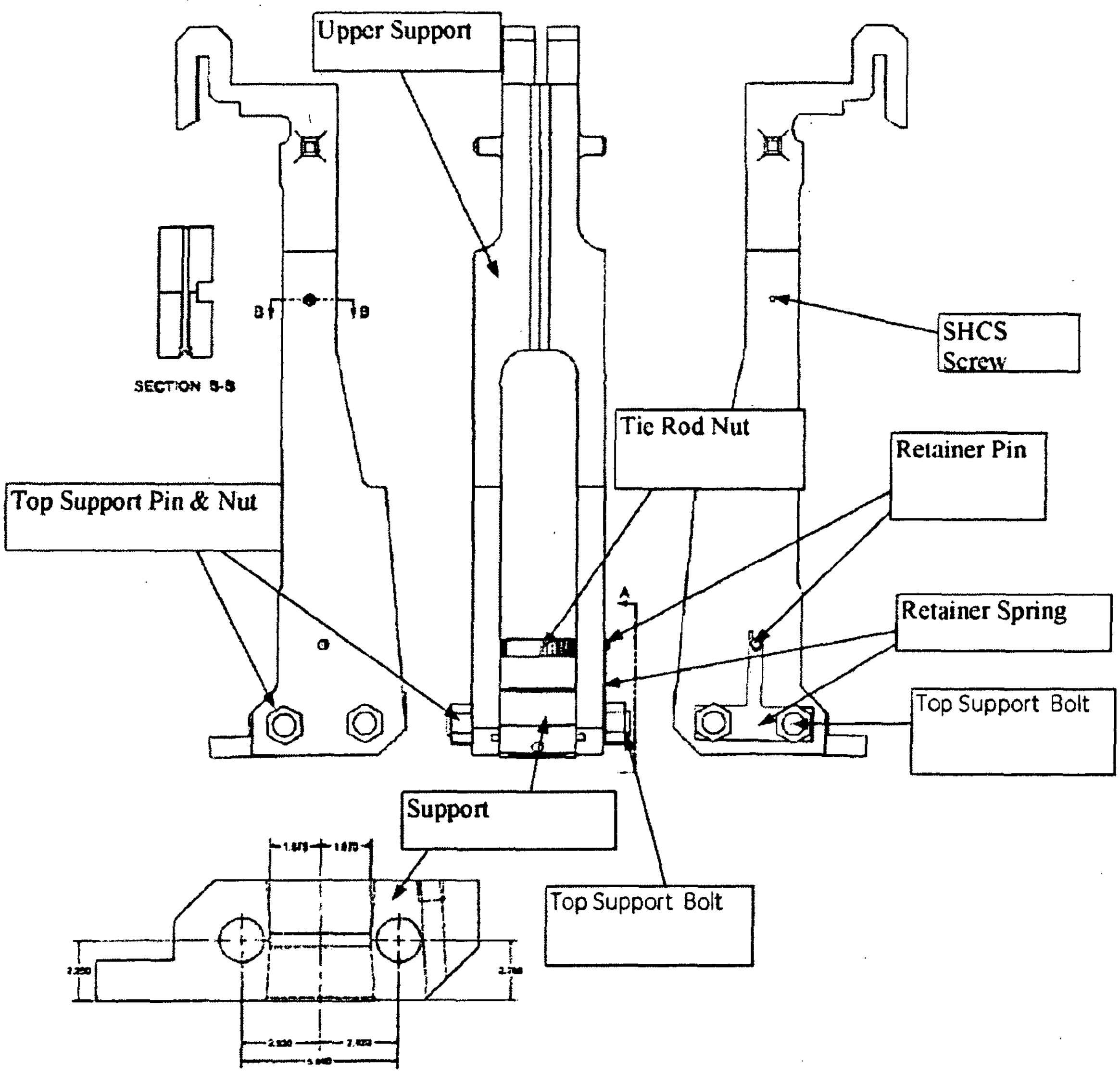

Figure 1. Components in the Replacement Upper Support Identified.

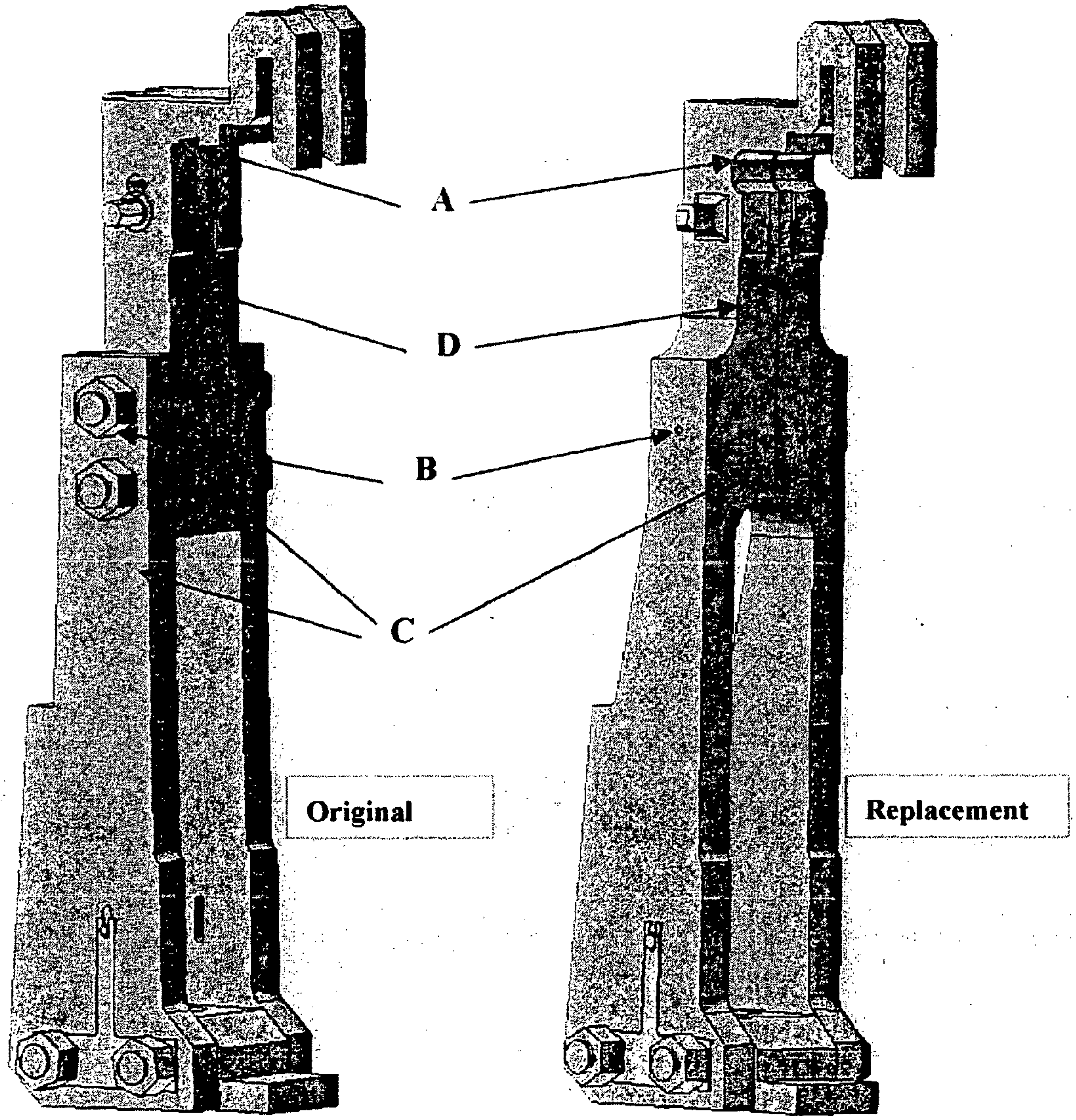

Figure 2. Comparison of Design Features in the Replacement Upper Support.

(A) Generous semi-elliptical stress-relief added (B) Number of Bolted Joint Reduced (C) Number of Components reduced (D) All Sharp edges rounded off.

[[

]]

Figure 3. Components in the Upper Support Finite Element Model.

[[

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Figure 4. One Half of the Upper Support Used in the Finite Element Model.

[[

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Figure 5. Boundary Conditions Applied at the Contact Areas of the Upper Support to the Shroud and the Shroud Head.

(Gap elements were added at the contact of the upper support with the shroud and shroud head flanges. A 27 mil initial gap was considered at the shroud head flange).

[[

]]

Figure 6. Maximum Tensile Principal Stress Due to Normal Sustained Load.

[[

]]

Figure 7. Stress Intensity (SI) plot for the Normal Condition Loading

(For ASME Code calculations, since the linearization path that gives the maximum (P_m+P_b) does not pass through the location of maximum stress intensity, the peak stress on this plot does not agree with that on the linearization chart.)

[[

]]

Figure 8. Linearization of the Upper Support Stress Intensity in the Normal Loading Condition.

[[

]]

Figure 9. Upper Support – Stress Intensity for Upset (Seismic) Loads.

(For ASME Code calculations, since the linearization path that gives the maximum (P_m+P_b) does not pass through the location of maximum stress intensity, the peak stress on this plot does not agree with that on the linearization chart.)

[[

]]

Figure 10. Upper Support - Linearization for Upset (Seismic) Loads.

[[

]]

Figure 11. Upper Support – Stress Intensity for Emergency Load

(For ASME Code calculations, since the linearization path that gives the maximum (P_m+P_b) does not pass through the location of maximum stress intensity, the peak stress on this plot does not agree with that on the linearization chart.)

[[

]]

Figure 12. Upper Support – Linearization of Emergency Condition Stress.

[[

]]

Figure 13. Upper Support – Stress Intensity for Faulted Condition Load.

(For ASME Code calculations, since the linearization path that gives the maximum (P_m+P_b) does not pass through the location of maximum stress intensity, the peak stress on this plot does not agree with that on the linearization chart.)

[[

]]

Figure 14. Upper Support – Linearization of Stress in the Faulted Condition.

[[

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Figure 15. Axisymmetric FE Model of the Tie Rod Nut and Tie Rod In Engagement, Shown With the Applied Boundary Conditions.

[[

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Figure 16. Bilinear Stress-Stress Properties Used in the Tie Rod Nut Analysis.
(Based on E and Est Values in Table 4-1)

[[

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Figure 17. Replacement Tie Rod Nut/Tie Rod Threaded Connection - Plot of Maximum Tensile Principal Stress (IGSCC).

[[

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Figure 18. Replacement Tie Rod Nut/Tie Rod Threaded Connection Plot of Maximum Total Principal Strain