ATTACHMENT 2

SUPPLEMENT TO GENE-771-39-0794, REVISION 1
SHROUD REPAIR HARDWARE STRESS ANALYSIS

The following pages labeled Class II are NOT PROPRIETARY.

Shroud Mechanical Repair Program

Hatch Unit 1

Supplement To Shroud Repair Hardware Stress Analysis

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ABSTRACT

This document provides the responses to NRC questions raised (Ref. 1) in the form of a supplement to the results of the stress analysis of Hatch Unit I Shroud Repair Hardware during seismic, LOCA, and other loading (Ref. 2). The objective of this supplemental analysis is to demonstrate the structural integrity of the shroud and repair hardware under normal & upset thermal loading conditions and to calculate gaps under postulated failure conditions.

The results of the supplemental evaluations show that the shroud and repair hardware meet the requirements of the Design Specification 25A5572, Rev. 2. The changes in this supplement do not adversely affect the original stress report & the conclusions of the original stress report (Ref. 2) remain unchanged.

Executive Summary

This supplement to the original stress report number GENE-771-39-0794, Rev. 1 provides the results of the analysis of Hatch Unit 1 Shroud and Repair Hardware which was performed in response to NRC questions (Ref. 1).

A 3-D linear static Finite Element Analysis (FEA) of the overall shroud assembly for stiffness calculations and hand calculations of the tie-rod have been performed. The FEA was done using FEA software COSMOS, 1.71 version which has been validated for this application using test cases. All the FEA results have been independently verified by using handbook analysis methods and alternate FEA software calculations.

Based on FEA and hand calculation results, it is concluded that all the repair hardware components and the shroud meet the requirements of the design specification. The changes in this supplement do not adversely affect the original stress report. The conclusions of the original stress report (Ref. 2) remain unchanged.

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1.0 INTRODUCTION

Cracks have been found during both visual and ultrasonic exami..ation (UT) in the shroud weld joints in several Boiling Water Reactors (BWR's). As a result, for Hatch Unit 1 Shroud, SNC is taking a pre-emptive measure by implementing a corrective action using the design modification developed by GENE without performing inspections. This supplement to the original report (Ref. 2) deals with an analysis of the GENE design modification in response to NRC Questions (Ref. 1).

2.0 STIFFNESS MODELS

The purpose of this analysis is to determine analytically the axial stiffness of the shroud which affects the tie-rod preload. The most flexible portion of the shroud is the top guide ring which rotates due to the moment loading , caused by the eccentricity of the vertical loading, when welds H2 & H3 are cracked. The following cases were analyzed:

2.1 Uncracked H2 & H3

A quarter 3-D model of the shroud was analyzed using FEA software COSMOS / M, 1.71 Version (Ref. 4). The model consists of 3-D brick elements. Symmetry boundary conditions were used for constraining the nodes at 0^0 and 90^0. For the nodes at the bottom surface of the model, vertical displacements were constrained, i. e. UY = 0.

A unit load of 10,000 lbs. was applied on the top surface of the model. The displacement plot is shown in Figure 1. The vertical displacement under the load = 0.00109 inches. The total load on the full model = 4 x 10,000 = 40,000 lbs. This results in the axial stiffness as equal to Ks = 40000 / 0.00109 = 36.7 E 6 lbs./ in. or 36,700 kips / in.

This case results in the upper bound value of the axial stiffness of the shroud.

2.2 Cracked H2 & H3

A quarter 3-D model of the shroud was analyzed using FEA software COSMOS. The model consists of 3-D brick elements. The ring is assumed to rotate about the toe of the fillet welds between the shroud & the ring. A one mil (0.001 inch.) gap was used between the ring & the shroud shells. The symmetry boundary conditions were used for constraining the nodes at 0^0 and 90^0. The nodes at the bottom surface of the model vertical displacements were constrained, i. e. UY = 0.

A unit load of 10,000 lbs. was applied on the top surface of the model. The displacement plot is shown in Figure 2. The vertical displacement under the load = 0.00354 inches. The total load on the full model = 4 x 10,000 = 40,000 lbs. This results in the axial stiffness as equal to Ks = 40000 / 0.00354 = 11.3 E 6 lbs./ in.

This case results in the lower bound value of the axial stiffness of the shroud.

2.3 Other Stiffness Models

FEA analysis was also performed to evaluate the effect of the upper stabilizer (spring) in restraining the top guide ring rotation. However, it was found that there is only a 2% increase in stiffness with the stabilizer. Another model was analyzed in which the effects of the stabilizer plus the aligner brackets were investigated and resulted in increased value of the vertical stiffness. To be conservative, both of these effects are neglected.

3.0 Preload and Gap Calculations During Normal Conditions:

3.1 Thermal & Mechanical Preload

Total mechanical preload = Fm = N x T / (0.15 x D) from the torque tension relationship for threaded fasteners.
Where :
Fm = Axial load, lbs.
N = Number of tie-rods = 4.
T = Torque, in-lbs. = 175 ft-lbs. = 175 x 12 = 2100 in-lbs.
0.15 = Coefficient of friction for lubricated surfaces.
D = Thread diameter, in. = 3.5".
Fm = (4 x 2100) / (0.15 x 3.5) = 16,000 lbs.
Axial stiffness of shroud = Ks = 11.3 E 6 lbs / in.
Axial stiffness of 4 tie-rods = Ktr = 4 x 483,790 = 1.9352 E 6 lbs /in.
Stiffness Ratio = Ktr / (Ks + Ktr)
= 1.9352E6/(11.3E6 + 1.9352E6)
= 0.1462
This factor gives the reduction in mechanical preload.
Hence, total mechanical preload = 16,000 (1-0.1462)
= 13,660 lbs. (Use 13,660 lb for gap calculation and 16,000 lb for tie rod stress calculation to be conservative in both cases)

Combined stiffness of the tie-rods & shroud assembly = Kaxial = (Ks x Ktr) / (Ks + Ktr).
Thus Kaxial = (11.3 E 6 x 1.9352 E 6) / (11.3 E 6 + 1.9352 E 6) = 1.6522 E 6 lbs / in.
The differential thermal movement between shroud and the tie rods = 0.112 inch., (Section 5).
Thus net preload = Kaxial x 0.112 = 185,046 lbs.
The thermal preload per tie-rod = Net preload / 4 = 46,262 lbs.

Minimum preload per tie-rod is equal to the sum of the mechanical & thermal preload = 46,262 + 13,660 / 4 = 49,677 lbs. Say 49,700 lbs.

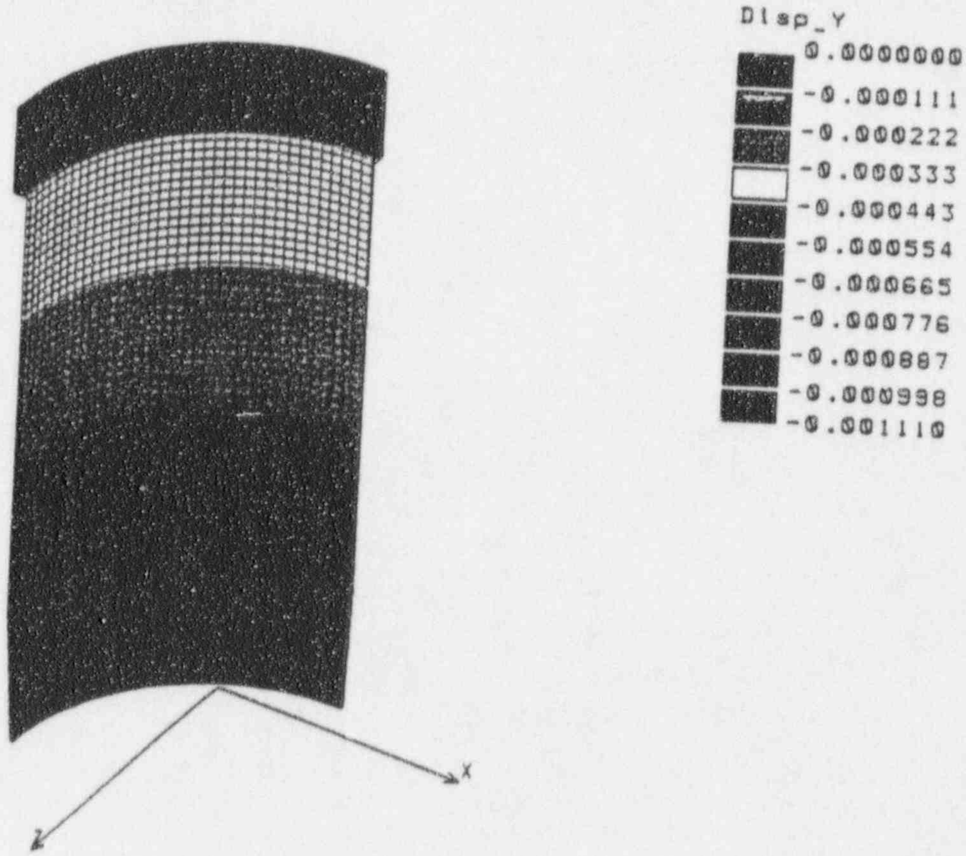


Figure 1. Displacement Plot of Hatch 1 Uncracked H2 & H3 Shroud for a 10,000 lbVertical Load.

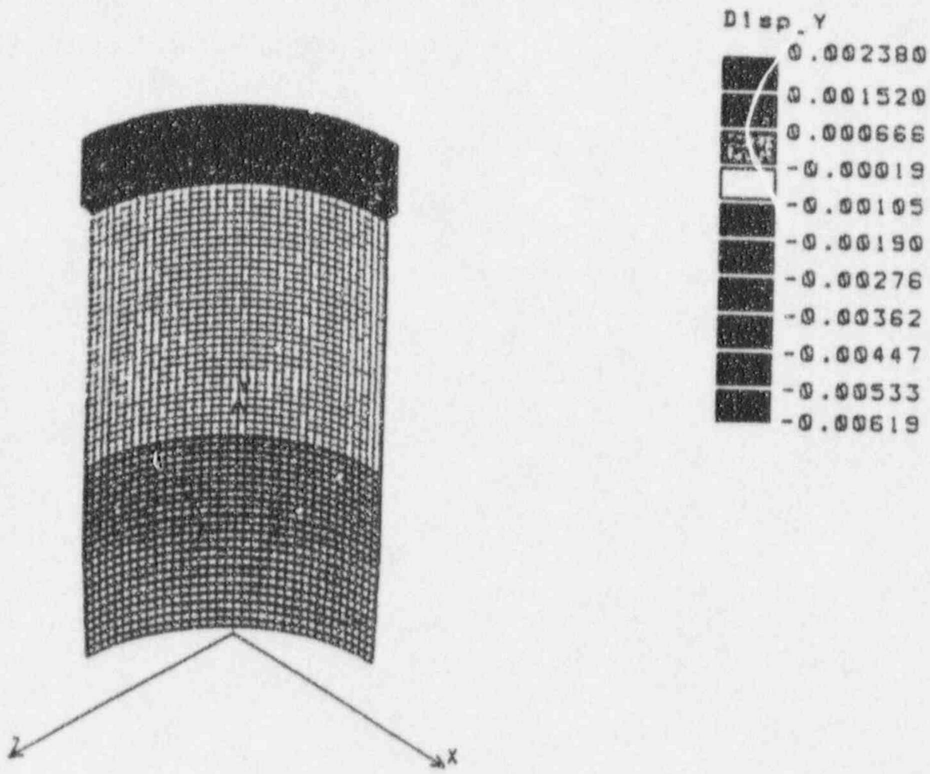


Figure 2. Displacement Plot of Hatch 1 Cracked H2 & H3 Shroud For a 10,000 lb Vertical Load

3.2 Axial Displacement due to Thermal and Mechanical Preload (Figure 3)

A force balance approach showed a possible opening (gap) of weld H8. Thus a more refined method of calculating the gap at H8 was used as outlined in this section.

Δt due to thermal load = 0.112 inches.
Δm due to mechanical preload = (13,660 x 0.112) / 185,046
= 0.0083 inches
Total $\Delta 1 = \Delta t + \Delta m$ = 0.112 + 0.0083
= 0.1203 inches downward

3.3 Net Axial Displacement at H8 Weld Due to Dead Weight, Figure 4

The distribution of dead weight is shown in Figure 5.
For the upper section of the shroud,
Dead Weight = W1 + W2 = 120,600 + 27,000
= 147,600 lbs
Stiffness of upper section (same as Ktr)
= 1.935 E6 lbs / in
Δu = 147,600 / 1.935E6 = 0.0763 inches
In a similar manner for the lower section
ΔL = 94,100 / 1.652E6 = 0.057 inches
Total $\Delta 2 = \Delta u + \Delta L$ = 0.0763 + 0.057 inches
= 0.133 inches downward

3.4 Axial Displacement Due to Pressure Loading, Figure 6.

Using the method of Section 3.2.
$\Delta 3$ = 182,100 / 1.935E6 + 260,700 / 1.652E6
= 0.2519 inches
Hence, gap at H8, assuming welds H2 & H3, & H8 have failed, = $\Delta 1 + \Delta 2 - \Delta 3$
= 0.120 + 0.133 - 0.2519
= 0 in i. e., No uplift
When weld H6B has cracked in addition to H2 & H3, there is a reduction in dead weight of 15,100 lbs
gap at H6B = 0.1203 + 0.124 - 0.2519
= 0.008 inches (Upward)

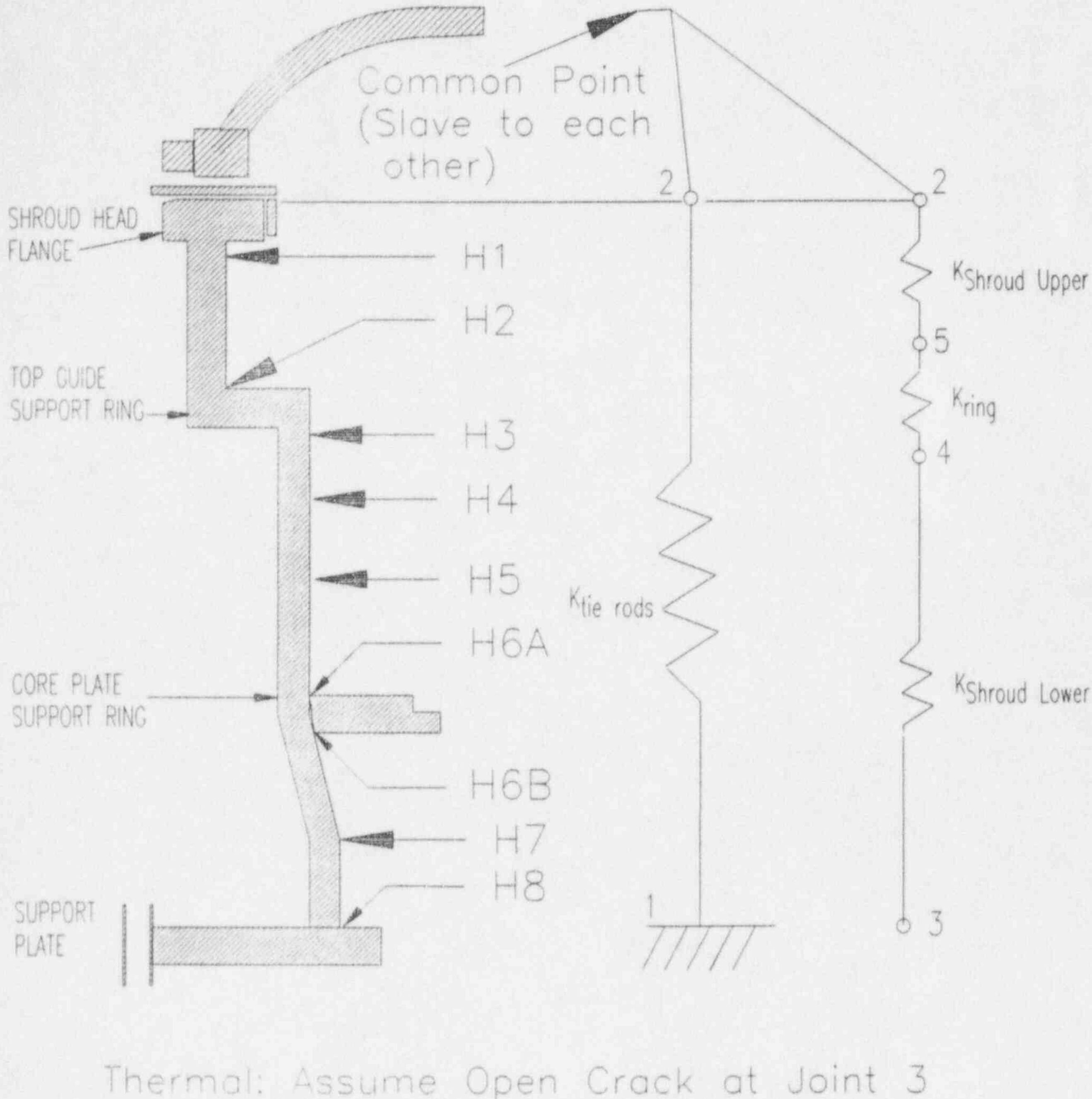
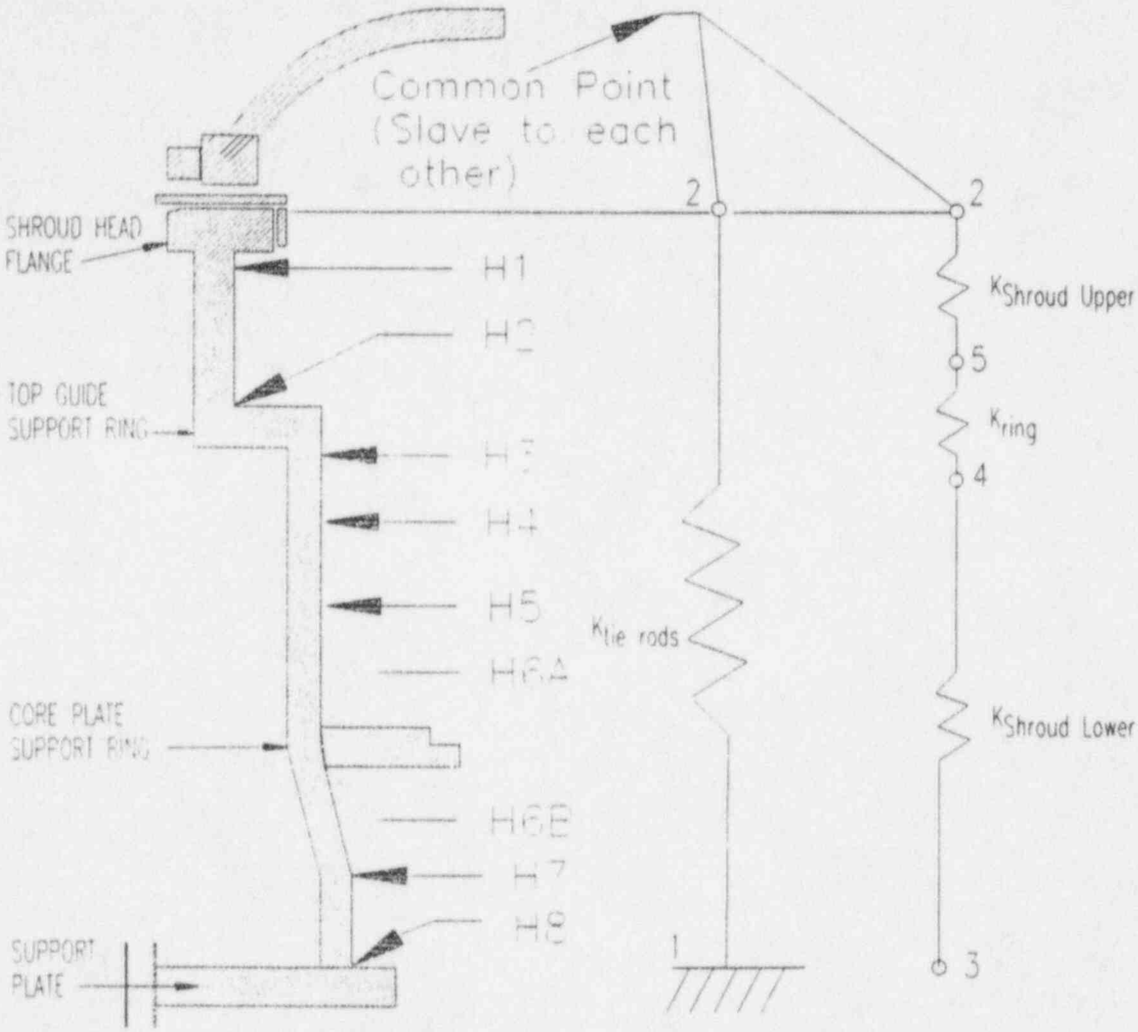


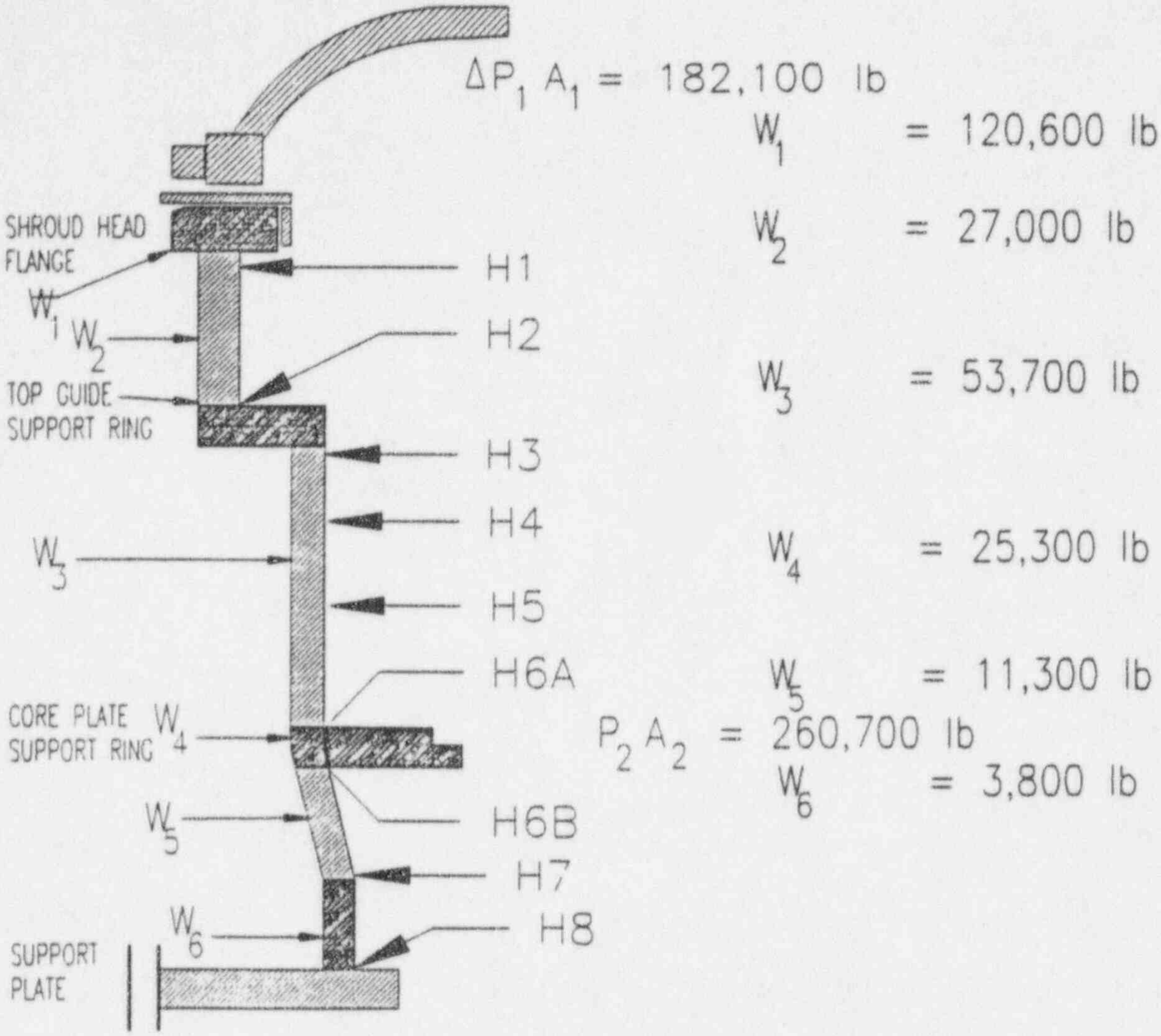
Figure 3. Model for Calculating Gap Due to Thermal & Mechanical Preload



Dead Loads 147,600 lb at Joint 2
94,100 lb at Joint 3

ASSUME SEPARATION AT JOINT 3

Figure 4. Model for Calculating Gap Due to Dead Weight



$\Sigma \Delta PA$ = 442,800 lb

$W_1 + W_2$ = 147,600 lb

ΣW at H8 = 241,700 lb

ΣW at H6B = 226,600 lb

Figure 5. Distribution of Weights & Pressure Loads on Shroud

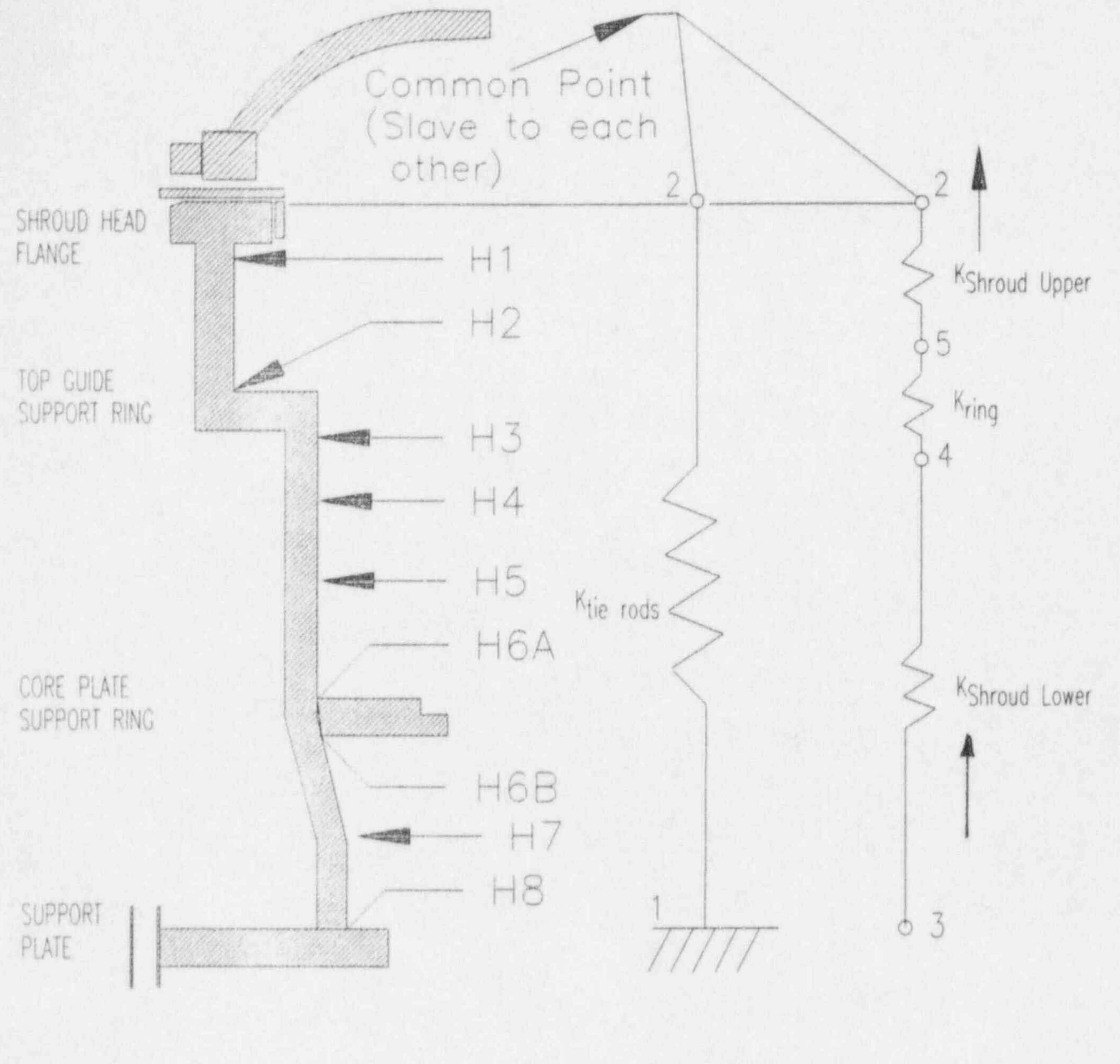


Figure 6. Model for Calculating Gap Due to Pressure Loads

4.0 Evaluation of OBE Results Using Roller Assumption

For this OBE case from seismic design report (Ref. 6), spring forces & displacements are:

spring force at top guide = 8,684 lbs
spring force at core support = 50,038 lbs
moment in tie rod = 6.147E6 in lb
spring displacement at top guide = 0.434 in
spring displacement at core support = 0.334 inch

Following the method used in Reference 2, page 19, for OBE + Normal, the new values are:

The tensile load on tie rod = 90,283 lbs

4.1 Shroud Stresses

As shown on page 23 of Reference 2,

Ratio = 50,038 / 92,480 = 0.54
Pm = 9,163 x 0.54 = 4,948
Pressure Stress = pr/t = (23.8 x 177.3)/(2 x 1.5)
= 1,408 psi
Pm = 4,948 + 1,408 = 6,356 psi < Sm or 16,900 psi.
Pm + Pb = 13,195 psi < 1.5 Sm or 25,350 psi.
Hence OK

4.2 Lower Spring

Axial Load = 90,283 lbs
Radial Load = 50,038 lbs

From the spring model used in Section 7.1.1 of Reference 2,

Pm + Pb = 60,607 psi. < 1.5 Sm or 71,250 psi.
Pm = 21,969 psi. < Sm or 47,500 psi.

using the the ratio of radial loads and liearized stresses from Reference 2,

4.3 Other Components

Other components such as upper spring and upper bracket have acceptable margins for this load case.

5.0 Thermal Stress Analysis

5.1 Normal Conditions

This represents the case when the shroud is at 534°F and the tie rod assembly is at 522°F. Since the coefficient of thermal expansion for Inconel X-750, the material for the upper support bracket and the lower spring is less than that of the shroud material (304SS), the shroud grows more than the tie rod assembly. This produces differential thermal expansion and a tensile load on the tie rod assembly.

Upper Support Bracket Expansion:

L1 = 48.9 - 4.50, 112D6317 and 112D6318
= 44.4 in.
α = 7.50 E - 6 in / in./ °F
ΔT = (522 - 70) = 452 °F
Hence, $\Delta L1$ = 44.4 x 7.50 E-6 x 452
= 0.15052 inches

Tie Rod Expansion:

L2 = 172.65 inches.
α = 9.4552 E-6 in / in / °F
ΔT = 452°F
$\Delta L2$ = 172.65 x 9.4552 E-6 x 452
= 0.73786 inches

Lower Spring Expansion:

L3 = 67.0 inches, 112D6314
α = 7.50 E-6 in / in. / °F
ΔT = 452°F
$\Delta L3$ = 67 x 7.5 E-6 x 452
= 0.22713 inches

For Total Tie Rod Assembly:

LTA = 44.4 + 172.65 + 67
= 284.05 inches
ΔLTA = 0.15052 + 0.73786 + 0.22713
= 1.1155 inches

Shroud and Inconel 600 Expansions:

Shroud Length Ls = 267.44 inches from 730E854
Length of Inconel 600 piece = 284.05 - 267.44
LI= 16.61 inches
α 600 = 7.7308 E - 6 in / in/ °F, from ASME B & PV Code, Appendices, 1992 Ed @522^0 F.

α Shroud = 9.4244 E-6 in / in/ °F, from ASME B & PV Code, Appendices, 1992 Ed, @ 534^{0}F
ΔTs = 534 - 70 = 464°F

ΔLs = 267.44 x 9.4244 E - 6 x 464
= 1.1695 inches

ΔTs = 522 - 70 = 452°F (For Inconel portion).

ΔLI = 16.61 x 7.7308 E - 6 x 452
= 0.05804 inches

Total ΔLSA for shroud assembly = 1.2275 inches

Net differential expansion = 1.2275 - 1.1155 = 0.112 inches

Stiffness of Tie Rod assembly:
= k = 483,790 lb./in., from Ref. 2.

∴ Force in Tie Rod, assuming shroud is rigid vertically = 483,790 x 0.112
= 54,184 lb.

Using uncracked stiffness of shroud as 36.7 E 6 lbs / in., the tie-rod preload = 0.95 x 54,184 = 51,475 lbs. with mechanical preload of 4,000 lb, net load = 55,475 lbs

Tie Rod area at the thread relief = $(\Pi/4) \times 3.33^2 = 8.709\ in^2$

Tensile Stress in Tie Rod = 55,475 / 8.709 = 6,370 psi
or Pm = 6,370 psi
Sm = 22,800 psi, from 25A5572, Rev. 2. Pm < Sm, Hence, O.K.

5.2 Upset Conditions

This is the case when the shroud temperature is at 430°F and the tie rod assembly is at 300 °F. Using the method used for Normal condition calculations:

Upper Support Bracket Expansion:

LI = 48.9 - 4.50
= 44.4 in.

α = 7.20E - 6 in / in. / °F

ΔT = (300 - 70) = 230°F

Hence, $\Delta L1$ = 44.4 x 7.20 E-6 x 230
= 0.0735 inches

Tie Rod Expansion

L2 = 172.65 inches.

α = 8.97 E-6 in / in / °F

ΔT = 230°F

$\Delta L2$ = 172.65 x 8.97 E-6 x 230
= 0.3562 inches

Lower Spring Expansion:

L3 = 67 inches

α = 7.20 E-6 in/in/°F

ΔT = 230°F

$\Delta L3$ = 67 x 7.2 E-6 x 230
= 0.1110 inches

For Total Tie Rod Assembly:

LTA = 284.05

ΔLTA = 0.0735 + 0.3562 + 0.1110
= 0.5407 inches

Shroud and Inconel 600 Expansions

Shroud Length Ls = 267.44 inches.
Length of Inconel 600 piece = LI = 16.61 inches.

α 600 = 7.612 E-6 in / in / °F, from ASME Code, 1992 Ed @ 430° F.
α Shroud = 9.244 E-6 in / in / °F, from ASME Code, 1992 Ed @ 430° F.

ΔTs = 430 - 70 = 360 °F
ΔLS = 267.44 x 9.244 E-6 x 360
ΔLS = 0.8900 inches
ΔLI = 16.61 x 7.612 E-6 x 360
ΔLI = 0.04552 inches

Total Δ LSA for shroud assembly = 0.93552 inches
Net differential expansion: = 0.93552 - 0.5407 = 0.39482 inches
Using uncracked stiffness of shroud as 36.7 E 6 lbs / in., the tie-rod preload = 0.95 x 54,184 = 51,475 lbs.
∴ Force in Tie Rod = 0.95 x 483,790 x 0.39482 = 181,460 lb. plus 4,000 lb mechanical preload = 185,460 lb.
Tensile Stress in Tie Rod =Pm= 185,460 / 8.709 = 21,295 psi.< Sm = 22,800 psi. Hence OK
Sm = 22,800 psi, from 25A5572, Rev. 2. Note that Sm value used is at 550 ° F & not at 300 °F & hence the conservatism in this analysis.
Hence, the tie rod meets the design specification requirements for both normal and upset conditions.

6.0 References

1 Letter to Mr. J. T. Beckham, Jr from Kahtan N. Jabbour, "Request for Additional Information Regardung Core shroud Modification or Hatch Nuclear Plant, Unit 1" , dated January 1995.

2 GENE-771-39-0794, Revision 1, Shroud Repair Hardware Stress Analysis Report For Hatch Unit 1, Nuclear Power Plant.

3 25A5572, Revision 2, Shroud Repair Hardware Design Specification.

4 COSMOS/M, Finite Element Structural Analysis Computer Code, Structural Research and Analysis Corporation, Los Angeles, California

5 ASME, Boiler & Pressure Vessel Code (B&PV), Section III, Appendices, 1992 Edition.

6 GENE-771-48-0894, Revision 1, Seismic Design Report For Hatch Unit 1, Nuclear Power Plant with Shroud Repair (including supplemental analysis dated February 8, 1995).