LARGE DEFLECTION AND ELASTIC-PLASTIC PIPING STRESS ANALYSIS OF FEEDER AND FEEDER SUPPORTS USED IN A CANDU REACTOR

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ABSTRACT

The piping stress analysis of the feeder and feeder supports used in a CANDU reactor is carried out using the finite element method for the combined effect of the fuel channel thermal and axial creep movement.

With the large fuel channel pressure tube creep elongation (approximately 150 mm (6 inches) over its design life), the behaviour of the feeder and feeder supports falls into the class of geometric and material non-linearities. The design adequacy of the linked welded eye-rod mechanism of the lower feeder support becomes a concern. The ordinary small deflection linear elastic analysis would not give realistic and acceptable results. Proper analysis of the system must consider large deflection and material strain hardening.

The "large deflection" capability of the finite element program ANSYS is used to determine the displacements and forces in the feeder supports. This is an iterative process in which changes in geometry are taken into consideration by continuously updating the structural stiffness as the channel axial movement is increased.

The large deflection elastic analysis is performed for the channel creep movement from 13 mm (0.5 inch) to 63 mm (2.5 inches). In addition, the large deflection elastic-plastic analysis is performed for the channel axial movement larger than 67 mm (2.75 inches) as the lower eye-rod begins to yield at about 75 mm (3.0 inches) of channel axial movement. By this analysis, the adequacy of the lower feeder support design is demonstrated.

The nonlinear elastic-plastic finite element analysis indicates that the axial stress of the eye-rod is significantly higher than that obtained from conventional linear elastic analysis. The behaviour of the swing mechanism of the eye-rod predicted by the nonlinear analysis is also more appropriate than that predicted by the linear analysis.

1. INTRODUCTION

CANDU reactor fuel channels are known to creep but the rates at which the creep occurs in fuel channels is anticipated to be much higher than earlier predictions of approximately 38 mm (1.5 inch). Feeders are vital part of the heat transport system and because of their configuration with several bends and longer length, they need to be supported at proper locations to be structurally acceptable. A typical lower cantilever support on a given feeder consists of a 9 mm (3/8-inch) diameter and up to 425 mm (17-inch) long slender rod. This type of support employs a linked welded eye rod mechanism which allow the feeders to swing by pivoting the lower eye rod at the eye of the upper eye rod (Figure 1). The pivoting mechanism of the linked welded eye rod will allow smaller fuel channel creep. However, with a large fuel channel creep elongation of approximately 150 mm (6 inches), the adequacy of the feeder support design which was not designed to accommodate larger pressure tube creep elongation, needs to be demonstrated.

With the large creep movement, the behaviour of the feeder and supports falls into the class of geometric and material non-linearities which include large deflection and strain hardening. The "large deflection " capability of the finite element program ANSYS[1] is used to determine the displacements and the forces in the feeder support.

In the conventional finite element analysis, the structural stiffness matrix is formed only once based upon the initial geometry of the structure. However, ANSYS program's large deflection capability allows it to modify the initial stiffness matrix based upon the displaced configuration of the structure. This is an iterative process and the solution becomes complete when the displacement result at any given node converge to a user defined tolerance criteria between two successive iterations.

2. METHOD OF ANALYSIS

The piping stress analysis of a typical feeder along with its supports is carried out using the finite element method.

2.1 Assumptions

The following assumptions are used in the analysis:

The origin of coordinate system (Figure 2) represents the end fitting Grayloc position. The fuel channel is allowed to move in the axial direction to simulate channel creep and thermal elongations.

The material stress-strain curve is assumed to be bi-linear[2].

The interference between the adjacent feeders, particularly for the vertical motion of the eye rod/pipe joint, is not considered.

The thermal stresses produced in the feeder due to coolant temperature are also ignored for this evaluation, however, the thermal elongation of the fuel channel is included in the analysis.

2.2 Finite Element Models

The finite element model of a typical feeder configuration is shown in Figure 2. The linear elastic analysis model consists of hollow pipe and spring elements. The feeder pipe is modelled as a 3D pipe element. The lower feeder support eye rod is modelled with 3D elastic beam elements. The channel annulus bellows is modelled as a torsional spring and the additional upper feeder support is modelled as a translational spring.

For the large deflection elastic-plastic analysis, a 3D plastic pipe element is used to model the feeder pipes and the lower eye rod. The eye rod is modelled as an equivalent pipe since this is the only appropriate element for plastic analysis. Bends in the feeder pipes are modelled with 3D plastic elbow elements.

The material properties for the feeder pipe and the lower eye rod material are gathered from References [2] and [3]. The ultimate tensile strength for the eye rod material (hot rolled carbon steel bar) is assumed to be 345 MPa (50,000 psi) at room temperature and the yield strength is taken as 128 MPa (18,500 psi) at 316°C (600°F).

2.3 Boundary Conditions

The following boundary conditions are applied at various locations of the model to simulate the behaviour of the fuel channel, reactor header, upper feeder supports and the pivoting mechanism used at the top end of the lower eye rod.

The feeder at the reactor header is assumed fixed in all directions.

The linkage between the lower eye rod and the feeder pipe (Figure 2) is modelled by tying the Y and Z translations and rotations of both parts.

The top end of the lower eye rod has its translations fixed and is allowed to only rotate.

The X and Y translations at the second upper feeder support are also fixed.

2.4 Loads and Load Cases

The loads considered for the finite element analysis are the feeder dead weight, the fuel channel thermal movement, fuel channel creep movement and the internal pressure of the heat transport coolant in the feeder.

Fuel channel creep together with thermal elongation is applied in small incremental load steps in terms of axial displacement from 0 to 95 mm (3.75 inches).

The large deflection elastic analysis is performed for the creep movement from 13 mm (0.5 inch) to 64 mm (2.5 inches). In addition, the large deflection elastic-plastic analysis is performed for the creep movement larger than 67 mm (2.75 inches) as the lower eye rod begins to yield at about 75 mm (3.0 inches) of creep movement.

The following four load cases were analyzed:

Load Case 1 Linear elastic analysis of the feeder along with lower Eye rod and the channel bellows modelled as a torsional spring.

Load Case 2 Large rotation/Elastic-Plastic analysis of the feeder along with lower Eye rod and channel bellows modelled as a torsional spring.

Load Case 3 Large rotation/Elastic-Plastic analysis of the feeder along with lower Eye rod but the channel bellows not modelled as a torsional spring.

Load Case 4 Large rotation/Elastic-Plastic analysis of the feeder without the lower Eye rod but the channel bellows modelled as a torsional spring.

3. DISCUSSION OF RESULTS

Figures 3, 4, 5 and 6 show the comparison of all four load cases analyzed. The results are presented in terms of displacements of the eye rod/pipe joint, the direct stress in the eye rod, the resultant moment and the torque on the Grayloc hub against the fuel channel creep.

For the load case 1 (linear elastic analysis), the direct stress produced in the eye rod is not a linear function of the imposed fuel channel creep displacement. The stress level drops as the imposed displacement is applied and it rises again, ever so slowly and reaches to a maximum of 35 MPa (5000 psi) at the maximum fuel channel creep displacement of 95 mm (3.75 inch). As can be seen from the results presented in Figure 3, the direct stress produced in the eye rod does not match up to the stretch produced in it by the large rotation of the upper eye rod and the negative displacement of lower eye rod and feeder pipe junction point (Figure 6). The reason for this discrepancy is that the linear analysis does not update the stiffness matrix if the structure under goes excessive rotational displacement as is the case here.

For the load case 2, the direct stress produced in the eye rod increases with the increase of fuel channel creep. At about 63 mm (2.5 inches) of fuel channel creep, the lower eye rod yields and an elastic-plastic analysis is performed as the imposed displacement is increased further (Figure 3). The direct stress in the eye rod matches up to the stretch produced in it by the rotation of the upper eye rod and the positive displacement of the lower eye rod/feeder pipe junction point (Figure 6). This is a non-linear analysis which takes into consideration both the geometric and material non-linearity. For the geometric non-linearity, the stiffness matrix is continuously updated during each iteration and the displacements are checked for convergence. If the imposed load is such that yield stress limit is exceeded then both the elastic-plastic and large deflection analysis is carried out side by side.

Results from load case 3 show the importance of using the channel bellows as a torsional spring. Without the bellows, the torque calculated on the Grayloc hub due to fuel channel creep is in the order of 5659 N-M (50,000 Lbf-inch) (Figure 4). By modelling the bellows as a torsional spring (load case 2), one can see that its magnitude drops to a more realistic value of around 4527 N-M (40,000 Lbf-inch) (Figure 4).

Analysis results from the load case 4 show that by removing the lower support all together, the torque exerted on the Grayloc hub due to fuel channel creep is greatly reduced to about 1019 N-M (9000 Lbf-inch) (Figure 4). The resultant moment is also small (Figure 5). This is due the fact that by removal of lower support, the lower portion of the feeder is allowed to sag and not rotate as much, thereby shifting some of the forces and moments to other supports.

4. CONCLUSIONS

Based on the results of the four load case analyzed, the stresses in the lower feeder eye rod are found to be below the ultimate tensile strength. This demonstrates the adequacy of the feeder support design and that it will accommodate the anticipated fuel channel creep. The following are the main conclusions:

1. The lower eye rod direct stresses, produced by just linear elastic analysis are unrealistically conservative.

2. For the feeder configuration analyzed, which under goes significant rotational displacement, it is necessary to perform an iterative <u>geometric non-linear</u> analysis to obtain correct and meaningful results.

3. The lower eye rod stresses are beyond the yield strength of 128 MPa (18500 psi) at about 75 mm (3.0 inches) of fuel channel creep elongation. At 95 mm (3.75 inches) axial elongation, the maximum tension force reaches 11,100 N (2,490 lbf), corresponding to a plastic stress of 156 MPa (22,560 psi). This is however, below the eye rod minimum ultimate tensile strength of 345 MPa (50,000 psi).

4. By modelling the channel bellows as a torsional spring, the torque exerted on the Grayloc hub decreases by about 20%.

5. Results for the feeder without the eye rod support show that the stresses in the feeder are within the elastic limit and the loads on the Grayloc hub are approximately 30% smaller than those with the eye rod present.

6. The stresses in all the feeder pipes are below the yield strength.

6. REFERENCES

(1) "ANSYS", a general purpose finite element analysis program, Swanson Analysis Systems Inc., Houston, PA, USA.

(2) MARSHALL, P., "Austentic Stainless Steels - Microstructure and Mechanical Properties", Elsevier Applied Science Publishers.

(3) ASME BOILER AND PRESSURE VESSEL CODE, Section III, Appendix I.

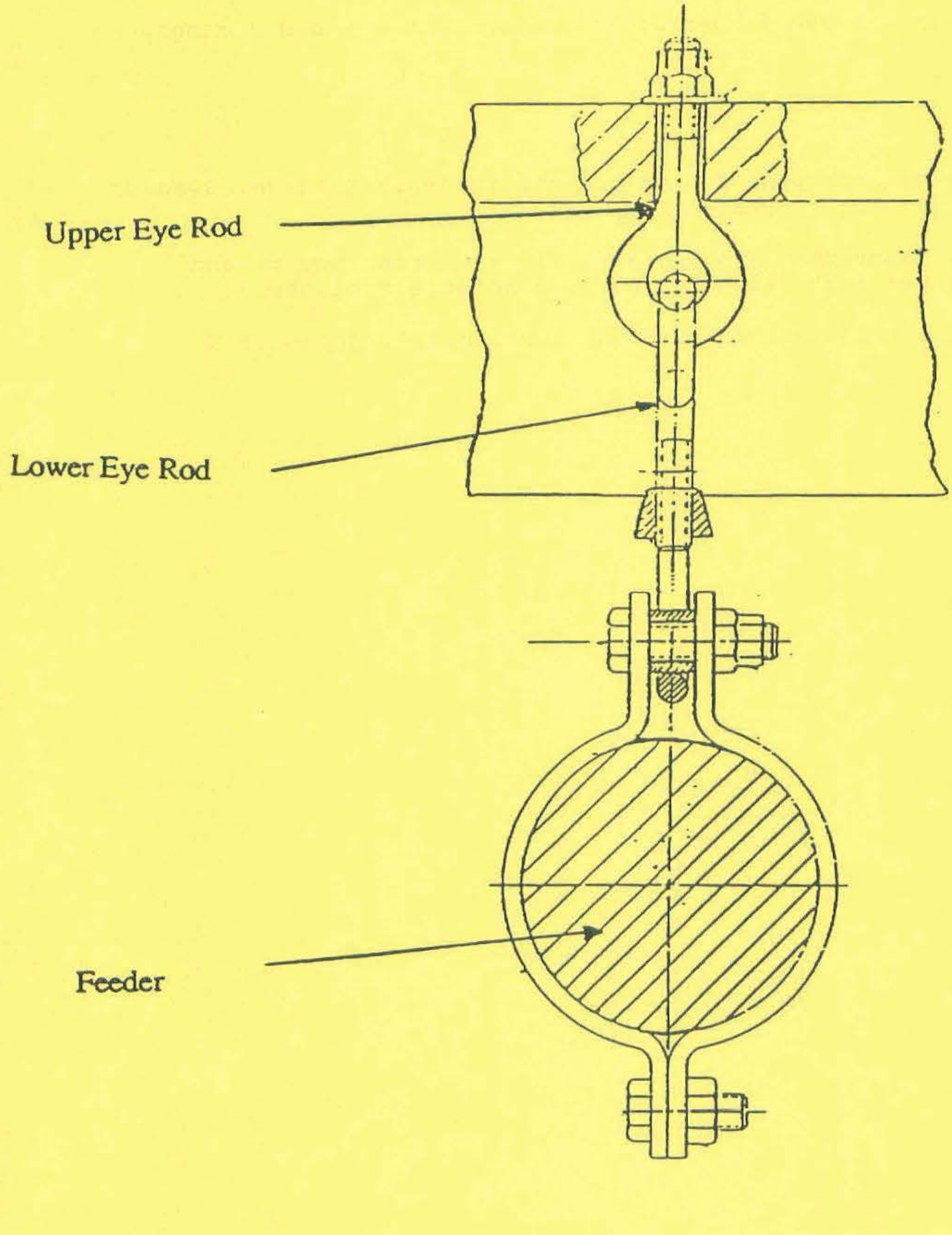

Figure 1: Lower Eye Rod Link Mechanism

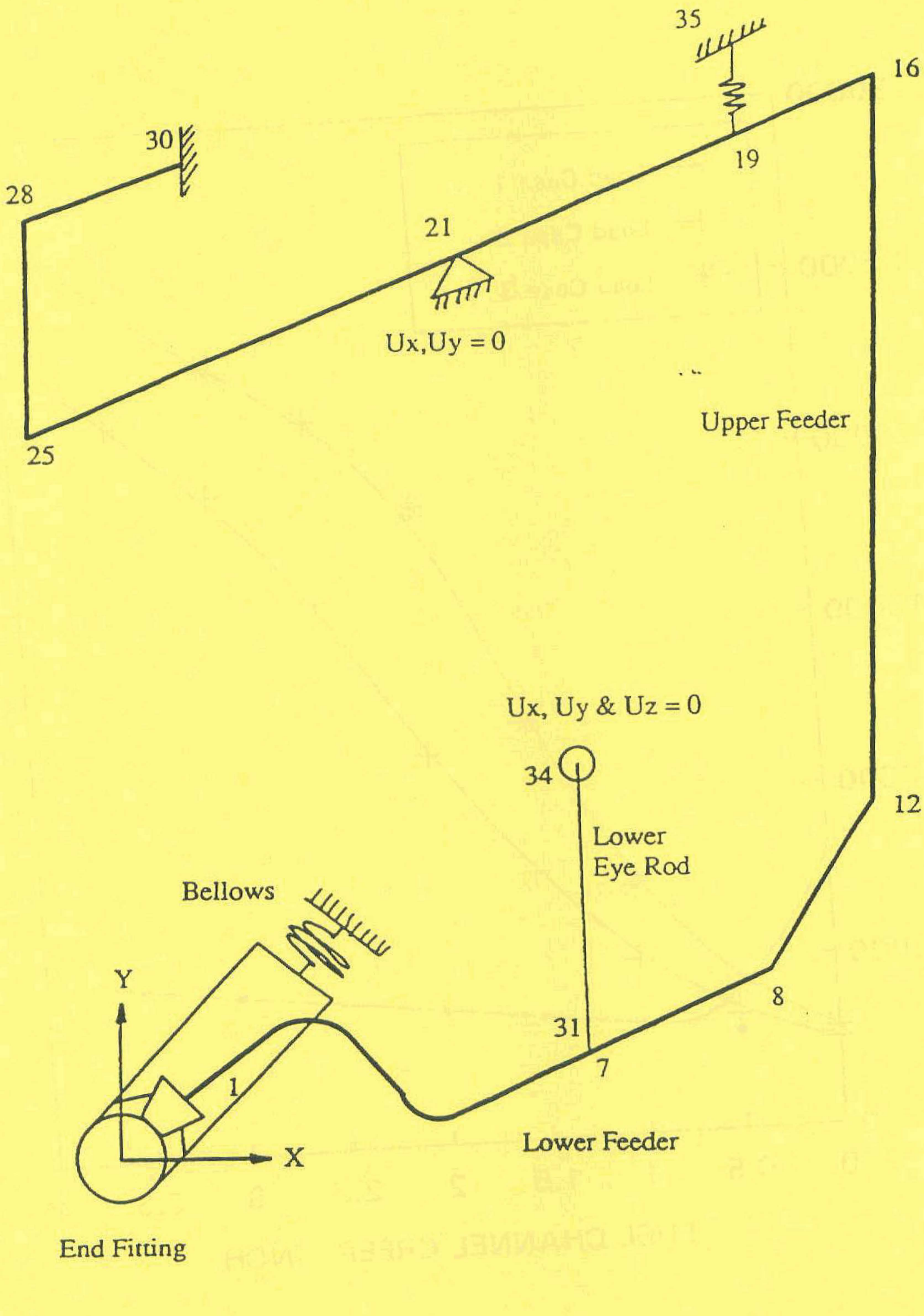

Figure 2: Finite Element Model of a Typical Feeder

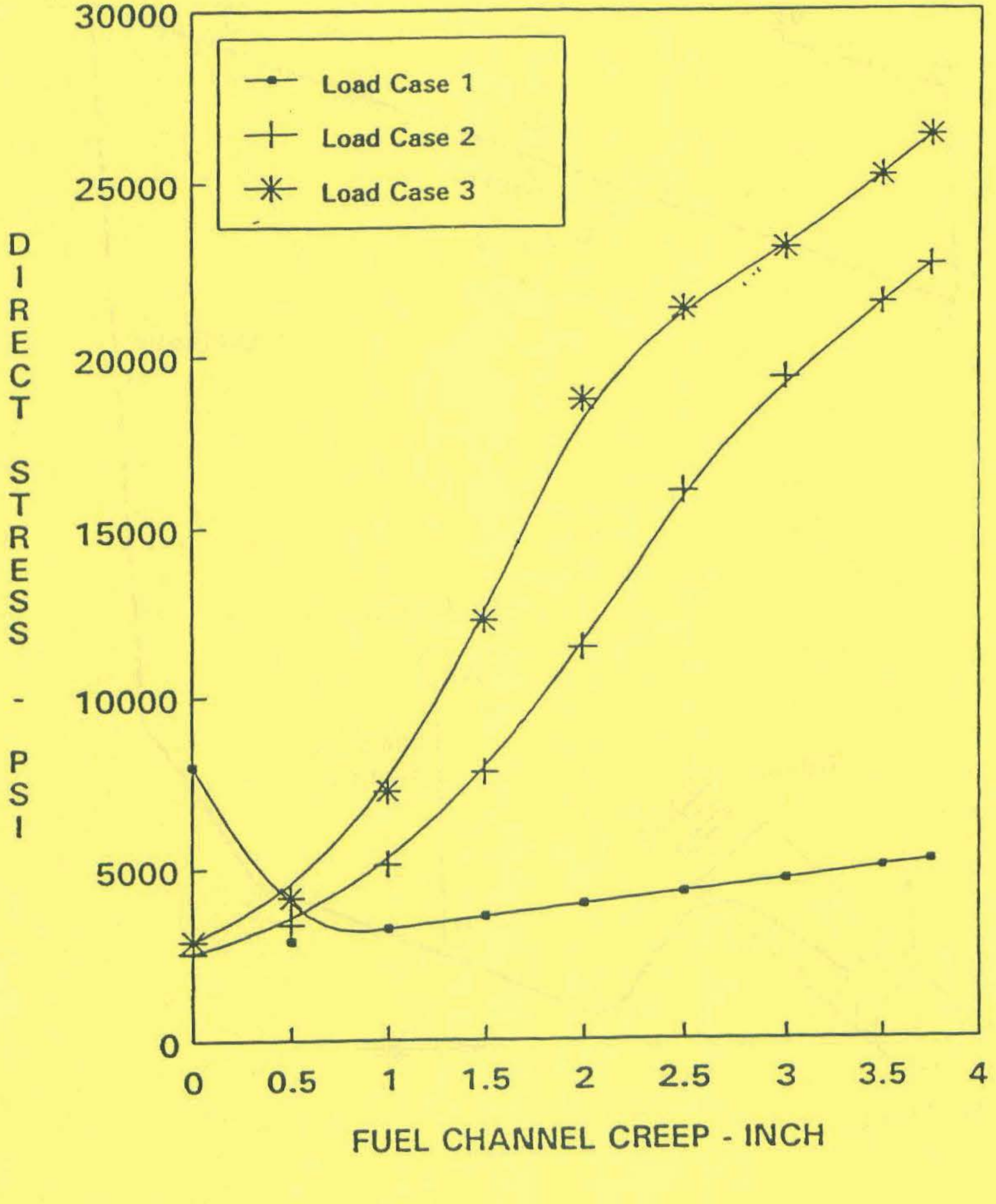

Figure 3: Direct Stress in the Eye Rod

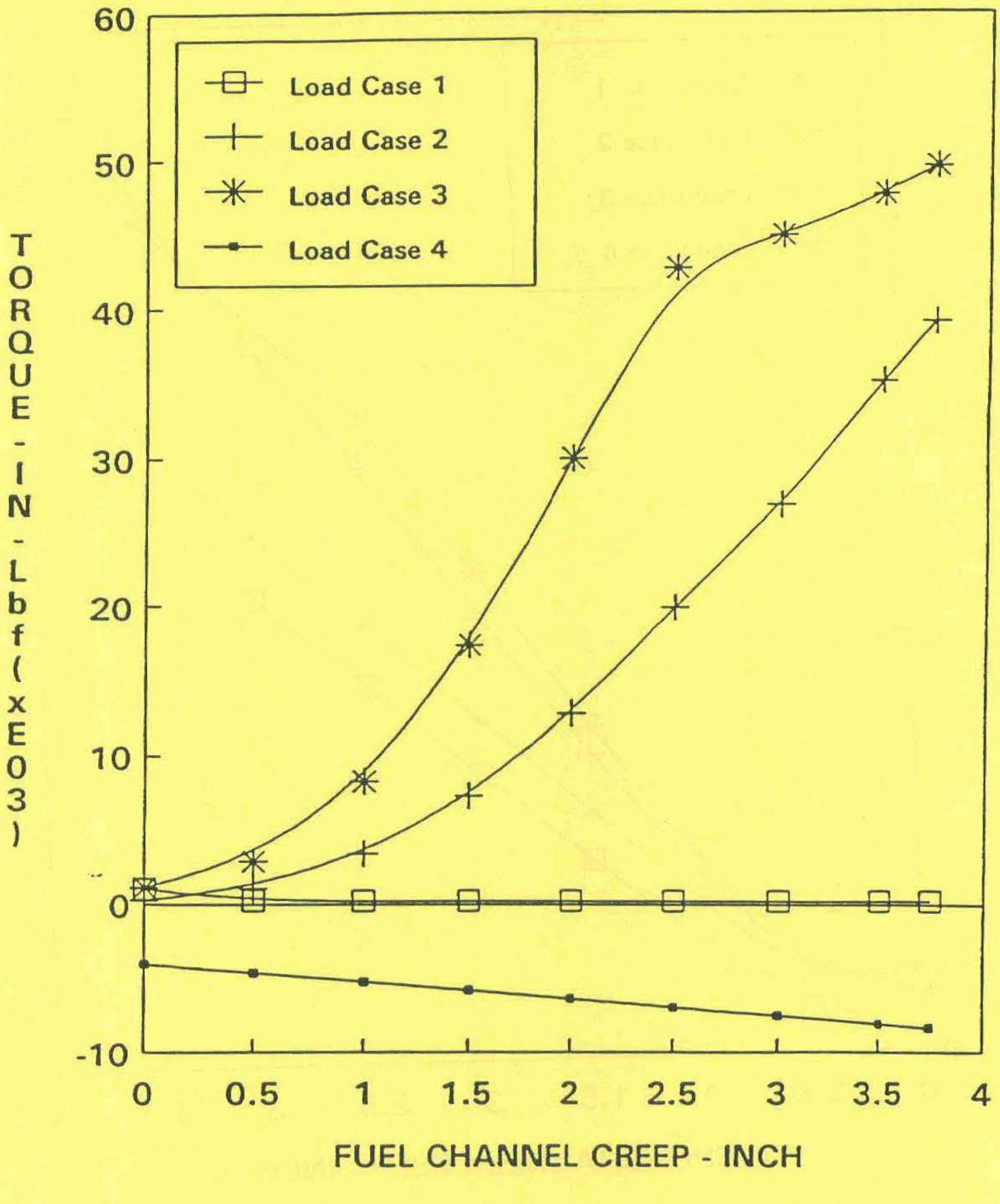

Figure 4: Torque on the Grayloc Hub

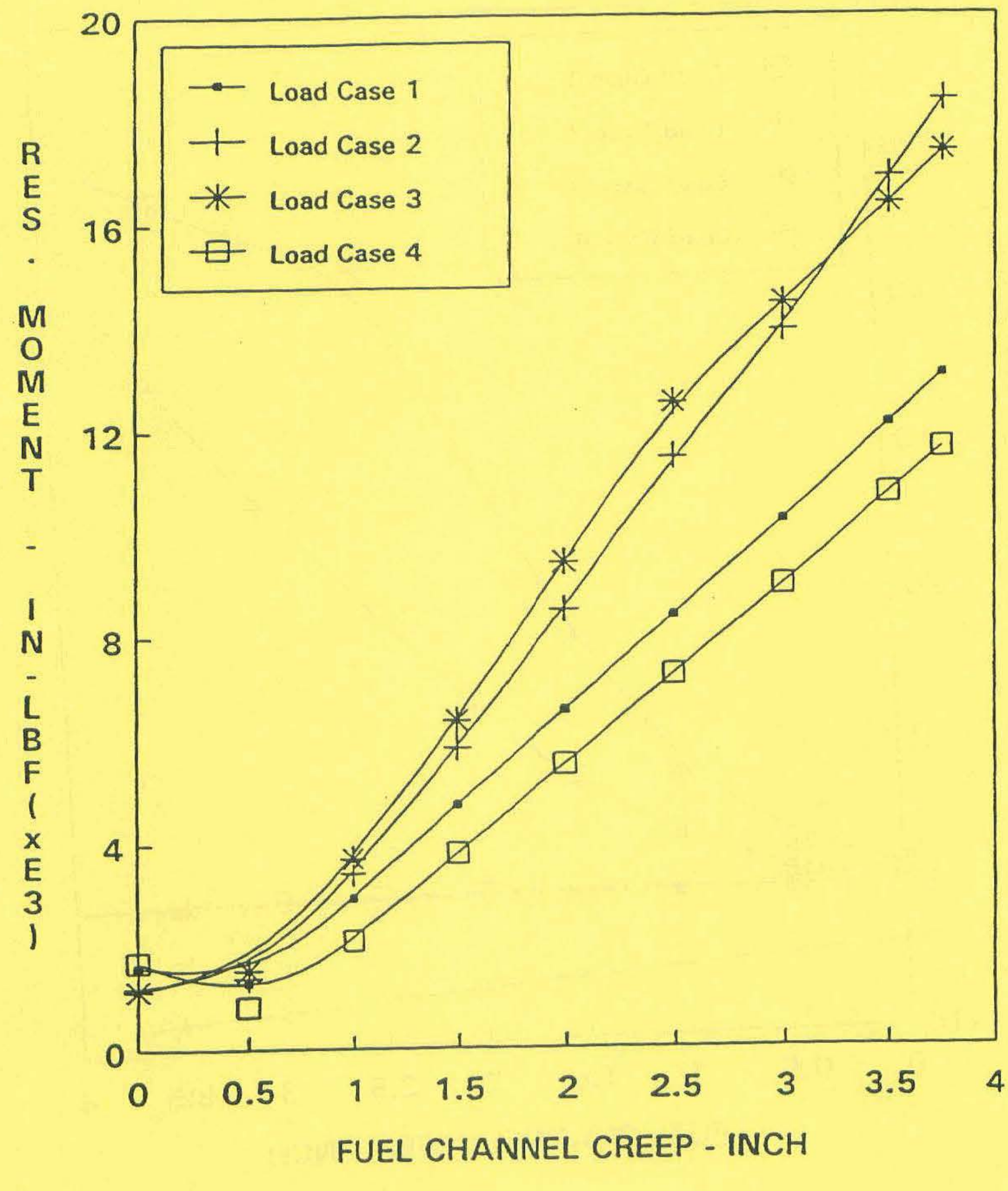

Figure 5: Resultant Moment on the Grayloc Hub

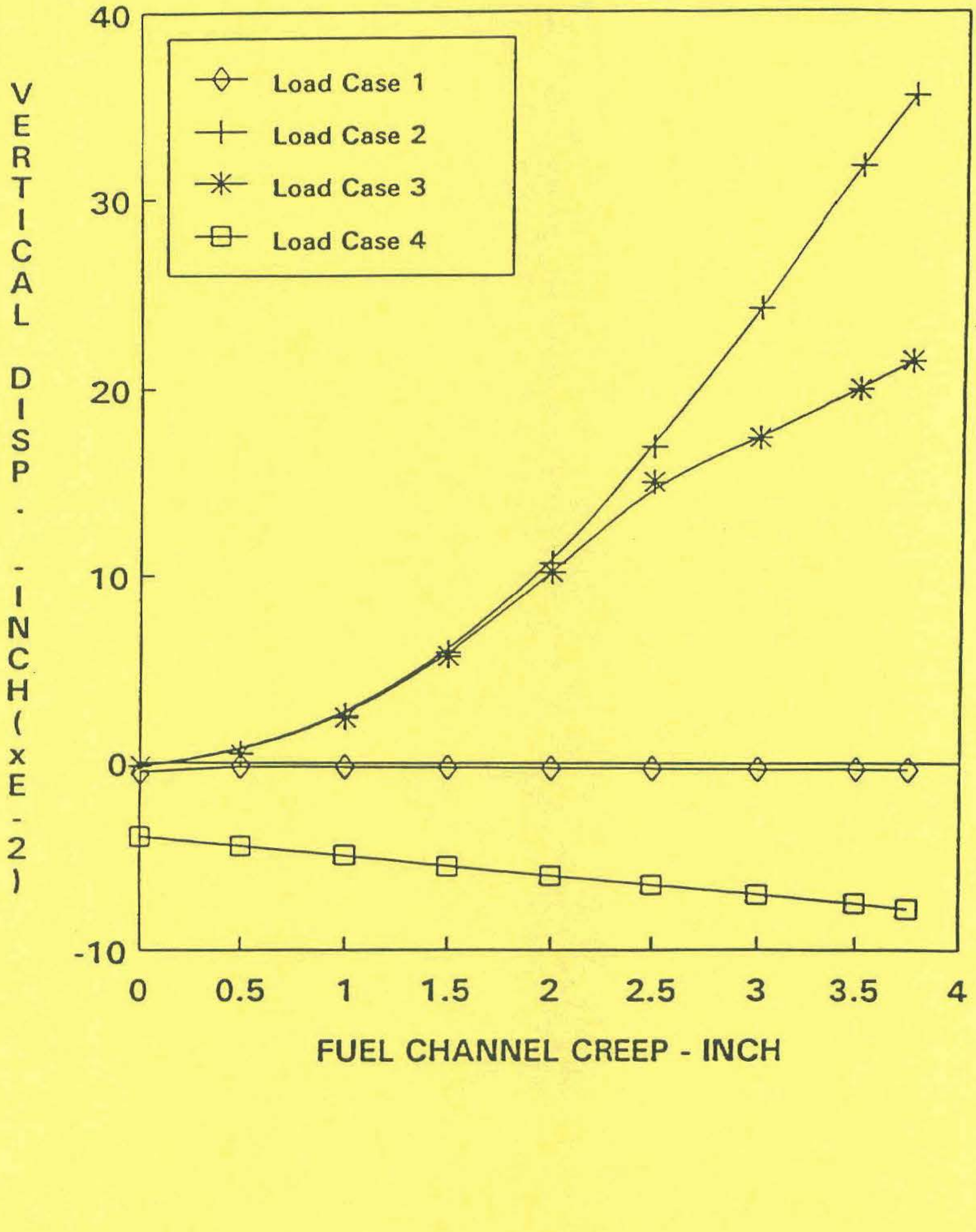

Figure 6: Vertical Displacement of Lower Eye Rod/Feeder Junction Point