DESIGN OF SINGLE PLATE FRAMING CONNECTIONS WITH A307 BOLTS

Prepared for
American Institute of Steel Construction
400 North Michigan Avenue
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Introduction

For the past several years, the American Iron and Steel Institute has funded a research effort at the University of Arizona to assess the strength and ductility of single plate framing connections and to establish design criteria and procedures that would insure adequate inelastic rotational capacity of this connection in order to prevent overstress of the fasteners, weldments, and supporting structure under design loadings with an adequate factor of safety. The results of this research was reported in Reference 1.

This research effort established that for A325 and A490 bolts in A36 plates, ductile behavior can be achieved by designing the connection so that the bolt shear mode of failure is circumvented. This can be accomplished by requiring the diameter of bolt to plate or web thickness ratios (D/t) to be greater than 2.0 for A325's and 1.5 for A490's and, additionally, providing a sufficient edge distance of twice the bolt diameter to prevent the tension tearing mode of failure. Included in the work done are design aids that have been developed for sizing the plate and the weldment of single plate connections with standard punched holes or slotted holes. Full-scale beam and single-plate single bolt tests provided experimental verification of the design criteria.

Also included in the research effort were single-plate single bolt shear tests for A307 bolts in round holes in A36 plates. The results of this study indicate that with standard round holes, the large D/t ratio required to avoid bolt shear would make their use impractical. However, when these bolts were used in slotted holes in full-scale beam tests, the measured eccentricities as defined in Figure 1 were far below those for A325 and A490 bolts because the bolts are not pretensioned. Since the D/t ratio

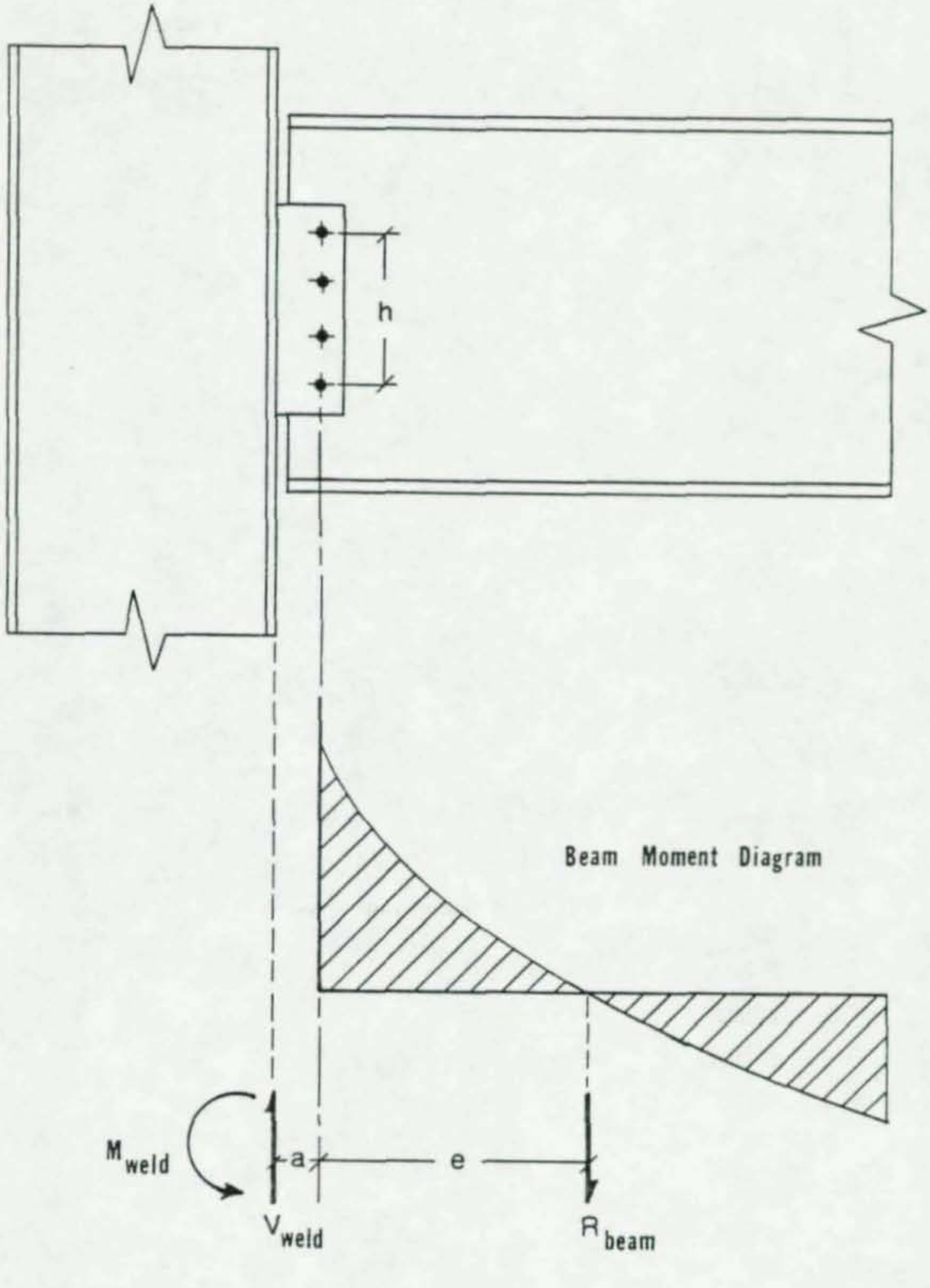


FIGURE 1. Definition of Eccentricity

does not apply to slotted holes and since the A307 bolts performed in a satisfactory way in the four tests (reported in Reference 2, repeated here in Table 1), the following research was funded.

Full Scale Beam Tests and Results

The proposed use of A307 bolts in single plate framing connections with slotted holes was evaluated using the test apparatus shown in Figure 2. This is the same test configuration used to evaluate and develop the design criteria for A325 and A490 bolts which was reported in Reference 1.

A total of 15 tests were made using 7/8" ϕ A307 bolts. Standard punched holes 15/16" in diameter were made in the beam and standard long slots were made in the framing plate which was welded to a W14 column support. Tests were conducted with the bolts installed under normal field erection procedures; i.e., tightened to a snug fit with a spud wrench. Tests were also made, for comparative purposes, with the bolts simply finger tight (no wrench used).

Two different L/d ratios of 16 and 10 for the beam were used to assess end rotation effects on the eccentricity generated by this connection when the beam was loaded to 1.5 times its service load.

The results of these tests are summarized in Table 1 whereas the detailed data for each of these tests is given in Appendix B. From these results, it is apparent that some eccentricity is developed and should be accounted for in the design of the plate weldment and its support. These tests result in a simple design aid wherein the eccentricity for uniformly loaded beams may be calculated using the formula

$$e = \frac{n\ h}{384}\frac{\ell}{d}$$

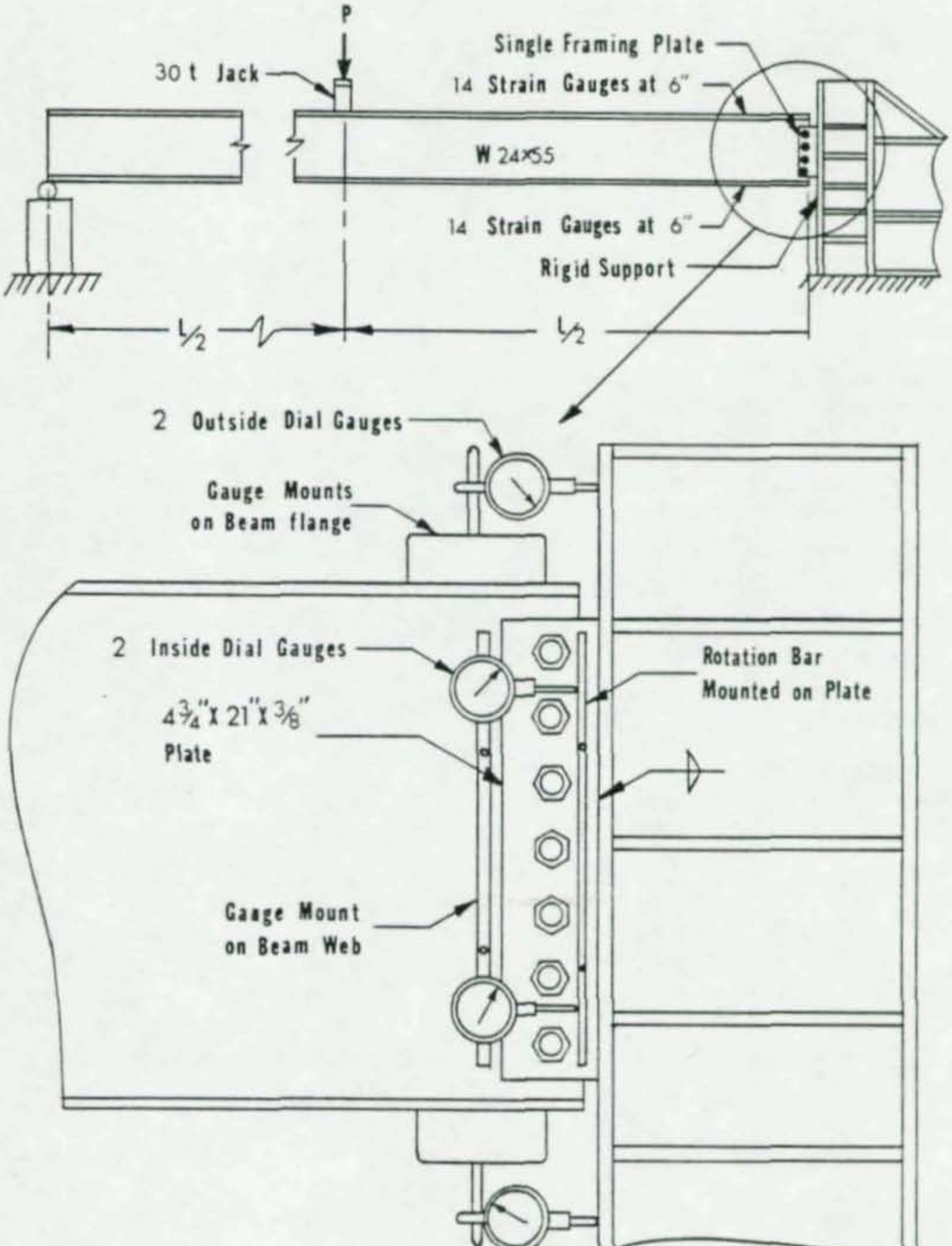


FIGURE 2. Full-Scale Test Apparatus

TABLE 1. TEST RESULTS

Test No.	No. of Bolts	ℓ/d	$\frac{n\ h}{192}\ \ell/d$	EXPERIMENTAL e_1	e_2	e_3
1	7	16	10.5	12.5	8.1	1.3
2	6		7.5	--	8.5	0.0
3	5		5.0	5.0	5.0	--
4	4		3.0	2.5	3.0	0.0
5	3		1.5	2.0	2.1	--
6	3 @ 6"		3.0	--	4.4	0.0
7	7	10	6.6	--	5.2	0.0
8	6		4.7	--	3.7	
9	5		3.1	--	1.7	
10	4		1.9	--	0.0	

Results for A307 bolts at 3" pitch (except where noted). Tests e_1 and e_2 are with normally torqued bolts. Test e_3 is for finger-tight bolts.

where e is the eccentricity as measured from the bolt line to the point of inflection in the beam (as shown in Figure 1), n is the number of bolts used, h is the height of the bolt pattern, ℓ is the length of the beam and d the depth of the beam. Test results indicate the formula is valid for a bolt pitch up to six (6) inches. For concentrated loads, the eccentricity coefficients presented in Reference 1, Appendix A, should be applied.

It is noted that the moment that is generated by this connection is primarily a result of the clamping force between the connection plate and the beam web since this moment is zero or very near zero for all the cases where the bolts were installed only finger tight. This observation is also consistent with the much higher moment that is developed by the torqued high strength A325 and A490 bolts as reported in our earlier research studies (1).

Since the moment is due to the clamping force and A307 bolts are tightened using a spud wrench, the above design formula should be valid for 3/4" ϕ and 1" ϕ A307 bolts since the torque applied to these bolts would be about the same as that for the 7/8" ϕ bolts used in the tests to derive this formula. Thus, this design formula may also be used for untorqued A325 and A490 bolts in slotted holes.

Recommended Design Procedure

Listed below is a detailed design procedure that is based upon the results of the experimental research study on single plate framing connections with A307 bolts.

1. Select plate thickness ±1/16-in. of supported beam web thickness.
2. Compute number of bolts required based upon allowable beam shear and allowable bolt loads. Insure connection ductility by providing long slotted holes.

3. Compute e for the uniform load case

$$e = \frac{n\,h}{384}\,\frac{\ell}{d}$$

where

n = number of bolts

h = depth of bolt pattern

4. Compute the moment at the weldment:

$$M = V \times (e + a)$$

where

V = beam shear force

e = eccentricity from Step 3

a = distance from the bolt line to the weldment

5. Check the plate normal and shear stresses:

$$f_b = \frac{6\,M}{tb^2}$$

$$f_v = \frac{V}{bt}$$

where t and b are the plate thickness and depth, respectively.

6. Design the weldment based upon the resultant of the normal and shear stresses from Step 5:

$$f_r = (f_b^{\,2} + f_v^{\,2})^{0.5}$$

7. Design support structure for moment from Step 4 (see Figure A.1).

Remarks on the Design Procedure

1. If according to Steps 2 and 6 a thinner plate will be adequate, such plate may be selected. Use A36 material.

2. The number of bolts computed here assumes equal shear in each bolt. This research has shown that this is not exactly true; however, by designing ductility into the connection through the prevention of bolt shear by means of slotted holes, adequate redistribution of the shear in the bolt pattern results in satisfactory connection performance at the bolt line.

3. The design formula is independent of the bolt pitch up to six (6) inches. For concentrated loads, use the eccentricity coefficients of Reference 1, Appendix A.

4. The distance from the bolt line to the weldment line, denoted here as a, (see Figure 1) is usually about three inches.

ACKNOWLEDGMENT

The American Institute of Steel Construction funded this research. The authors extend their appreciation to this organization and to the members of the committee chaired by Mr. Ned Young for their guidance and financial help in completing this research.

REFERENCES

1. Richard, R. M., et.al., "The Analysis and Design of Single Plate Framing Connection", Engineering Journal, AISC, Second Quarter, Volume 17, No. 2, 1980.

2. Hormby, D. E., Richard, R. M., and J. D. Kriegh, "Design of Single Plate Framing Connections", Final Report submitted to the American Iron and Steel Institute under Project 305b, May 1981.

APPENDIX A

DESIGN EXAMPLE

Given: W16 x 40, A36 steel
Span: 20 ft, laterally supported
Loading: Uniform with W = 52 kips

Solution:

1. Select t_{plate} = 5/16-in. (t_{web} = 0.305 in.)
2. Try 7/8-in. A307 bolts, R = 52/2 = 26 kips

   $N_{req'd}$ = 26 kips/6.0 kips = 5 bolts

3. For 3" pitch, h = 12"

   $$e = \frac{5 \times 12}{384} \frac{20 \times 12}{16} = 2.35"$$

4. For a = 3 in., V = R = 26 kips

   M = 26 x (2.35 + 3) = 139 kip-in.

5. $$f_b = \frac{6 \times 139}{0.305 \times 15^2} = 12.16 < 24 \text{ ksi}$$

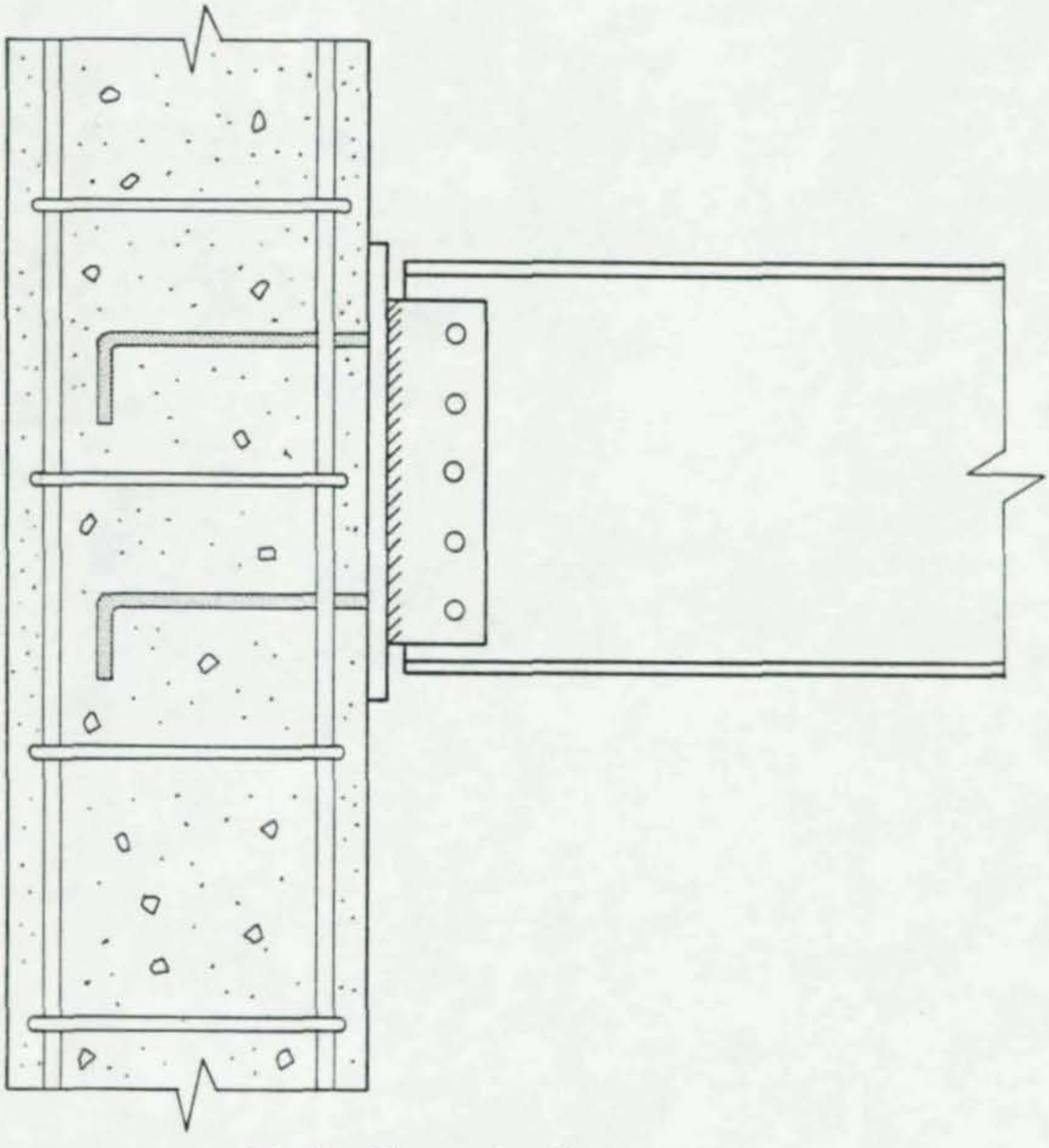
   $$f_v = \frac{26}{0.305 \times 15} = 5.68$$

6. $f_r = (12.16 + 5.68)^{1/2} = 13.42$ ksi

   $$\text{70 XX weld req'd} = \frac{13.42 \times 0.305}{0.93} = 4.40 \text{ sixteenths}$$

   Use 3/16 fillets each side

7. See Figure A.1 for support design considerations.

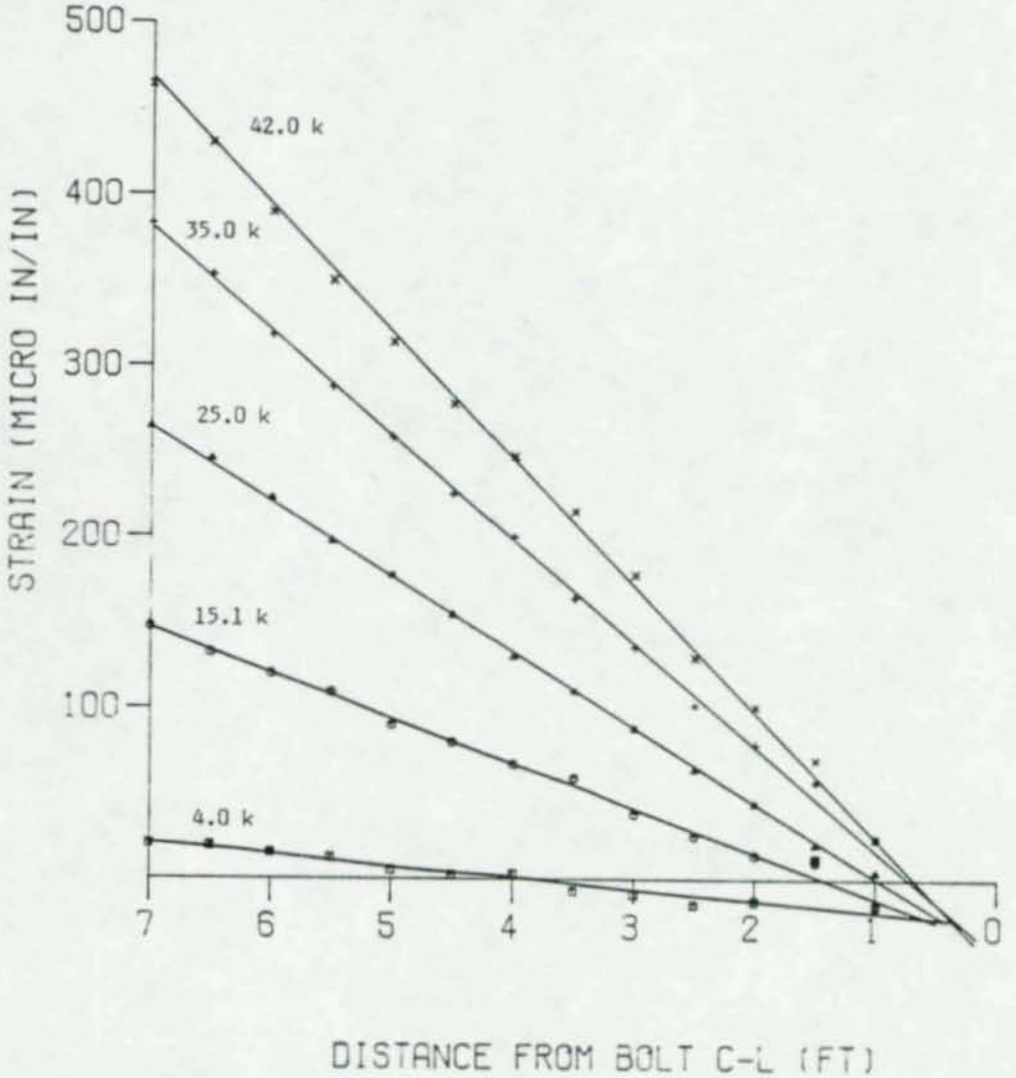


APPENDIX A.1. Single Plate Application in Mixed Construction

APPENDIX B

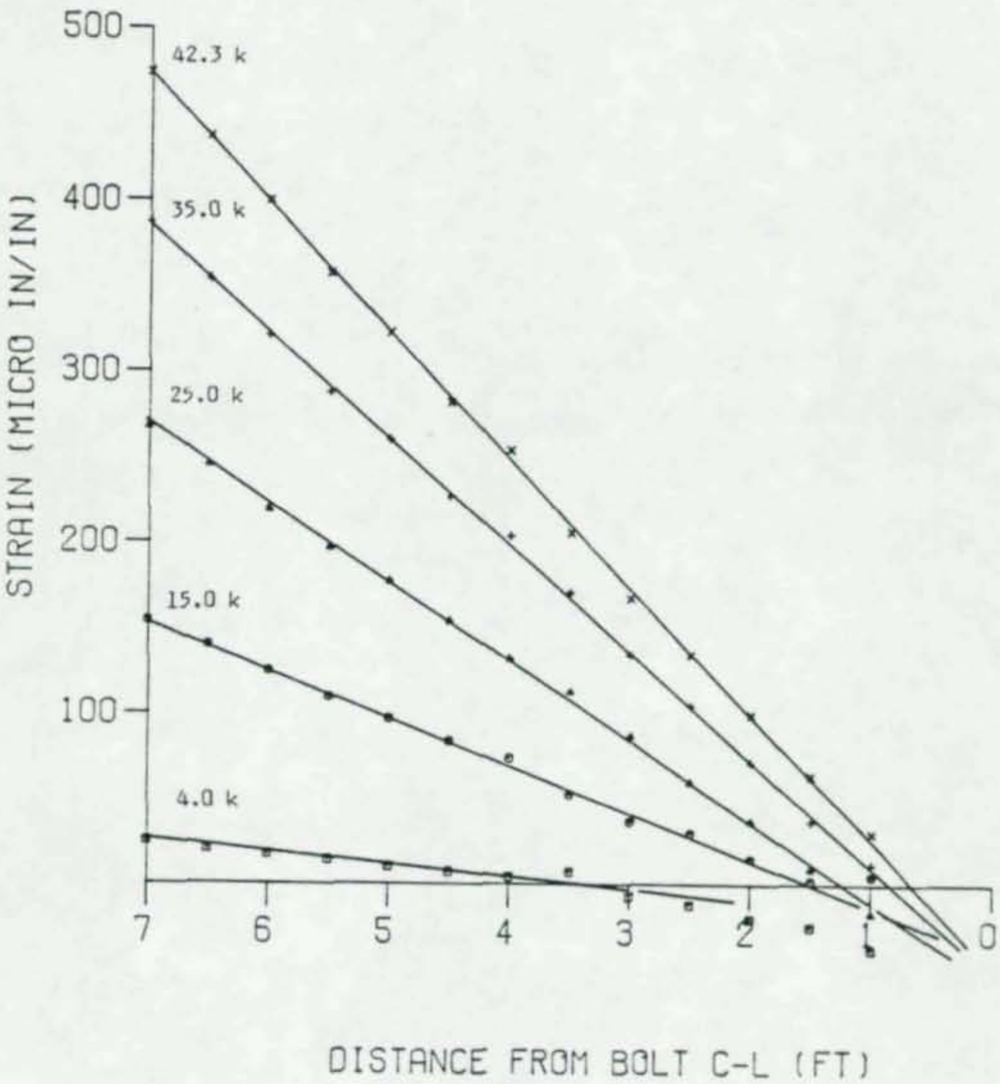
FULL-SCALE TEST RESULTS

(Tests with the suffix "L" were run finger tight.)



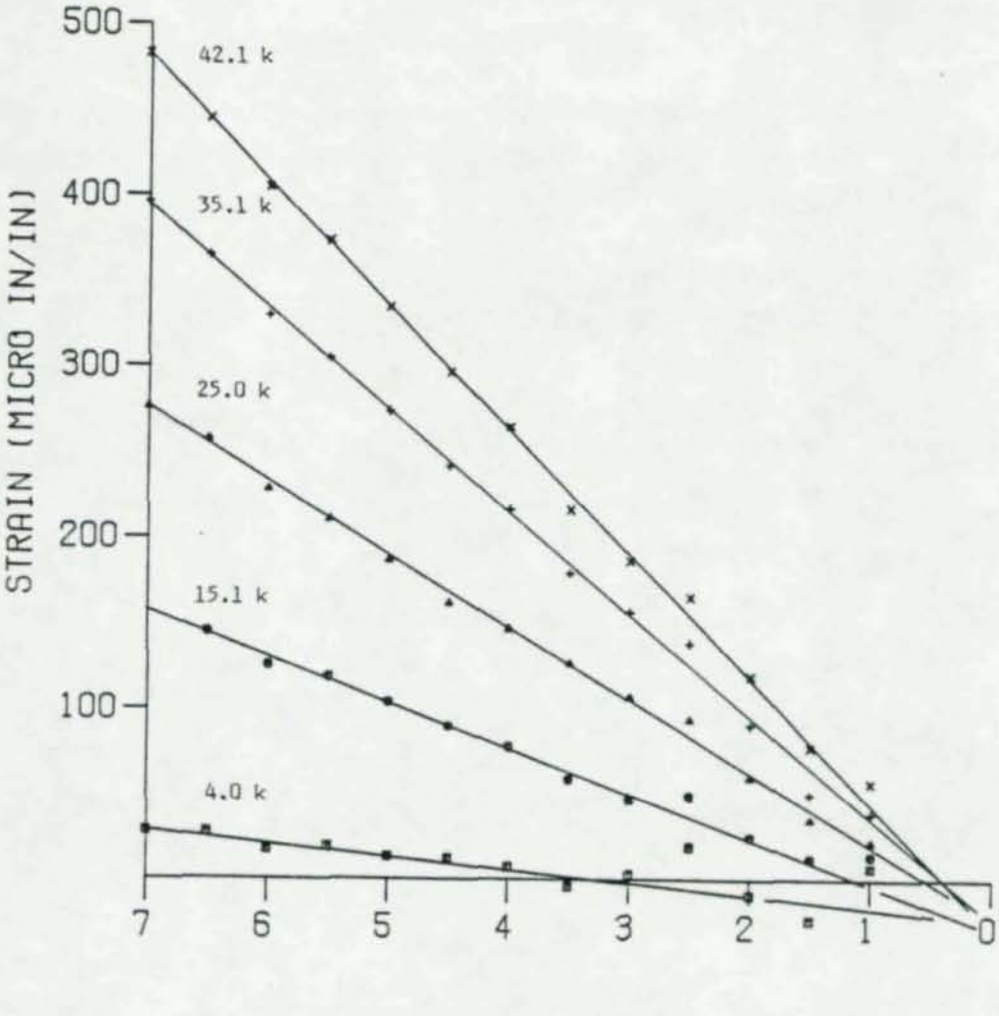
7 A307 BOLTS

APPENDIX B.1.



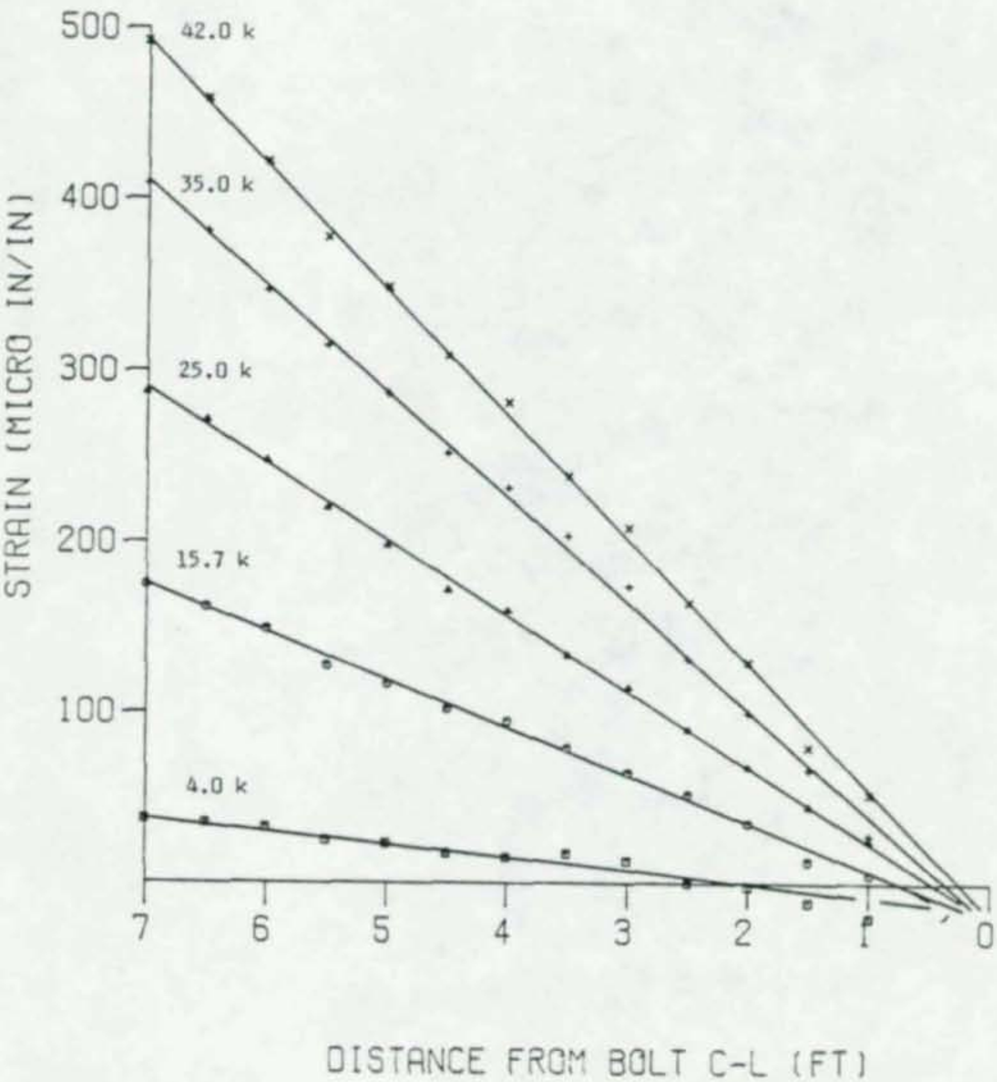
6 A307 BOLTS

APPENDIX B.2.



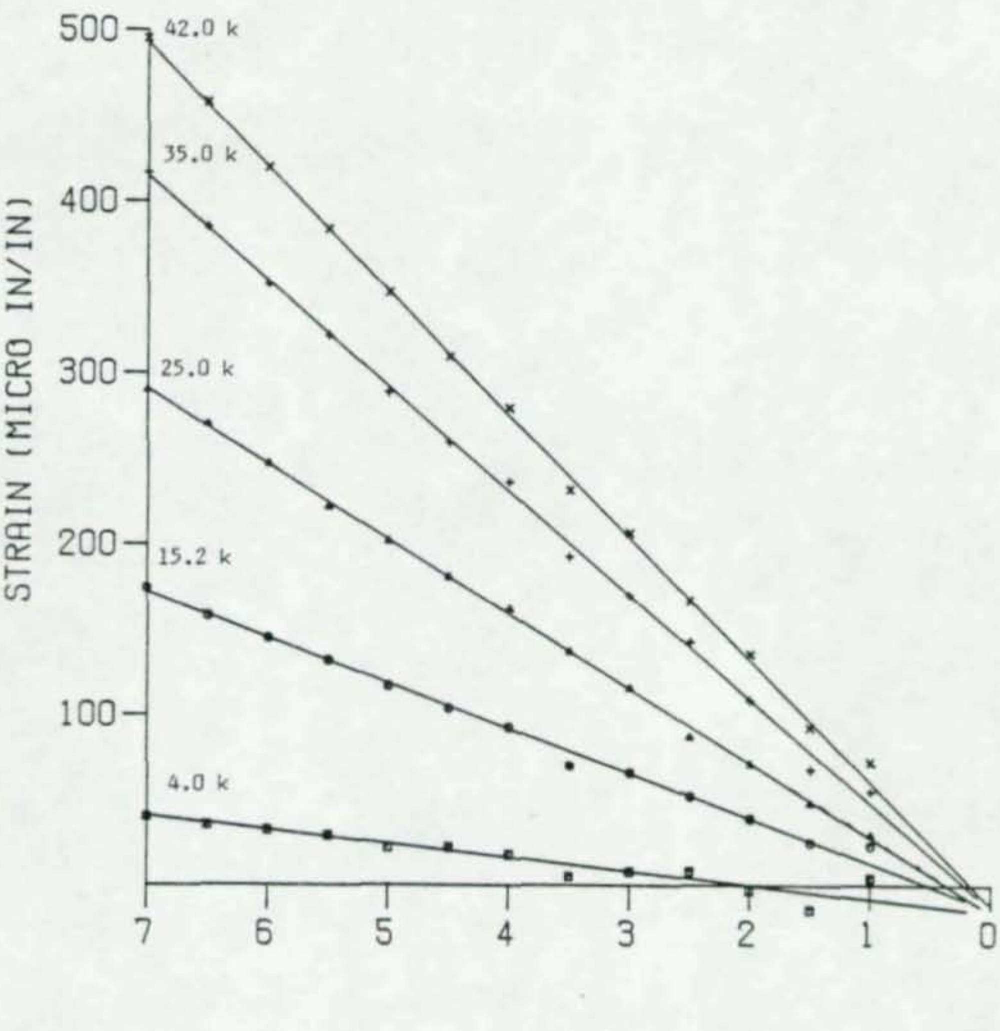
5 A307 BOLTS

APPENDIX B.3.



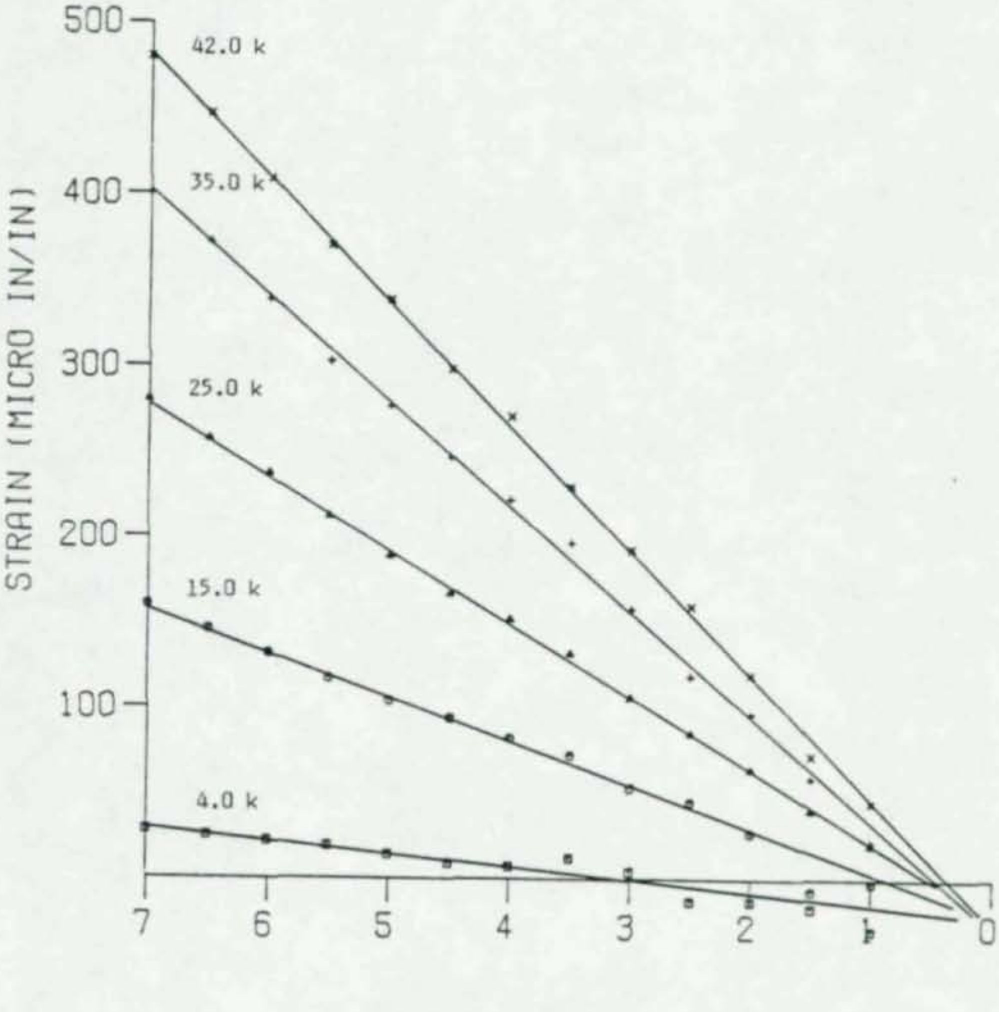
4 A307 BOLTS

APPENDIX B.4.



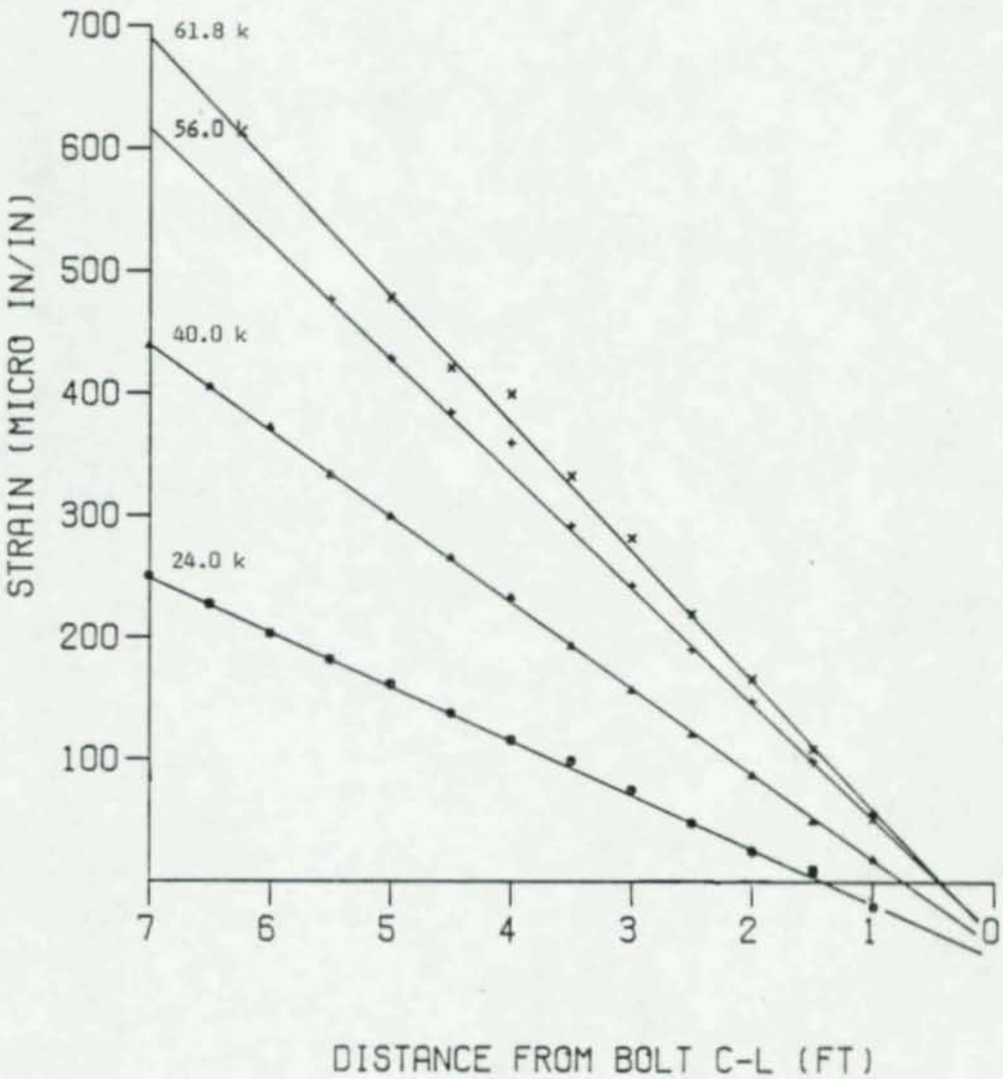
3 A307 BOLTS

APPENDIX B.5



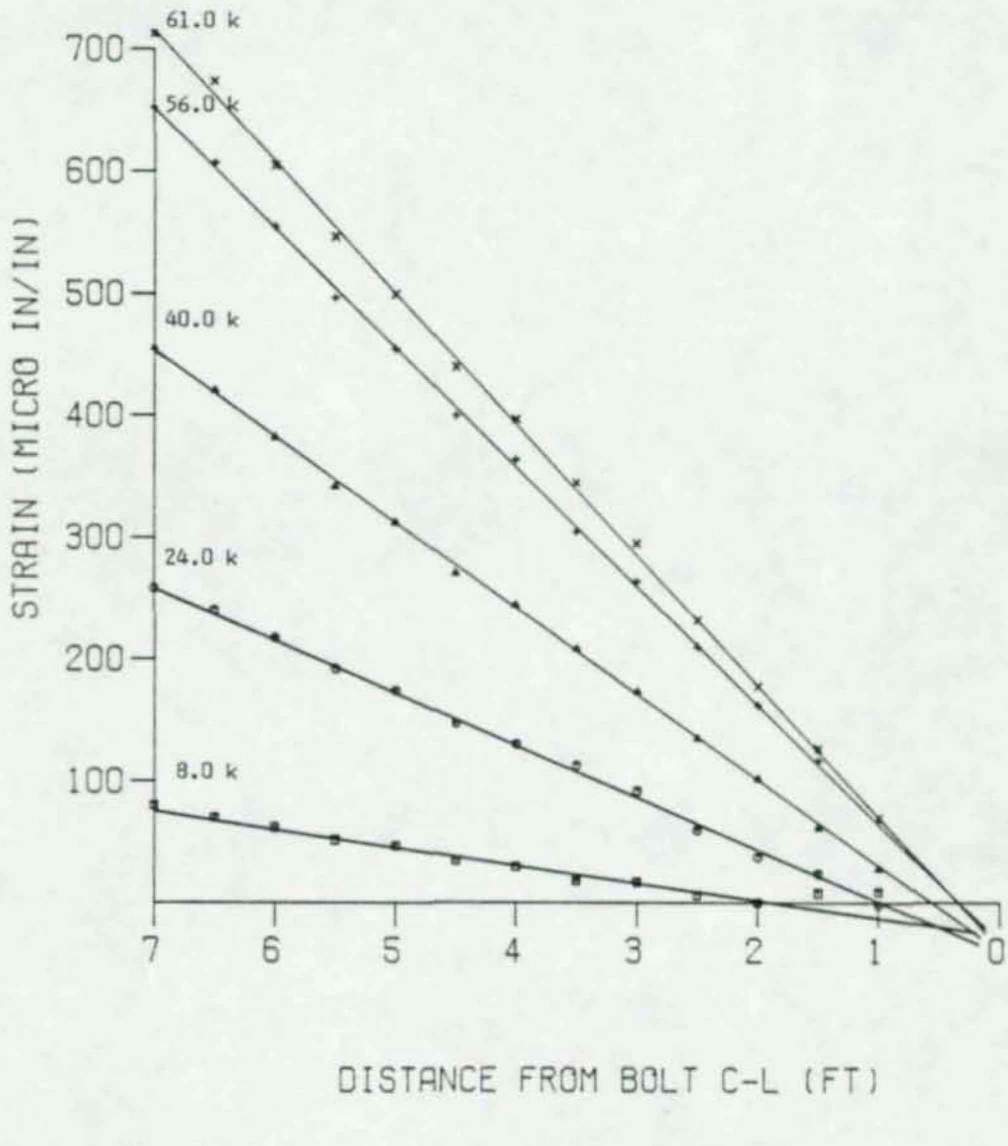
3 A307 BOLTS AT 6 IN.

APPENDIX B.6.



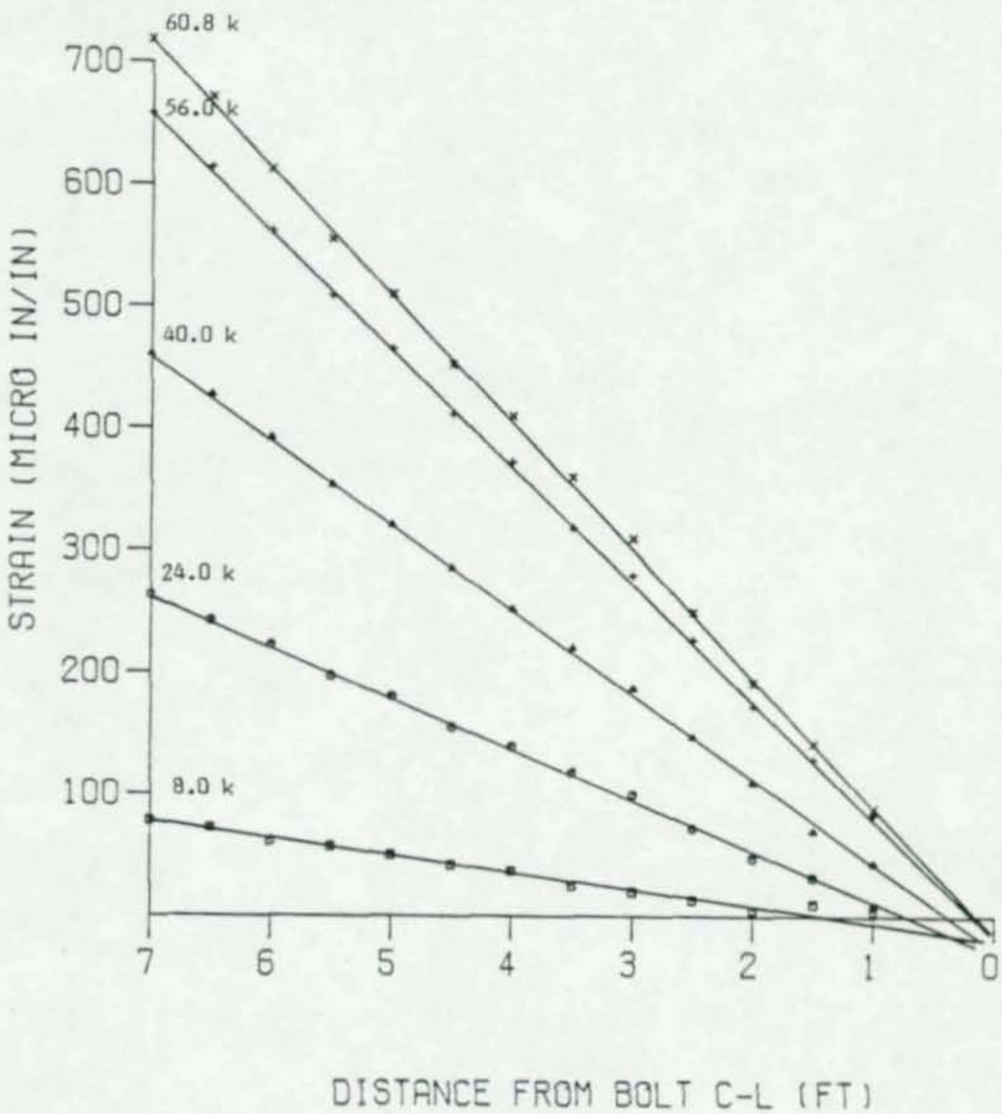
L/D=10   7 - A307 BOLTS

APPENDIX B.7.



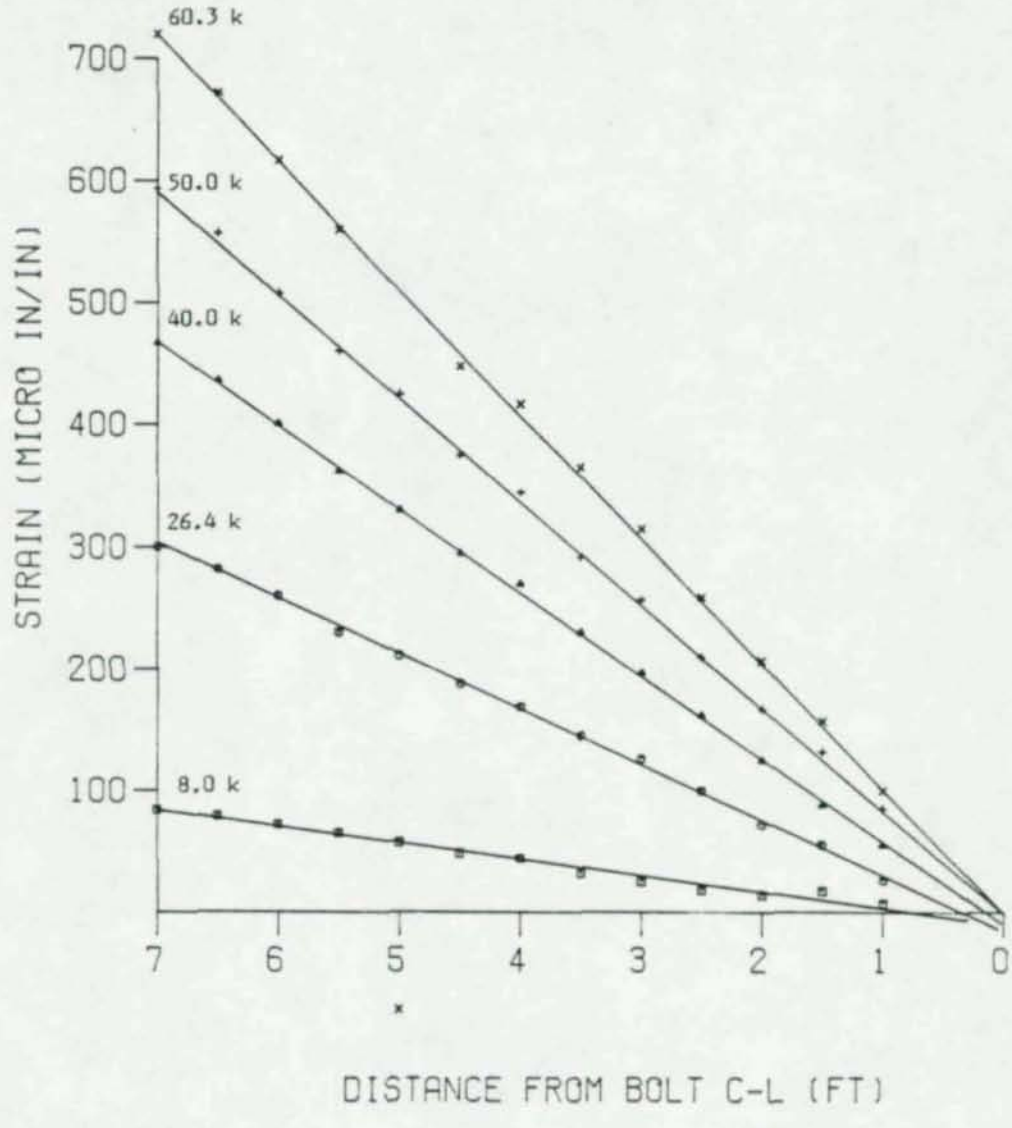
L/D=10 6 - A307 BOLTS

APPENDIX B.8.



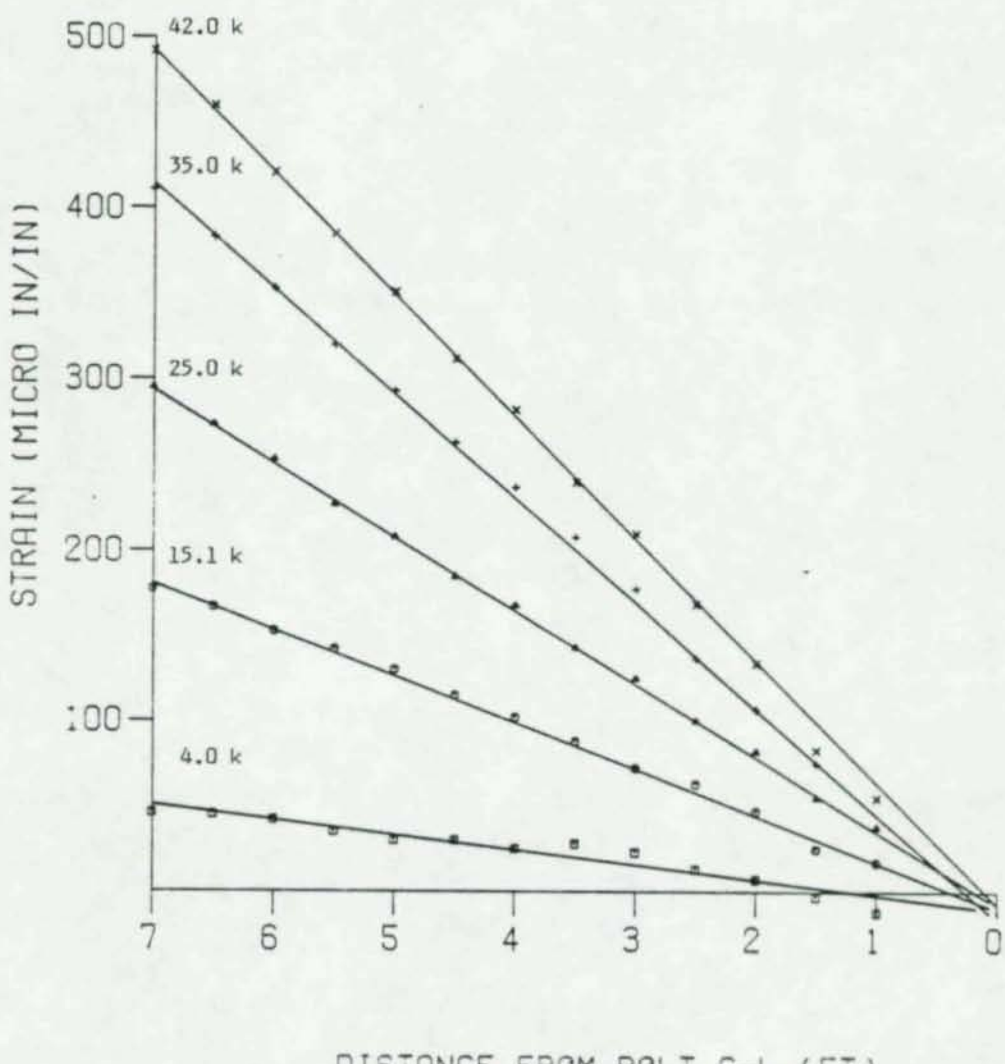
L/D=10 5 - A307 BOLTS

APPENDIX B.9.



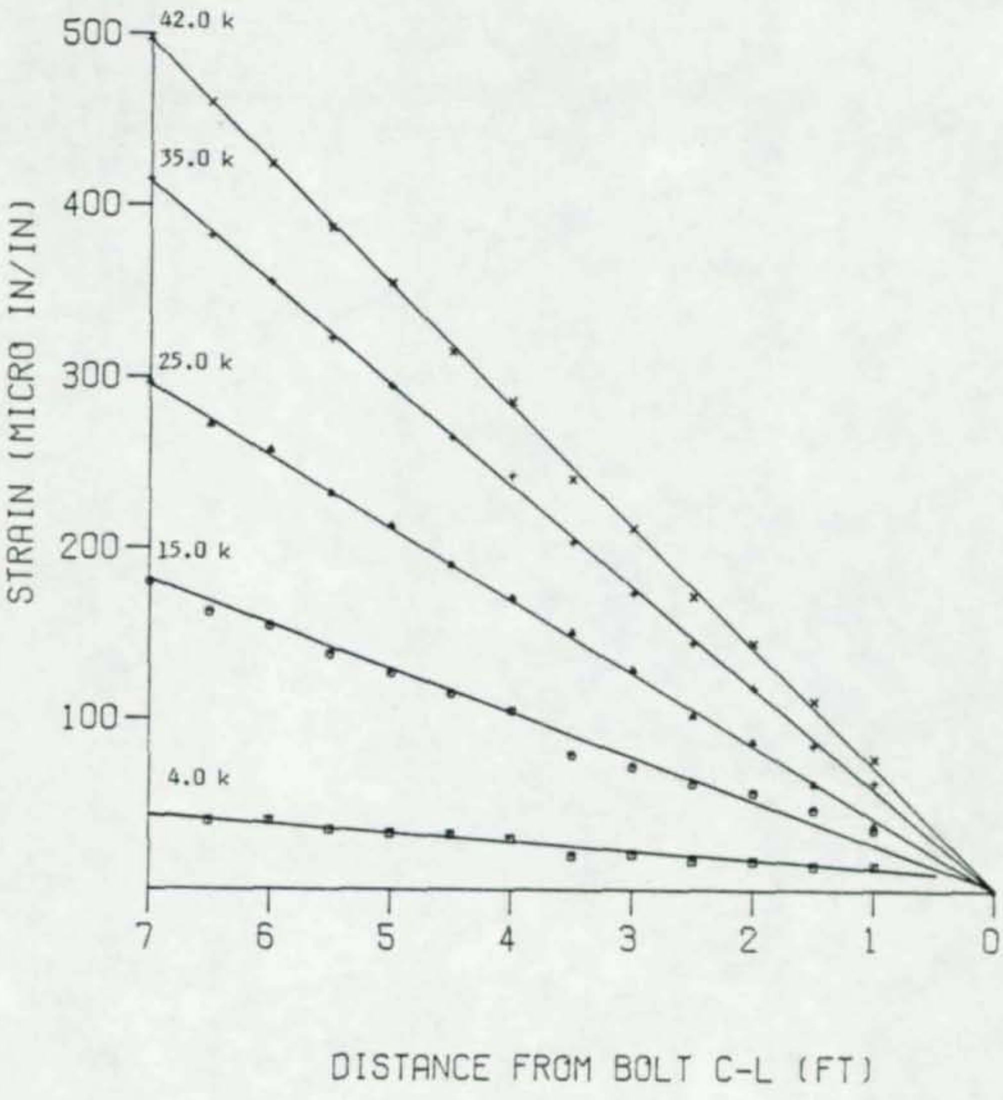
L/D=10 4 - A307 BOLTS

APPENDIX B.10.



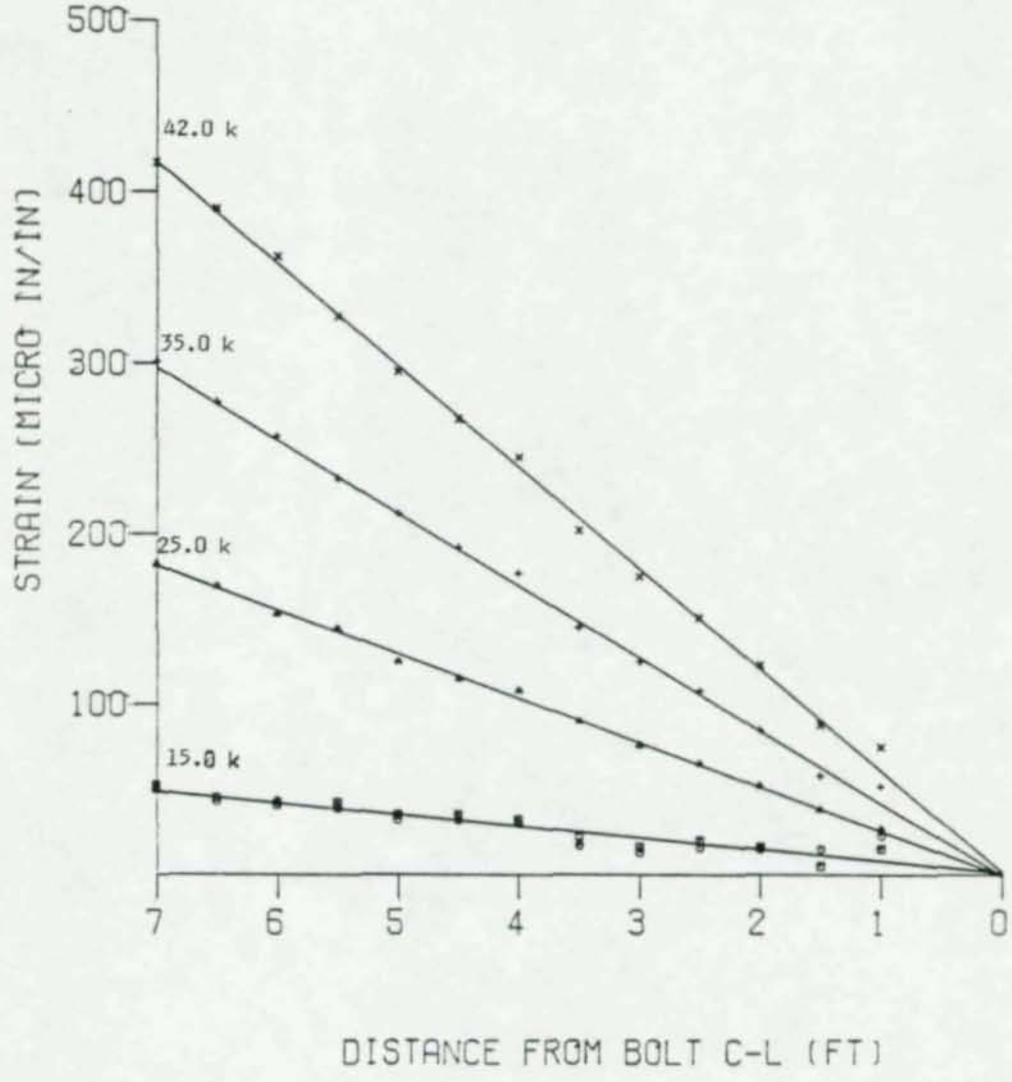
7 A307 BOLTS - FINGER TIGHT-L

APPENDIX B.11.



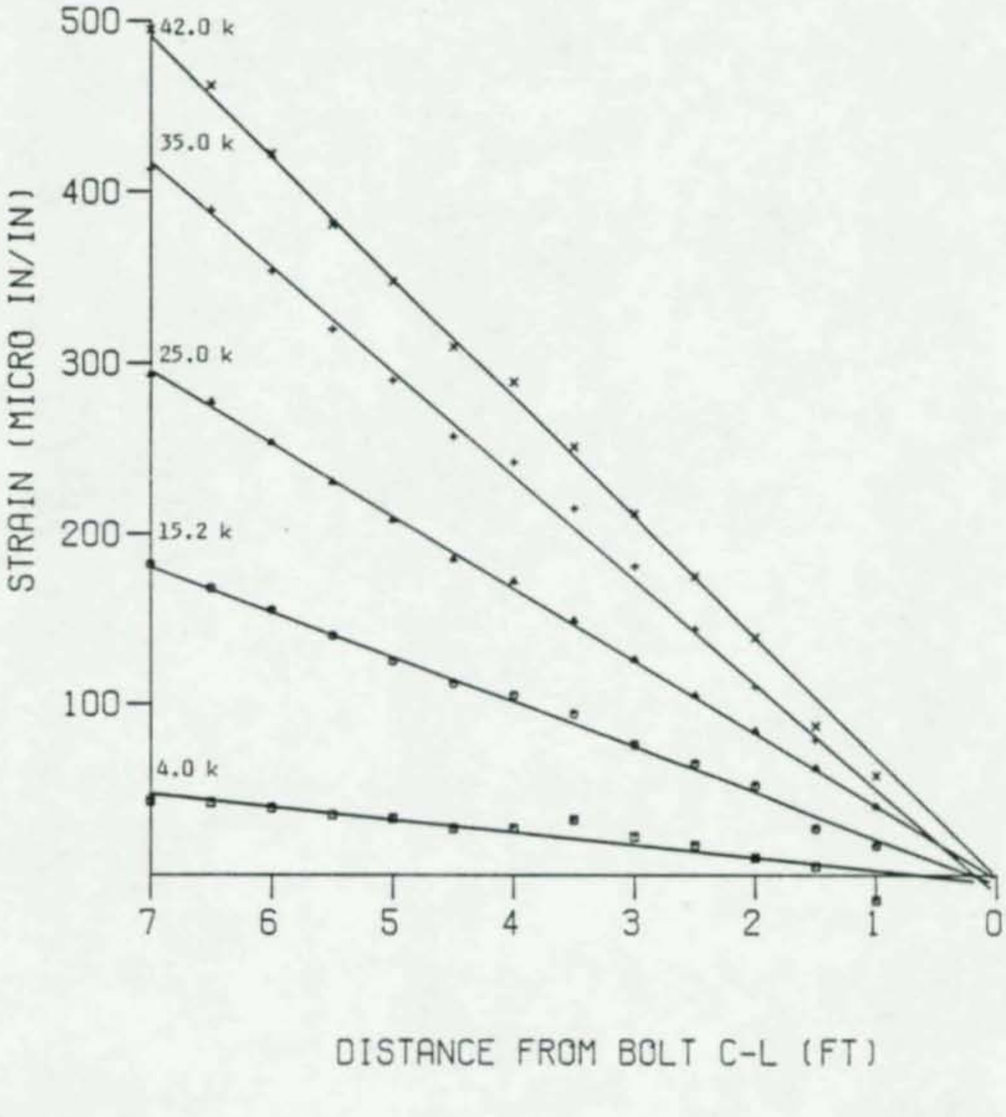
6 A307 BOLTS L

APPENDIX B.12.



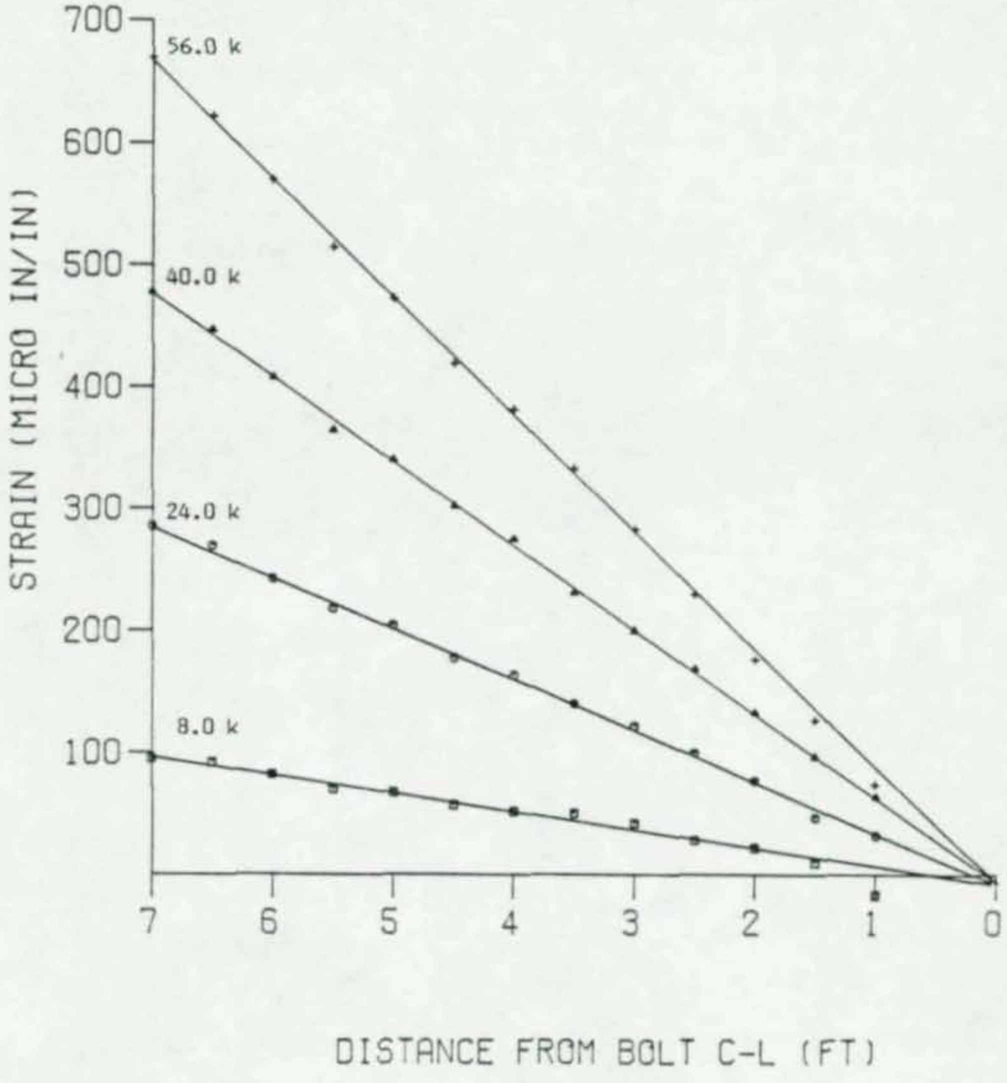
4 A307 BOLTS - L

APPENDIX B.13.



3 A307 BOLTS AT 6 IN. - L

APPENDIX B.14.



L/D=10 7 - A307 BOLTS - L

APPENDIX B.15.