GE Nuclear Energy

GENE B13-01739-22
Revision 1
April 1997

Design Report for Improved Shroud Repair Lower Support Latches

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REVISION STATUS SHEET

Revision	Approval	Date	Description
0	G.A. Deaver	4/6/97	Initial Issue
1	R. M. Horn	4/24/97	Revision of Proprietary Markings

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1.0 INTRODUCTION

The purpose of this report is to provide the results of an evaluation performed by GE regarding the redesign of the spring latch which holds the lower wedge in place and is part of the shroud repair assembly. The original function of the latch was to provide a locking feature for the lower wedge which is held onto the lower spring assembly. In the course of installing the lower wedge, the latch only experiences dead weight loads. During plant operation, the original latch was not designed to accommodate sliding of the lower wedge with respect to the lower spring assembly, since it was postulated that the lower wedge would slide on the vessel wall. Since sliding will occur at the wedge to lower spring interface when the lower wedge does not slide on the vessel wall, the redesign of the latch includes a flexible member which can accommodate vertical displacements which occur during plant operation. See Figure 4.1 for the configuration of the new latch.

2.0 SUMMARY

This report demonstrates that the new latch design is a significant improvement over the previous design, and that even under very conservative assumptions regarding the loading and displacement of the latch that no failure of the latch will occur in the next operating cycle. It is fully expected that the new latch will last for a significantly longer time based on a 8 to 12 factor of improvement which has been determined based on its ability to accommodate vertical movements. For the expected sliding case where the movement is always along the lower wedge/lower spring interface, the latch will last the remaining life of the plant. Therefore, based on the new latch improvements in combination with the installation change to remove looseness in the lower attachment to the shroud support, satisfactory shroud tie rod repair hardware performance is expected in the future.

3.0 EVALUATION

The following evaluations were performed using nominal conditions. In reviewing the issues associated with the latch failure phenomena, there are numerous variables such as friction factors, material properties, dimensional tolerances, reactor operating conditions, hardware installation details, equipment measurement accuracy, etc. Therefore, the use of nominal conditions is the most realistic approach to assess the redesign of the lower spring latch.

3.1 Plant Operating Conditions

The following paragraphs identify the plant operating conditions which cause loads to occur on the latch. The geometry of the hardware at the lower spring support of the shroud repair is shown in figure 1.1. Relative vertical movements between the tie rod components that could affect the loading on the new latch are described in sections 3.1.1 through 3.1.5. Section 3.3 will utilize the displacements defined in sections 3.1.1 through 3.1.5 to establish the maximum latch vertical deflections for the wedge sliding scenarios defined in section 3.2. The adequacy of the new latch to meet the required stress criteria is then demonstrated in section 4.0.

3.1.1 Hydrotest

The hydrotest event occurs just prior to plant startup, and involves pressurizing the vessel to approximately psi at a temperature of approximately (this is conservative for this evaluation since the plant minimum temperature is). During this condition, the lower spring load initially increases due to differential thermal expansion of the reactor vessel, shroud, and the shroud repair hardware. However, when the hydrotest pressure is applied, the vessel expands and the loads on the lower support will go to zero since the vessel pressure expansion exceeds the spring preload and the additional contact from the differential thermal expansion. During the pressurization, the dead weight from the lower wedge and any forces due to flow in the vessel acting on the wedge will be held by the latch. The weight of the lower wedge is . and the flow forces with 105% core flow equals for a total force of . When the pressure is dropped, the lower spring will again establish contact against the vessel wall and the shroud. Since the new latch has a spring rate of , the vertical downward displacement of the wedge will be inches while the hydrotest pressure is applied.

3.1.2 Normal Operating Conditions

Following the hydrotest, it is assumed that the reactor will be proceed with startup, and the reactor temperature will increase from to . It is also possible that the vessel temperature could drop to as low as prior to startup to full power operation, but this would have a minor affect on the latch displacement. During the heatup, the temperature and pressure changes in the vessel will cause an increase in the vertical load of the tie rod. For the complete startup from , the total differential movement at the lower support is . Part of this value is the differential thermal expansion between the vessel and the lower section of the tie rod assembly ______ and the remainder of this value is from the loading of the "C" spring from a vertical force caused by differential expansion of the tie rod. Since the initial heatup to operating conditions included the hydrotest, which released the contact of the lower support from the vessel, only the heatup from results in an increase in vertical loads which are applied to the wedge and latch. The resulting vertical displacement is . The total vertical displacement of the lower support with respect to the vessel for this

combination of events is 0.090 inch for the first complete heatup cycle. Therefore, during heatup, a vertical movement of 0.090" at either the lower wedge to vessel contact or the lower wedge to lower spring contact, or a combination of the two will occur since friction is not capable of resisting the applied loads.

During reactor startup, the lower support loads increase due to the differential expansion of the materials. The initial lower spring force of spring compression) increases to inch spring compression).

3.1.3 Loss of Feedwater Heating Event

The most severe transient condition postulated which affects the shroud repair hardware is the Loss of Feedwater Heating (LOFWH) event. For this event, the annulus region is cooled with 300°F water. The cooling in the annulus increases the vertical loads in the shroud repair assembly. The vertical load in the shroud repair assembly increases from to . Therefore, the total vertical displacement from ambient shutdown conditions to the LOFWH event is 0.135 inch. The expansion of the "C" spring accounts for of the displacement, and the thermal differential expansion of the materials is .

During this event the average temperature of the shroud is cooled to from which causes the annulus space between the shroud and the vessel to increase. The amount of the increase is * 9.76E-6 in/in-°F *] which exceeds the 0.065 inch horizontal lower spring displacement. Therefore, there is a period of time during this event that the lower support is not loaded against the vessel and shroud. During this time period, any existing loads on the latch are relaxed, and only the dead weight and flow forces are acting displacement on the latch), which will not overstress the latch.

For less severe transients which are similar to the LOFWH event, temperature effects could result in increased vertical loads without the horizontal lower spring force losing contact with the vessel and shroud. A conservative worst case is when the annulus is cooled to a temperature which reduces the lower spring contact to essentially zero, but the increased vertical loads cause the latch to be loaded. (In reality, sliding at the vessel wall will occur before a zero horizontal load condition occurs.) The zero load condition occurs when the shroud average temperature reaches when an initial lower spring compression (zero spring force at startup) is assumed at the start of the LOFWH event. The annulus temperature becomes under these conditions. Under these temperature conditions, the resulting load on the "C" spring is . and the vertical displacement is . The differential thermal expansion between the vessel and the lower shroud repair assembly is . Therefore, the maximum net vertical movement from ambient shutdown conditions is .

3.1.4 Seismic Event

During a maximum earthquake event the lateral movement of the shroud will cause the lower springs to be temporarily unloaded. This releases any vertical restraint that has occurred in the latches, and returns the latch to the case where it is supporting the dead weight and flow forces (.). During this time when the wedge losses contact, the latch will not be overstressed.

3.1.5 Cooldown and Reheating during Operating Cycle

During an operating cycle, it is possible that the plant will need to be cooled down to perform an unscheduled maintenance activity. The worst case condition is when the vessel is cooled all the way down to ambient conditions. When the vessel is reheated, a hydrotest is not performed. Therefore, the latch can potentially see a maximum vertical displacement of when the reactor reaches full power operating conditions.

3.2 Latch Displacement/Loading

3.2.1 Differential Expansion

When the operating events described above occur, vertical displacements occur at the lower support which necessitate that sliding between components occur since friction can not restrain the forces created. At the lower support, there are three potential scenarios where sliding can occur:

1. Sliding only occurs at the interface between the lower wedge and the vessel wall.

2. Sliding only occurs at the interface between the lower wedge and the lower spring.

3. Sliding occurs at both of the identified locations. The worst case is when the lower wedge/lower spring interface slides during reactor heatup, and the lower wedge/vessel interface slides during reactor cooldown.

The lower wedge/vessel interface surface is in the same plane as the applied vertical loads on the shroud repair assembly. Since the vertical load reaches . (primarily from thermal expansion) while the horizontal lateral load is only ., sliding will occur on this surface when the friction forces are exceeded. The lower wedge surface is a machined stainless steel surface; whereas, the vessel wall is an as-welded clad stainless steel surface which has peaks and valleys on the surface.

The lower wedge/lower spring interface has a 5 degree angle with respect to the vertical load direction. When the vessel is heated, the 5 degree angle is oriented such that it increases the possibility of sliding as compared to an in-plane orientation. Likewise, when the vessel is cooled down, the 5 degree angle acts to resist sliding. The lower wedge contact surface is a machined stainless steel surface, and the lower spring contact surface is a machined X-750 surface. Having

dissimilar metals with different hardnesses at this interface is an optimal condition for sliding to occur.

In comparing the above two surfaces which are subject to sliding, it is expected that the vessel clad surface will have a higher friction factor than the corresponding friction factor at the machined surfaces at the lower wedge/ lower spring interface. Therefore, sliding at the lower wedge/lower spring interface is more likely to occur. Considering the operation of the NMP1 plant with the original latches, it was concluded that sliding on the vessel wall must have occurred at the locations where the latches did not fail; whereas, the failed latches experienced sliding at the lower wedge/lower spring interface. Therefore, the location where sliding occurs is highly dependent on the friction factors at the contact surfaces. Consequently, when there is a relatively higher friction factor at one of the surfaces in comparison to the other one, sliding will predominately occur at the contact surface with the lower friction factor.

In reviewing the heatup and cool down conditions, whenever the applied vertical load reaches a level which exceeds the friction forces, the interface surface will slide. Therefore, it is expected that sliding will not be a continuous action, but will have several independent movements during heatup and cool down. For the heatup condition, the lower wedge/lower spring interface with the 5 degree angle favoring the sliding activity and a low friction factor is clearly the probable location for sliding. During cool down, the 5 degree angle acts to resist sliding, but because the angle is small the influence of the angle is small. To evaluate the significance of the angle, the cool down forces were studied in detail. The following are the assumptions and results of this study.

1. Reactor vessel has been operating at full power, and sliding at the lower wedge/lower spring interface has occurred which has moved inches due to loads created during heatup (no sliding of the wedge at the vessel wall).

2. The lateral spring force decreases due to the lowering of the lower wedge. The amount of decrease is . The resulting spring deflection is .

3. At full temperature conditions, the sliding which occurred during heatup results in no remaining vertical loads at the lower wedge sliding interfaces.

4. During cool down, the vertical load at the wedge sliding interfaces starts to increase in a linear relationship based on temperature differentials. Also the lateral lower spring force decreases as a linear function of the temperature changes.

5. A temperature drop is assumed which was predetermined to approximate the point when enough force is developed to cause the initial sliding to occur. At this time the following forces are created:

6. At the lower wedge/lower spring interface, the forces are then aligned along the 5 degree angle and the vector sum of the applied vertical load and the reaction friction force are calculated to be:

Now assuming f1 = 0.5 (typical value for machined surfaces)

Resultant friction reaction force =

Therefore, sliding in this theoretical case would occur since the applied force is greater than the friction force.

7. The loading at the vessel interface are the following:

   Applied force =

   Friction reaction force =

8. Now assuming that the friction forces are equal at both sliding surfaces, solve for f2:

Therefore, for this example f1 ≈ f2; however, since it is anticipated that the friction factor at the vessel wall (f2) is much larger than at the spring interface (f1), sliding should occur at the spring interface. The above evaluation supports the theory that only the interface at the spring should slide in both the heatup and cooldown events.

3.2.2 Flow Induced Vibration

The only time that FIV is of interest is when the lower wedge looses contact with the vessel wall. This can occur during the hydrotest, maximum seismic conditions, and during the Loss of Feedwater Heating event. These events have a short duration with the longest potential duration being 8 hours for the hydrotest event. The lose of contact at the lower spring support is not a concern in either the tie rod assembly or the subassembly of the latch and lower wedge for the following reasons:

1. The time when contact is lost is a relatively short duration and the associated number of cycles is limited.

2. The clearance which is created between the lower wedge and the vessel wall is less than which will limit the motion of the lower wedge in the lateral direction. This prevents any significant contact forces from being produced, and contact would dampen out any excitation of the lower wedge. The relative radial movements between the vessel and the shroud are such that surface contact is likely to remain at one of the two surfaces during the postulated events.

3. Even postulating that no support is present at the lower spring, analysis has been performed for the tie rod assembly which demonstrates that flow induced vibration will not occur.

4. An independent calculation of the new latch and lower wedge assembly with no contact with the vessel shows that the natural frequency is sufficiently high to avoid flow induced vibration.

In conclusion, none of the shroud repair components are susceptible to flow induced vibration when contact is lost at the lower spring contact.

3.3 Maximum Latch Deflection Calculations

The following paragraphs calculate the potential displacements in the latch for the two postulated sliding cases which result in loads on the latch.

3.3.1 Spring Interface Sliding Only Case

The sequence of operating events which create the largest displacements of the latch are the following:

1. Initial heatup and hydrotest
2. Remainder of heatup to full power operation
3. Loss of Feedwater Heating transient

Using the calculated latch displacements from section 3.1, the following are the maximum latch displacements:

Event	Latch Displacement (inches)
1. Initial heatup and hydrotest	0.042
2. Remainder of heatup to full power operation	0.090 =
3. Loss of Feedwater Heating transient	0.132 *

* The latch displacement caused by the LOFWH event is the full power displacement 0.090 plus the differential displacement from ambient conditions of the full power operation and LOFWH events). Total displacement equals

3.3.2 Sliding at Both Wedge Interfaces

The sequence of operating events which create the largest displacements of the latch for both sliding surfaces are the following:

	Surface Assumed to Slide
1. Initial heatup and hydrotest	Spring Interface
2. Remainder of heatup to full power operation	Spring Interface
3. Cooldown to Ambient (70°F)	Vessel Interface
4. Heatup to Full Power Operation	Spring Interface
5. Loss of Feedwater Heating	Spring Interface

Using the calculated latch displacements from section 3.1, the following are the maximum latch displacements:

Event	Latch Displacement (inches)
1. Initial heatup and hydrotest	0.042

2. Remainder of heatup to full power operation 0.090 =
3. Cooldown to Ambient (70°F) 0.115*
4. Heatup to Full Power Operation 0.182 =
5. Loss of Feedwater Heating 0.224 =

* In the cooldown condition the maximum displacement is limited by the amount of travel down the 5 degree angle of the spring which results in no lateral spring force on the vessel. (Max. Displ. = 0.010 / Tan 5° = .115 inch). There is no further load which can push the wedge any further down.

4.0 STRESS EVALUATION

4.1 Stress Results

The stress resulting from the predicted displacements were calculated and are reported below:

Table 4-1
Subsection NG Stress Analysis

Conditions	Displacement		Allowable Stress
Sliding only at wedge/spring interface (Normal Operation)	.090"*		142.5 ksi
Sliding only at wedge/spring interface (LOFW Operation)	.132"		142.5 ksi
Sliding at both interfaces (Normal Operation)	.182"		142.5 ksi
Sliding at both interfaces (LOFWH Operation)	.224"		142.5 ksi

*The stress results reported are for a 0.100" displacement which is conservative.

The material properties for Alloy X750 at 550 °F are given below:

Sy = 92,300 psi
Sm = 47,500 psi
Su = 142,600 psi

The ASME Code Subsection NG normal and upset condition Pm + Pb + Q allowable is 3Sm which is equal to 142,500 psi. Since the applied stresses on the latch are secondary stresses, 3Sm

is the applicable stress limit. The calculated stresses for all of the postulated displacements meet the code limit.

Also, the membrane + bending stress is less than the material's yield strength for all except the 0.224" displacement condition and even that case exceeds yield only at the very outer fiber location. No significant permanent displacement is expected for any of the postulated conditions.

4.2 Stress Corrosion Evaluation

In addition the ASME Code Subsection NG stress limits, the sustained stress in Alloy X750 components must be evaluated to confirm that the stress are below the material IGSCC threshold. Stress Rule Index (SRI) is the criteria used to evaluate this concern. The following table summarizes the stresses which need to be considered for the SRI evaluation.

Table 4-2
Stress Corrosion Evaluation

Conditions	Displacement		Calculated SRI	SRI Allowable
Sliding only at wedge/spring interface (Normal Operation)	.090"*		0.40	0.50 for 40 year life
Sliding at both interfaces (Normal Operation)	.182"		0.73	0.80 for 2 year min. life

*The stress results reported are for a 0.100" displacement which is conservative.

Under the SRI evaluation requirements, only events which have sustained tensile stresses which have a duration of over 100 hours during the design life of the plant need to be evaluated. Therefore, only the two normal operation cases identified in Table 4-2 need to be considered with regard to stress corrosion. The duration of the LOFWH or other transient events is not sufficient enough to warrant any consideration for stress corrosion.

The SRI equation is given below:

In this case, the applied stresses are classified as secondary and there are no residual stress (Pm + Pb = 0; Resid = 0). Therefore, the maximum stress that can be applied and still meet a specific SRI is calculated by the following equation.

Using this equation and the stress results for the 0.100" displacement, the allowable displacement was calculated.

For a 40 year service life, the SRI for Alloy X750 is limited to 0.5. For this case, the allowable displacement is 0.123". The displacement for the condition which assumes sliding only at the wedge spring interface meets this limit. The condition where sliding occurs at both interfaces does not. Therefore, the allowable displacement for a 2 year minimum service life (one operating cycle) was calculated. For a 2 year minimum service life, the SRI for Alloy X750 is limited to .8. The allowable displacement corresponding to this SRI is 0.197". The normal operating condition displacement with sliding at both interfaces meets this requirement.

4.3 Finite Element Model

A 2D plain stress finite element model was prepared for the latch and the Algor© linear static analysis software (Algor © Linear Stress Analysis - SSAP0H Rel. 15-FEB-95 Ver. 11.08-3H) was used to determine the latch stresses. Figure 4-1 contains a sketch of the model. Figure 4-2 contains stress contour plot of the Z-direction component stress. The plots show that at the maximum stress location, the stress is almost exclusively bending.

Deflection due to deadweight + flow loads

A resultant force is developed for the 0.100" applied displacement. The displacement for the dead weight + flow load of . dead weight added to a . flow load) was determined by ratioing the FEA results.

4.4 Comparison of Latch Designs

A 2D plain stress finite element analysis was also performed for the original latch. Figure 4-3 contains a sketch of the model for the original latch. Figure 4-4 contains a stress contour plot of the maximum stress location for the original latch for a 0.100" applied displacement. The calculated membrane + bending + peak stress was 772 ksi and the membrane + bending was approximately 400 ksi (using a linear elastic analysis). The original latch was much more highly stressed (by a factor of 8 to 12 times) than the new latch.

5.0 CONCLUSIONS

The new latch has been designed to accommodate larger vertical displacements while still maintaining its original function of locking the wedge to the lower spring structure. The stresses are within ASME code limits and the latch has been analyzed to be resistant to stress corrosion for a minimum of 2 years assuming conservative worst case displacements in the latch. It is fully expected that the latch will last for a significantly longer time based on the factor of improvement which has been demonstrated from the original design. For the expected sliding case where the movement is always along the lower wedge/lower spring interface, the latch will last the remaining life of the plant. Consistent with the inspection recommendations made for the original shroud repair hardware installation, it is recommended that the latches should be visually inspected after the next operating cycle. The condition of the latches and the position of the lower wedge should be evaluated based on a criteria which utilizes reactor temperature and pressure information from the operating cycle. As discussed in this report, some amount of displacement of the lower wedges can be expected which would be considered normal.

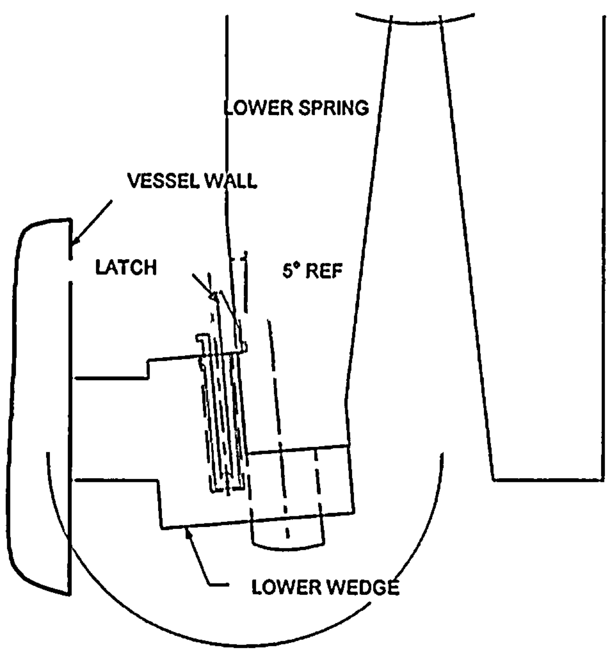

FIGURE 1.1 SHROUD REPAIR LOWER SUPPORT CONFIGURATION

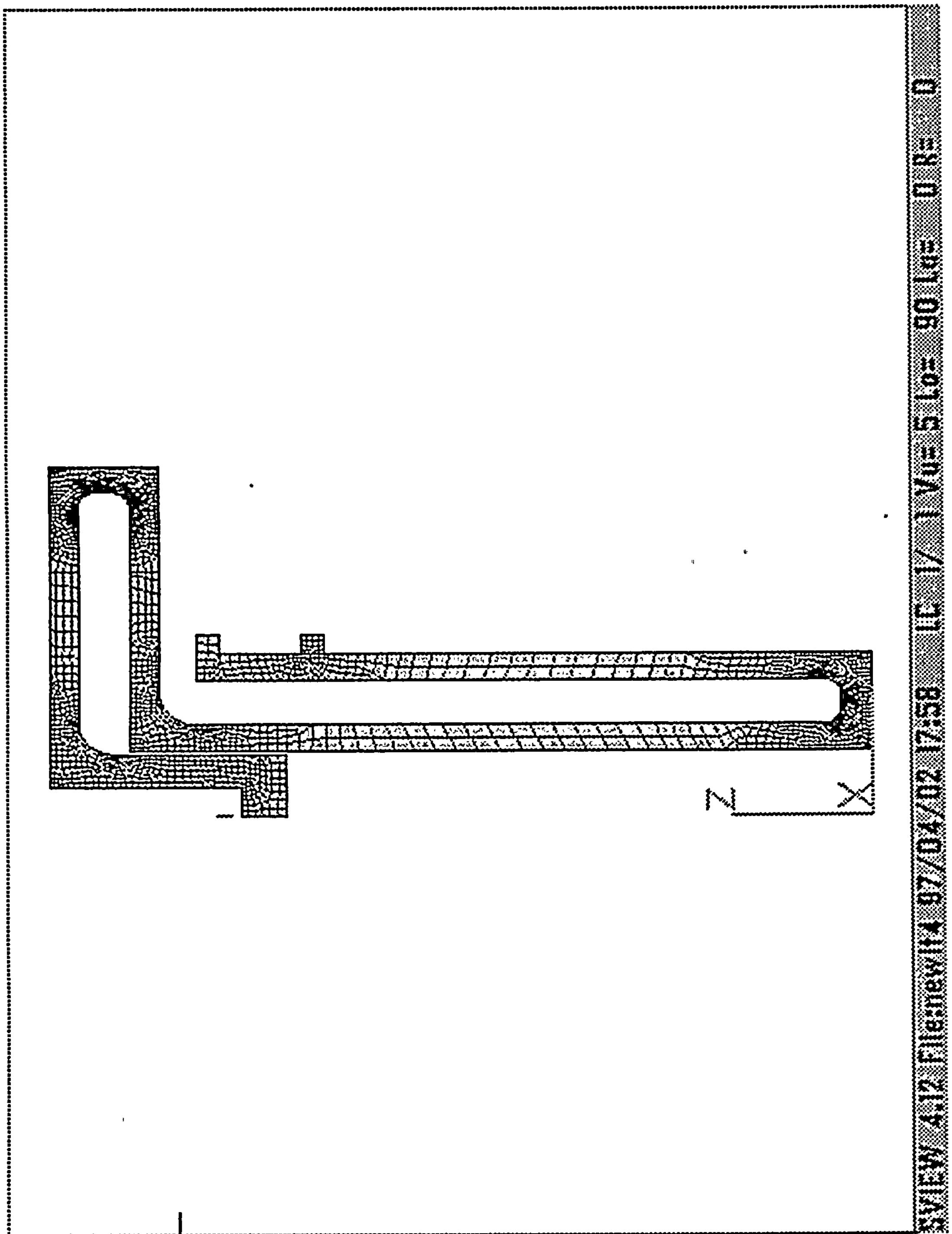

FIGURE 4-1 LATCH FEA MODEL

FIGURE 4-2 STRESS RESULTING FROM A 0.100" DISPLACEMENT

FIGURE 4-3 ORIGINAL LATCH FEA MODEL

FIGURE 4-4 ORIGINAL LATCH STRESSES

(MAXIMUM STRESS LOCATION)