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ROBERT. E. GINNA NUCLEAR POWER STATION

CONTAINMENT BUILDING TENDON INVESTIGATION

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SUMMARY

This report describes an investigation into the possible causes for the lower-than-predicted tendon forces which have been measured during past tendon surveillances for the R.E. Ginna containment. The tendons are vertical tendons which are anchored into the rock foundation. Causes investigated included the rock anchors and surrounding rock, stressing equipment, stress relaxation, and others. Stress relaxation tests were conducted on unstressed wires pulled from actual tendons. Field testing was performed to determine the accuracy of the stressing equipment. The elongations that the tendons exhibited during previous stressing operations were evaluated.

From the investigation it is concluded that stress relaxation of the tendon wires is the only single cause which would explain the larger-than-predicted force loss in the tendons. The predictions of tendon force loss were based on a relaxation grade of wire which would exhibit 12% stress relaxation after 40 years under load. However, tests on the wire specimens described in this report indicate that the wires, as they exist in the tendons, could exhibit a 40 year stress relaxation in the range of 15% to 18.5%. This difference in stress relaxation property is large enough to account for the differences between the forces measured at past surveillances and those predicted based on a 12% relaxation grade wire. For example, the 39 kip average value by which measured forces were less than predicted for a sample of 35 tendons in June 1980 is accounted for by the fact that the stress relaxation of the actual tendons are expected to have ranged from 4 to 7.5 percentage points higher than that of the 12% wire. This additional stress relaxation would result in a corresponding decrease in tendon force of 30 to 56 kips, and the 39 kips previously unaccounted for is consistent with these values.

The measured forces were evaluated for a sample of 64 tendons comprised solely of wires from the same heats as the test wires. It was determined that these tendons exhibited an average effective stress relaxation in June 1980 of 15%, which was consistent with the test results for the wires.

The report also describes the results of retensioning the tendons in June 1980, and of the first surveillance after this retensioning, which was performed in July 1981. Included in this surveillance were tests on the accuracy of the stressing equipment using a strain gaged stressing rod.

To predict the forces in the retensioned tendons at future surveillances, the stress relaxation properties for the retension wires must be determined. Two possible approaches to accomplish this are described.

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1.0 INTRODUCTION

1.1 TENDON DESCRIPTION AND FORCE HISTORY

The R. E. Ginna containment structure, shown in Figure 1-1, is post tensioned by 160 vertical tendons. Each tendon is approximately 115 feet long and consists of 90 wires, each 1/4 inch diameter. The plan location of each tendon is shown in Figure 1-2. Each tendon is connected at the containment base to another 90-wire tendon, approximately 34 feet long, which is grouted into rock and functions as a rock anchor (Figure 1-3).

The tendons were originally stressed in March and April 1969, and tendon surveillances have been performed over the past 10 years as indicated in Figure 1-4. The tendon lift-off forces measured in the first four surveillances were generally lower than predicted by an average value of 20 kips. This 20 kip discrepancy represented less than 3% of the original stressing force specified for the tendons (742 kips). However, it was significant because by the eight year (8) surveillance, the average force of the tendons was only marginally above the design requirement of 636 kips.

Because of the lower measurements, additional lift-off tests were conducted on 22 tendons in October 1979, which is referred to as the "10-year retest". The lift-off forces measured at the 10-year retest generally confirmed the lower-than-predicted results from past surveillances. As a result, Gilbert Associates, Inc. (GAI) was requested in the Fall of 1979 to evaluate the liftoff test results for the past 11 years. Reference 1 contains this evaluation.

1.2 JUNE 1980 RETENSIONING

Resulting from the evaluation referenced above was the decision by Rochester Gas and Electric Corporation (RG&E) to retension 137 of the 160 tendons. This work was completed in June 1980 and is referred to as the "11-year retensioning". The twenty-three (23) tendons which were not included in the June 1980 retensioning program had been previously retensioned in May 1969, approximately 1000 hours after original stressing, and their lift-off force history indicated that another retensioning was not necessary.

The results of the June 1980 retensioning are presented in Table 1 of Appendix A. The forces measured before (lift-off) and after (lock-off) retensioning are given for each tendon along with a comparison of the measured and calculated (predicted) elongations. Table 1 indicates that the average forces for the 137 tendons were 607 kips before and 760 kips after retensioning.

Reference 1 contains forty-two (42) figures which document the measured forces for all tendons included in past surveillances. These figures have been updated and presented in Appendix A of this report to include the forces measured immediately before (lift-off force) and immediately after (lock-off force) retensioning. There are 35 of the 137 retensioned tendons for which predicted force curves are shown in the Appendix A figures. From the figures for these 35 tendons, the average lift-off force measured prior to retensioning was 606 kips, which is 39 kips less than the average predicted force of 645 kips (Base Value). Thus, the lift-off tests performed immediately prior to tendon retensioning in June 1980 confirmed the lower-than-predicted forces which the tendons had exhibited in the past.

As a result of tendon retensioning, the 760 kip average tendon force exceeded the design minimum required average tendon force of 636 kips by 19.5%. The measured and calculated elongations were in good agreement, which indicated no abnormal behavior of the tendons during the retensioning operations. Based on the force and elongation data, the June 1980 retensioning program was considered successful.

1.3 JULY 1981 SURVEILLANCE

Approximately one year after the retensioning, in July 1981, the forces in 18 tendons were measured as part of the first tendon surveillance subsequent to the June 1980 retensioning. The various objectives and conclusions of this surveillance are discussed in detail in Section 5.0. The primary results are:

a. The 18 tendons had measured force levels above the 636 kip technical specification limit.

b. The average measured tendon force was 714 kips, which is 12.3% above the 636 kip minimum requirement.

c. The measured forces were in reasonable agreement with those predicted for the retensioned tendons.

1.4 PURPOSF

The purpose of this report is to present:

a. The investigation and conclusions from a study of postulated causes for the lower-than-predicted tendon forces which have been measured during past tendon surveillances (Section 2.0).

b. The results and conclusions of the stress relaxation tests performed at Lehigh University on selected tendon wires (Section 3.0).

c. A study of a methodology for predicting stress relaxation losses in the retensioned tendons; consequently, enabling a prediction of their forces at future survei lances (Section 4.0).

d. The results of the first tendon surveillance (July 1981) performed after the tendon retensioning in June 1980 (Section 5.0).

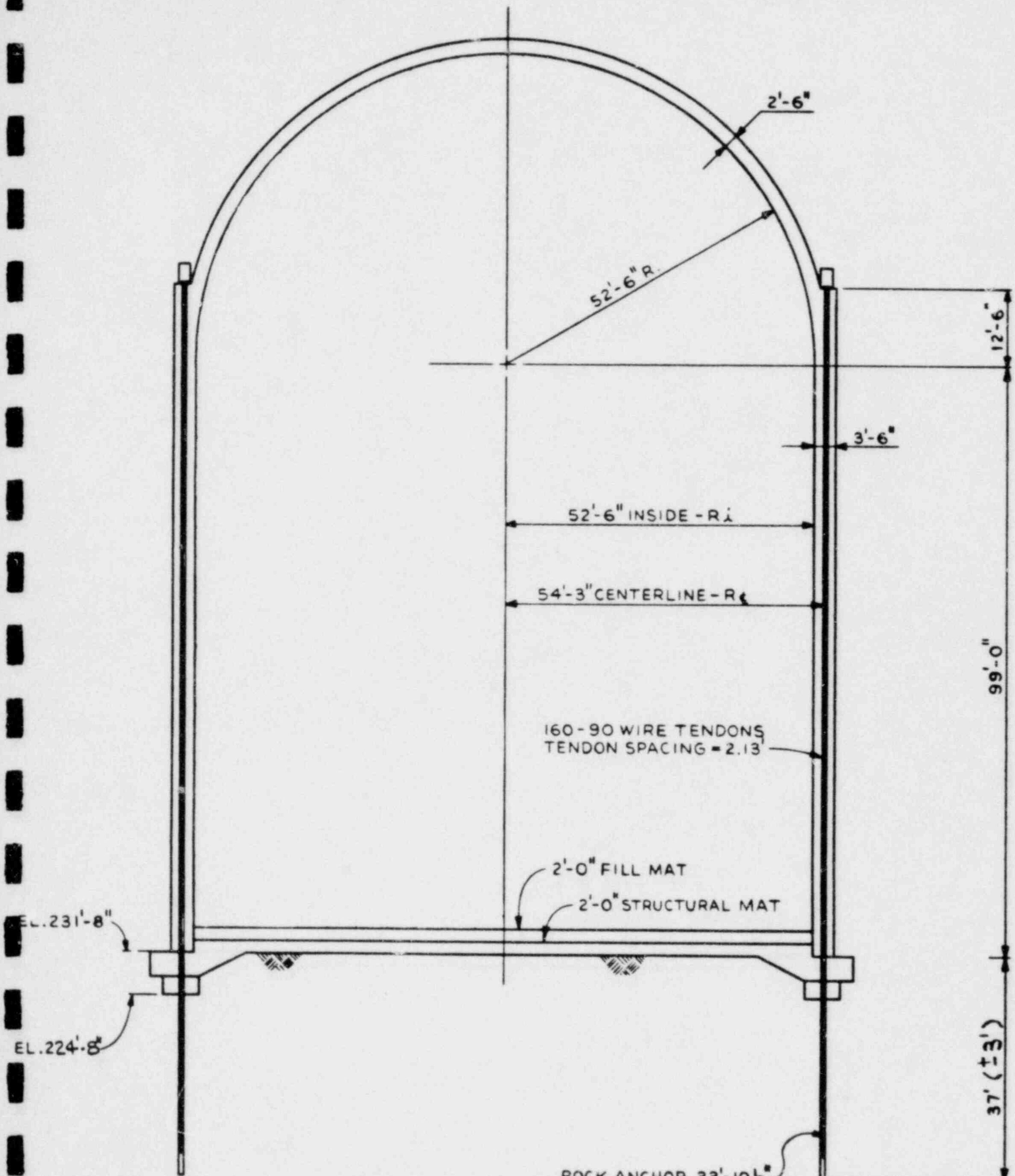
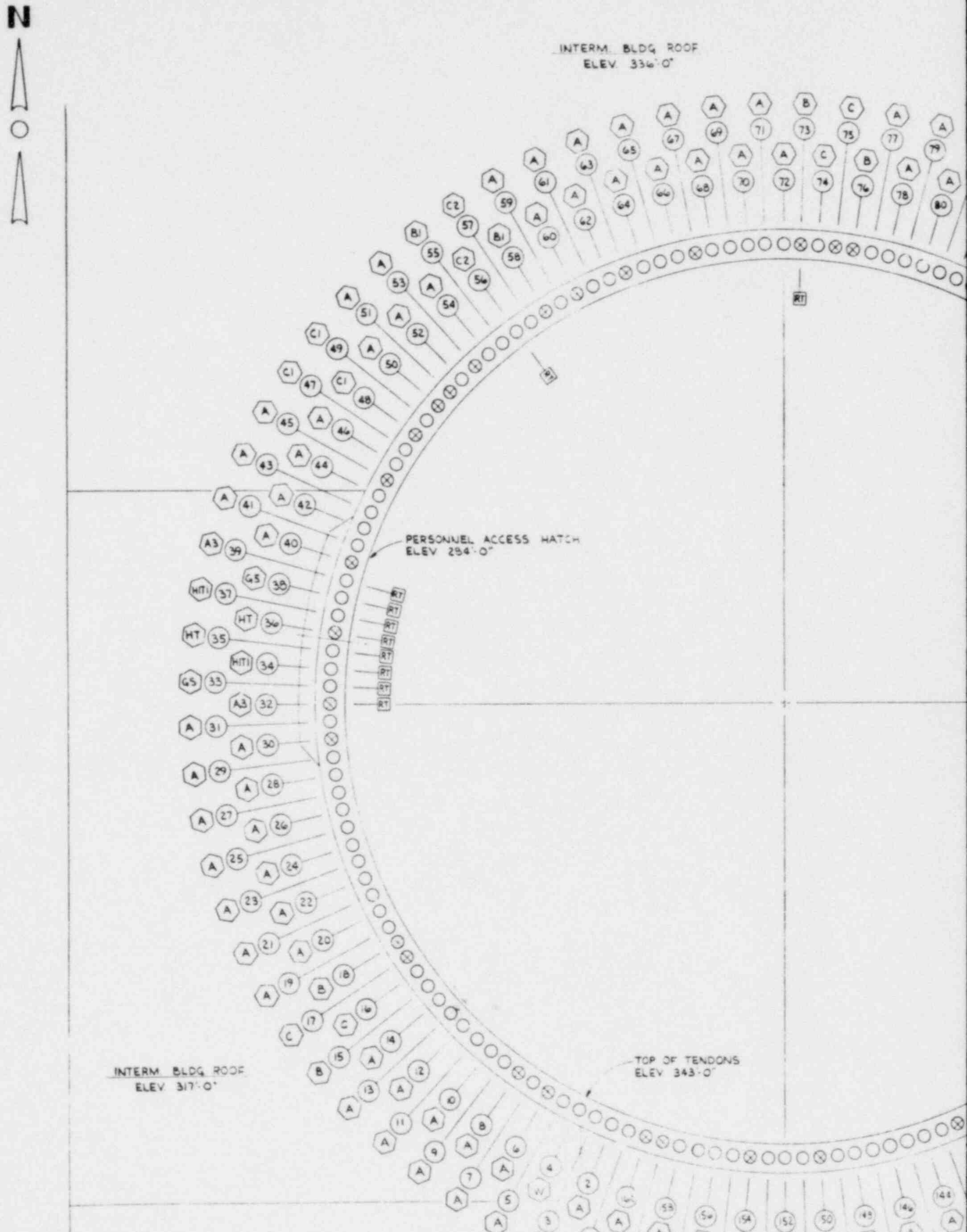


FIGURE 1-1
CONTAINMENT BUILDING


N
INTERM. BLDG ROOF
ELEV. 336'-0"
PERSONNEL ACCESS HATCH
ELEV 284'-0"
TOP OF TENDONS
ELEV 343'-0"
INTERM BLDG ROOF
ELEV 317'-0"

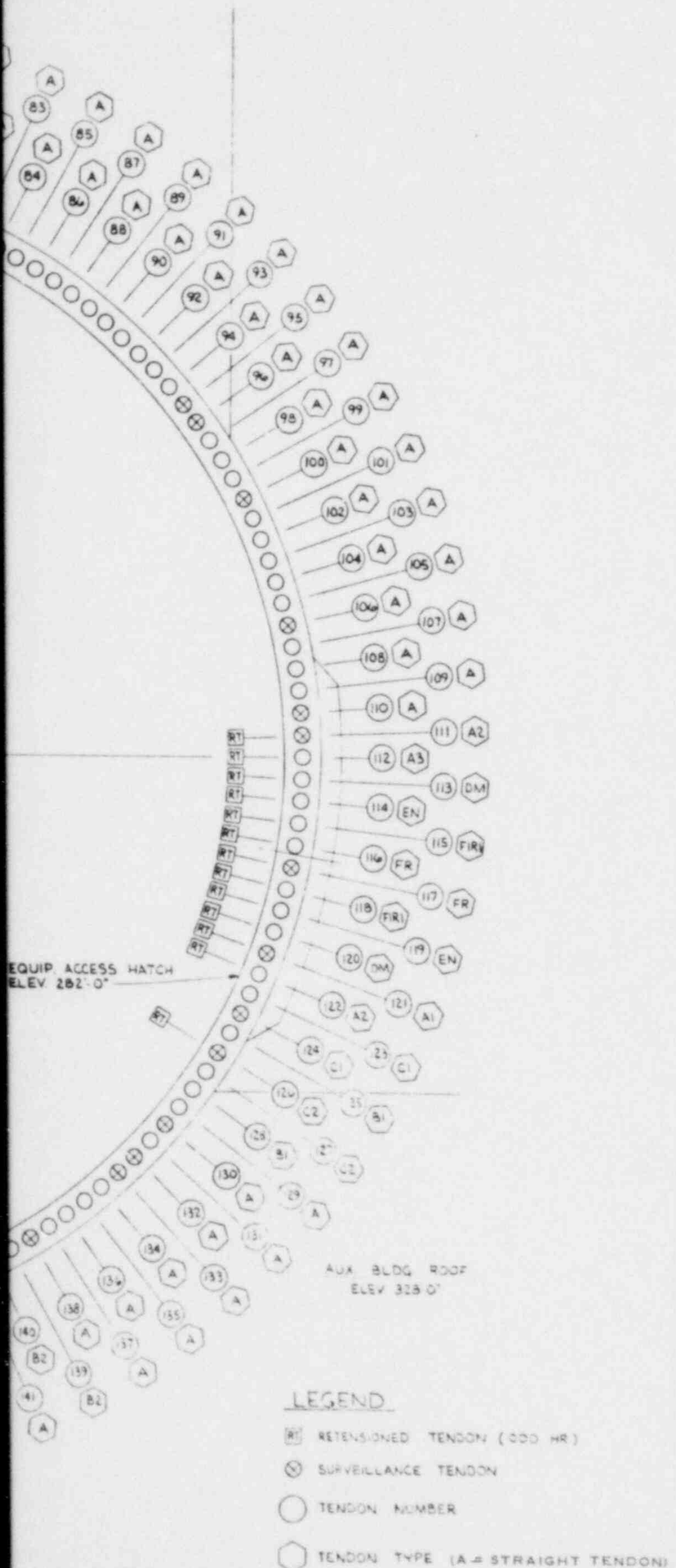


FIGURE 1-2
TENDON LOCATION

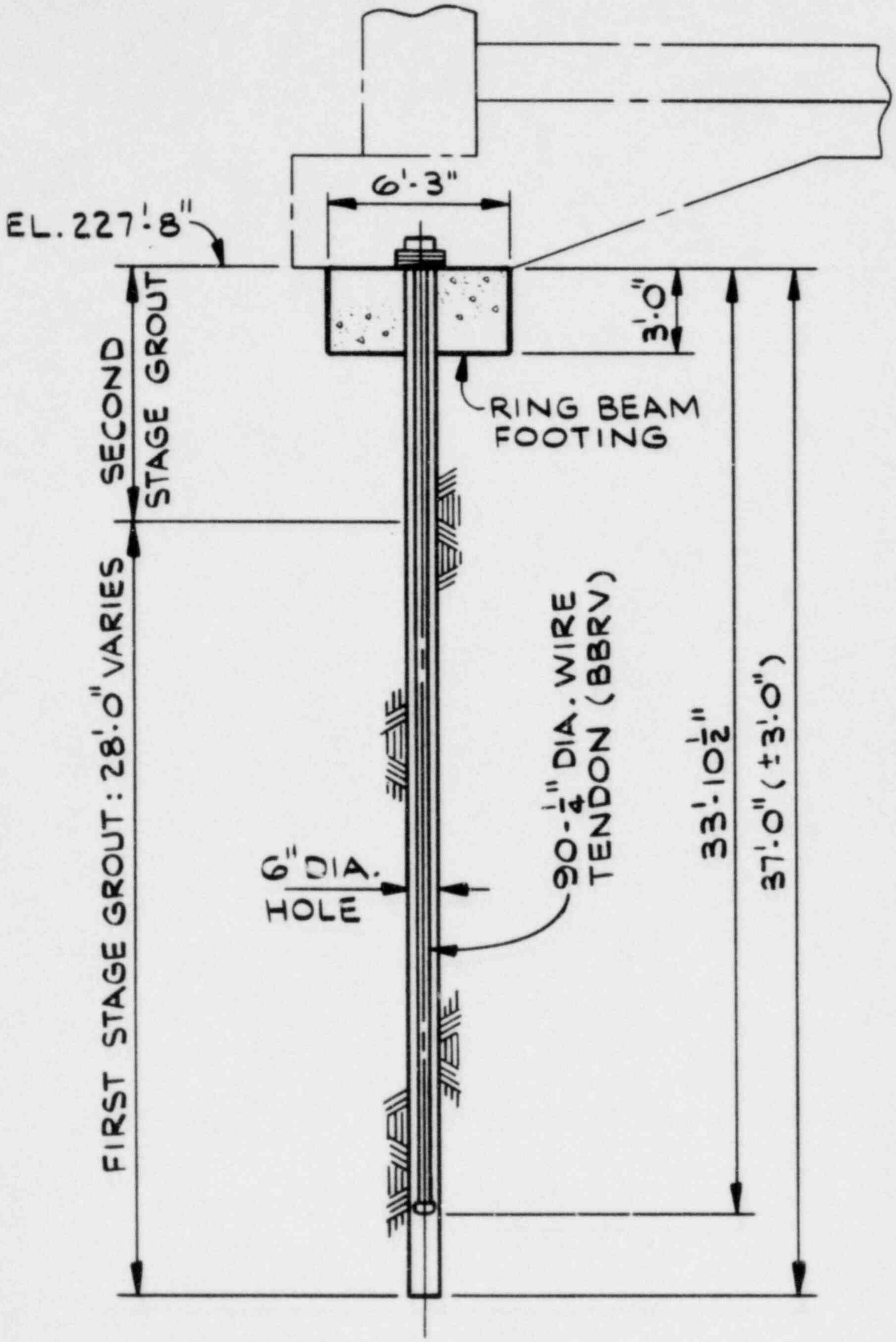


FIGURE 1-3
ROCK ANCHOR TENDON

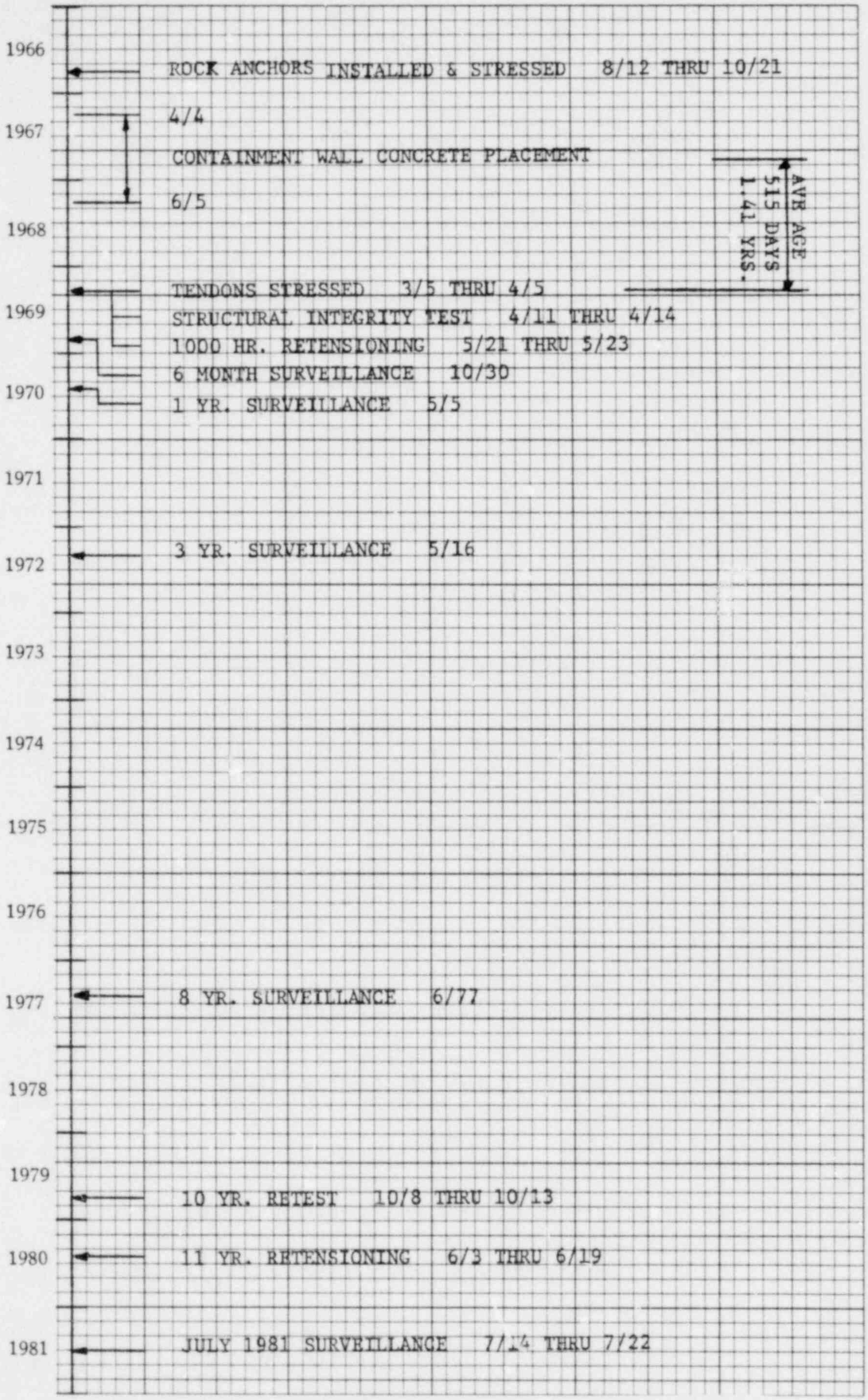


FIGURE 1-4
R.E. GINNA NUCLEAR POWER STATION
CONTAINMENT HISTORY

2.0 INVESTIGATION OF TENDON FORCE LOSSES AND CONCLUSIONS

This section describes the investigation of possible causes of the larger-than-predicted tendon losses which have been determined during past surveillances. These include: (1) Failure of the Rock Anchors, (2) Rock Creep, (3) Rock Failure, (4) Tendon Stresses, (5) Tendon Thermal Expansion, (6) Stressing Equipment Calibration and Lift-off Procedures, (7) Effect of 6% Overstressing, (8) Elastomeric Pad Creep, (9) Stress Relaxation, and (10) Tendon Type.

Conclusions are stated relative to each possible cause and its likelihood of contributing to the tendon force losses. Consideration of these possible causes collectively and resulting overall conclusions appear in Section 6.0.

2.1 ROCK ANCHORS

The continued ability of the rock anchors (shown in Figure 1-3) to resist the tendon force was investigated. If the rock anchors had experienced a loss of bond at the grout-rock interface after the wall tendons were stressed, this could have caused the wall tendons to experience a reduction in force. The possibility of this condition was investigated by: (1) a review of the original rock anchor tests reported in the FSAR; (2) an evaulation of the original stressing data for both the rock anchors and the wall tendons; and (3) an evaluation of the stressing data from the June 1980 retensioning.

2.1.1 Original Tests

Prior to the installation of the rock anchors for the containment, tests were performed on small scale (28 wire) versions of the rock anchors. These tests are described in the Ginna FSAR on pages 5.6.1-4,-4a, and -5, and test results are presented in Figures

5.6.1-6 through 5.6.1-8 of the FSAR. Three tests were performed for the purpose of demonstrating the bond capacity between the grout plug surrounding the rock anchor and the rock. A fourth test demonstrated the hold down capacity of the rock.

An evaluation of test results reported in the FSAR was presented at a meeting with the USNRC on February 19, 1981(2). The results of this evaluation confirmed the conclusions on rock anchor capacity given in the FSAR. Specifically, at the maximum load applied to the rock anchors, the tests demonstrated an average bond stress along the grout-rock interface of 448 psi. For each test the value of applied load which produced a "slip" of the rock anchors was noted and a corresponding average bond stress obtained. For one test, no slip was detected up to the maximum load. For the remaining two tests, average bond stresses of 280 psi and 340 psi were obtained. In these results "slip" was defined as the first point in the application of the load where an increase in rock anchor displacement was observed without an accompanying increase in load. All of the bond stresses exceeded the 170 psi value used for the design of the full size rock anchors.

In addition to the small scale bond tests described above, four of the actual full size rock anchors were tested. The results from these tests are discussed in Section 2.1.2.

2.1.2 <u>Bond Stress and Slip of Rock Anchors</u>

After installation and first stage grouting, but before tensioning of all the rock anchors, rock anchors 46, 61, 58 and 64 were selected for testing. The elongation of each rock anchor was measured in the tests to evaluate the variation in the wire stresses produced by the unequal wire lengths protruding above the anchorhead. The tests were also conducted to confirm the in-place strength of the 90 wire rock anchors before the second stage grout was placed.

The elongations of the rock anchors measured during these tests indicated that bond slip at the grout-rock interface did occur. In each case the predicted elongation of the tendon was calculated using basic linear elasticity (Elongation, $\Delta = PL/AE$). The value used for L was the length of the rock anchor protruding out of the first stage grout, which varied from 9 to 12 feet. This predicted elongation was then compared with the measured elongation. Among the four rock anchors, the predicted values ranged from 0.71 inches to 0.98 inches versus measured values which ranged from 1.23 inches to 1.93 inches. The ratio of measured to predicted elongation averaged 1.84, with a high of 2.02 and a low of 1.68 for the four tests. Thus, the average measured elongation was 84% greater than predicted. Therefore, the effective length was greater than the actual unbonded length (L), and bond slip had occurred to cause this. By direct ratio, the average effective length was 1.84 L, but there still remained at least eight feet of tendon in the rock which had not experienced slip.

The above findings were supported by a review of the rock anchor tensioning elongations. From the rock anchor tensioning records, a 10% sample of rock anchors (16) was selected and evaluated using the same technique as described above. The average ratio of measured-to-predicted elongation for this sample was 1.75, with a high of 1.90 and a low of 1.64. This again suggests that the effective length is 75% longer than the free length of the rock anchor and that there was bond slip. Even with this bond slip it is expected that most, if not all, of the rock anchors contain an essentially unstressed length of tendon above the bottom anchor head.

Figure 2.1-A illustrates one plausible bond stress distribution at the interface of the rock and grout plug of the rock anchor. During initial stressing with only the first stage grout present, the rock anchor tendon was stressed to 0.80 GUTS (Guaranteed Ultimate Tensile Strength), causing the bond stress distribution

shown. The bond stress is shown to be sustained at its maximum value. The unstressed length is also shown at the bottom anchor head. The rock anchor tendon was locked-off at 0.70 GUTS and the second stage grout was placed shortly thereafter. Approximately two and one-half years later, the wall tendons were installed, coupled to the rock anchor, and stressed initially to as high as 0.80 GUTS and locked-off at 0.70 GUTS. The wall tendon force is transferred to the rock anchor through the anchor heads. This transfer began immediately as force was applied to the wall tendon. However, the grout did not "feel" any of this force until the rock anchor tendon anchor head was lifted-off, which occurred when the wall tendon force equaled the rock anchor tendon force. Beyond this point, the additional force was carried in bond to the grout and adjacent rock. The effect of a conservative estimate of this force is discussed below.

It is assumed that the force in the rock anchor two and one-half years after tensioning had decreased to 0.60 GUTS, through normal losses, which is a conservatively low value for this relatively short duration. Thus, the differential force which would potentially affect the existing bond stresses would be 0.20 GUTS, corresponding to the difference between the 0.60 GUTS rock anchor force and 0.80 GUTS wall tendon force. However, it is expected that the first stage grout bond stresses were changed very little, if at all, because the second stage grout length is sufficient to develop the 212 kip force which corresponds to 0.20 GUTS, without any significant slip. Depending on the height of the second stage grout the average bond stress is calculated to be approximately 100 psi due to the 212 kip force. The bond stress distribution is shown in Figure 2.1-B in an idealized form. In this figure note that the bond stresses in the first stage grout are shown as unchanged from rock anchor stressing. Actually, these stresses would change somewhat as a result of the rock anchor force change due to normal losses over the two and one-half years.

Therefore, from the above discussion it would be expected that the stressing of the wall tendons caused only small changes in the bond stress distribution in the rock anchors. Moreover, the change in bond stresses and increase (if any) were not large enough to produce slip at the grout-rock interface. This conclusion was supported from the evaluation of tendon elongations discussed below.

To confirm that bond slip did not occur during the original stressing of the wall tendons, the elongation of each tendon was calculated (predicted) assuming its base was fixed at the elevation of the lower anchor head. Consequently, for the purposes of calculations it was taken to be a non-rock anchored tendon. These predicted elongations were compared with those measured during the stressing operation. A similar comparison was also made for the June 1980 retensioning. In addition, these comparisons were evaluated with respect to a recently constructed nuclear power plant with 115 vertical wall tendons which were not rock anchored. These tendons are anchored in the concrete containment and, thus, any significant difference between the two results might be attributed to the rock anchor system used on Ginna. Two tables are used to present the comparison. Table 2.1-1 presents the number and percent of tendons for which measured elongation exceeded the predicted value and for which predicted elongation exceeded the measured value. Table 2.1-2 concentrates on the tendons for which measured elongations were in excess of their predicted values.

Table 2.1-1 shows that 80% of the non-rock anchored tendons had measured elongations which exceeded their predicted values. However, for Ginna, measured elongations exceeded predicted for only 40.6% of the tendons at original stressing and for 65% of the tendons retensioned in June 1980. Thus, these results do not show any tendency for the rock anchored Ginna tendons to exhibit measurable bond slip during either original stressing or retensioning. The actual difference between measured and predicted elongation for each of the tendons retensioned in June 1980 can be seen in Table 1 of Appendix A.

Table 2.1-2 compares the percent by which the measured elongations exceed their predicted values during the original stressing of the Ginna tendons and for the non-rock anchored tendons. For Ginna, 41.5% of the tendons had measured elongations within 2% of their predicted values. The elongations are approximately 7-1/2 inches. In this same category, the percentage for the non-rock anchored tendons was practically the same at 39.1%; their elongations being approximately 9-1/2 inches. For both tendon systems, 97% of the measured elongations are within 6% of their predicted values, which is well within the current ACI 359 Containment Code requirement of 10%. The agreement between measured and predicted elongations, with any differences correlating well with those experienced on the non-rock anchored containment, indicates that the rock anchors experienced no discernable bond slip during either original tendon stressing or at tendon retensioning.

Observations were also made during the July 1981 tendon surveillance. During this surveillance, there were a number of times when the hydraulic system was required to hold the tendon force for several minutes. These hold periods were usually at a force level greater than the lift-off force in the tendon. For example, hold periods were necessary so that the shim stack could be rearranged for better alignment, or data was being recorded. It is believed that if bond slip were to occur it would occur at high loads. However, during these periods the hydraulic pressure gauge reading remained constant. This provides supporting evidence that bond slip was not occurring.

2.1.3 Conclusions

The elongations measured for the wall tendons during their original stressing in April 1969 and also during their retensioning in June 1980 were evaluated to determine if slip at the grout-rock interface occurred. It was postulated that if the rock anchors had experienced a loss of bond at this interface, this condition could possibly have caused the tendons to experience an unpredicted gradual force reduction in time. However, this was determined not to be the case. The magnitude of the measured elongations were found to be reasonable, and their values agreed well with predictions. These predicted elongations assumed that the bottom anchorages of the wall tendons were fixed, an assumed condition which corresponded to a non-slipping rock anchor. Based on this evaluation it is concluded that the rock anchors are securely engaged in the rock; no loss of their structural integrity has occurred; and the larger-than-predicted tendon losses were not caused by the rock anchors.

TABLE 2.1-1

COMPARISON OF PREDICTED VS. MEASURED ELONGATIONS

		Ginna Original	Ginna Retensioning	Non-Rock Anchored System
Measured Less than Predicted	Number	68	28	12
	%	42.5	20.4	10.4
Measured Greater Than Predicted	Number	65	89	92
	%	40.6	65.0	80.0
Measured Equal to Predicted	Number	27	20	11
	%	16.9	14.6	9.6
Total Tendons		160	137	115

TABLE 2.1-2

MEASURED ELONGATIONS IN EXCESS OF PREDICTED VALUES

Elongations: Meas./Pred. %	Ginna-Original Tensioning No.	%	Σ%	Non-Rock Anchored Tendon System No.	%	Σ%
0 to 1	13	20.0	20.0	8	8.7	8.7
1 to 2	14	21.5	41.5	28	30.4	39.1
2 to 3	3	4.6	46.1	28	30.4	69.5
3 to 4	10	15.4	61.5	15	16.3	85.8
4 to 5	8	12.3	73.8	8	8.7	94.5
5 to 6	15	23.0	96.8	4	4.3	98.8
6 to 7	1	1.5	98.3	1	1.1	99.9
7 to 8	1	1.5	99.8	0	0	
Total	65	≈100.0%		92	≈100.0%	

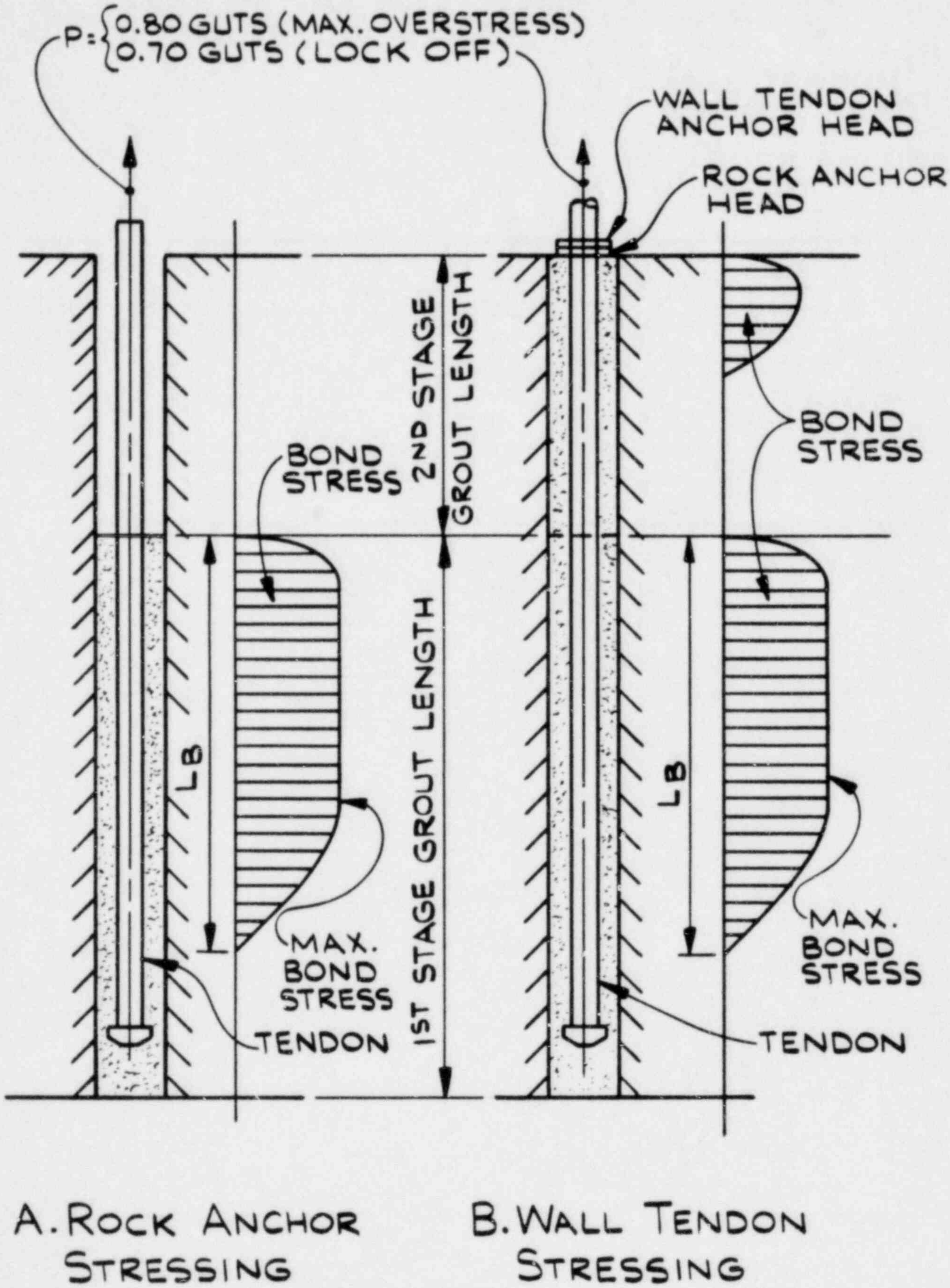


FIGURE 2-1
IDEALIZED ROCK ANCHOR BOND STRESSES

2.2 ROCK CREEP

The creep characteristic of the rock foundation was evaluated to determine if rock creep could have caused the larger-than-predicted force loss in the tendons. Existing creep test results were used for the evaluation.

Unconfined axial compression tests were conducted in 1973 on cored rock samples taken at the location planned for the Ginna Unit 2 site. The tests results are reported in Appendix B. One rock sample was tested in unconfined axial compression creep. This core was located about 1600 feet from the Unit 1 containment, and the sample is representative of the rock surrounding the rock anchors under investigation. This specimen was loaded to 10,000 psi for four hours and strain data collected at the time intervals indicated in Appendix B. In the following evaluation, this creep data is used to estimate the creep strain that the rock surrounding the tendon would experience. This, in turn, is used to calculate the potential shortening of the rock anchor tendon and the corresponding force loss due to rock creep.

2.2.1 Analysis

The creep data is plotted in Figure 2.2-1. Even though the four hour duration of the test is brief, the expected linear relationship between creep strain and ln t appears to have been established. A linear regression analysis of the creep data results in the following expression for creep strain, ε_{cr}, (inches per inch) as a function of time after loading, t (seconds):

$$\varepsilon_{cr} = -21 \times 10^{-6} + 10.77 \times 10^{-6} \ln t \quad \text{(Equation 1)}$$

For any value of uniaxial compressive stress, σ, and modulus of elasticity, E, a general expression for uniaxial creep is given by equation (4-18) of Reference 3:

$$\varepsilon_{cr} = (\sigma/E)^n \ln t \quad \text{(Equation 2)}$$

The value for n depends on the creep property of the rock, and it can be obtained from the creep data. Equating the slopes of equations (1) and (2) results in an equation from which n is obtained:

$$(\sigma/E)^n = 10.77 \times 10^{-6} \text{ .... (Equation 3)}$$

From the test data, $\sigma = 10{,}000$ psi and $E = 4 \times 10^6$ psi. Substituting these values into equation (3) and solving for n yields n = 1.91.

For the actual rock anchors, when stressed and locked-off at 0.70 GUTS (Guaranteed Ultimate Tensile Strength), a bearing stress of 397 psi is calculated for the rock at the base of the ring beam footing shown in Figure 1-3. Adding the containment dead load increases the bearing stress to 472 psi. For the purpose of obtaining a conservatively high value of creep strain in the rock, the rock is idealized as a column having a width equal to that of the ring beam footing, i.e. 6'-3". Consequently, the 472 psi compressive stress is taken to be uniform over the entire depth of the rock.

The creep strain in the rock is, from equation 2:

$$\varepsilon_{cr} = (\sigma/E)^n \ln t = \left[\frac{472}{4 \times 10^6}\right]^{1.91} \ln t$$

or

$$\varepsilon_{cr} = 0.0314 \times 10^{-6} \ln t \text{ .... (Equation 4)}$$

Using this equation, the creep loss in the tendons is evaluated at the June 1980 retensioning (11 years) and end of plant life at 40 years.

June 1980 Retensioning

time, t $= 11 \times 365 \times 24 \times 60 \times 60 = 347 \times 10^6$ seconds

creep strain, $\epsilon_{cr} = 0.0314 \times 10^{-6} \ln (347 \times 10^6)$

$= 0.62 \times 10^{-6}$ inches/inch

$\epsilon_{cr} = 0.62$ micro inches per inch

stress loss, $\Delta f_{ps} = \epsilon_{cr} E_{ps} = 0.62 \times 29 = 18$ psi

force loss, $\Delta F_{ps} = (\Delta f_{ps})$ (Tendon Area) $= (0.018)(4.42 \text{ in}^2)$

$= 0.08$ kips

Thus, there is practically no loss of force due to the very small creep property exhibited by the rock.

End of Plant Life

$t = (40/11)(347 \times 10^6) = 1261 \times 10^6$ seconds

$\epsilon_{cr} = 0.0314 \times 10^{-6} \ln (1261 \times 10^6) = 0.66 \times 10^{-6}$ inches/inch

$\Delta f_{ps} = \epsilon_{cr} E_{ps} = 0.66 \times 29 = 19$ psi

$\Delta F_{ps} = (.019)(4.42 \text{ in}^2) = 0.08$ kips

Here again, there is essentially no rock creep effect.

2.2.2 Conclusions

Based on the available creep properties, the rock creep is practically zero and has no effect on the tendon forces.

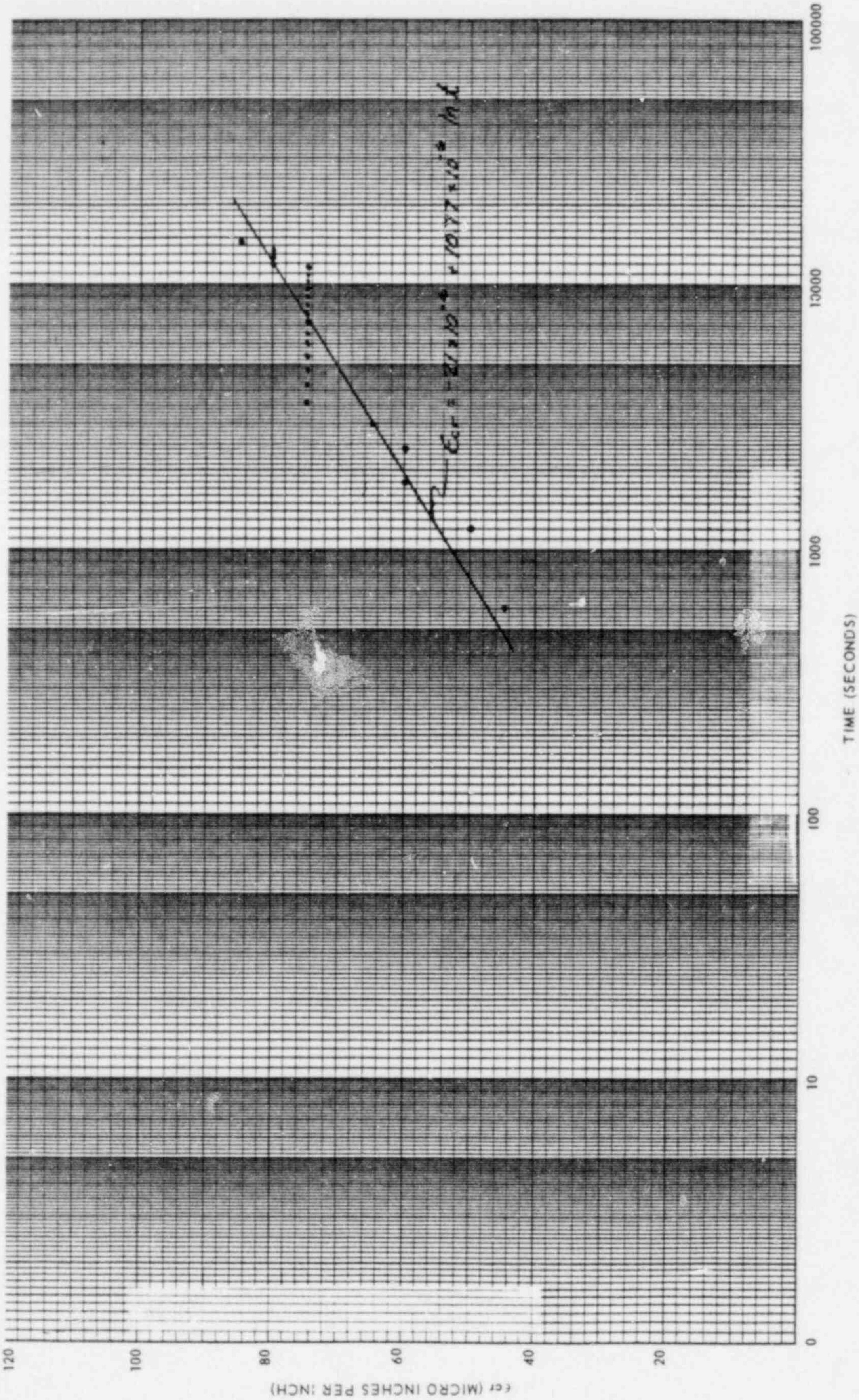


FIGURE 2.2-1
ROCK CORE CREEP TEST

2.3 ROCK FAILURE

The possibility of a failure in the rock which would produce a loss of tendon force was investigated. The loading history on the rock was reviewed along with the results of elevation measurements which were taken during the stressing of the rock anchors.

2.3.1 Load History

During the stressing of the rock anchors, the upward force exerted on the rock at the grout-rock interface was entirely equilibrated by the reaction bearing pressures produced at the base of the ring beam footing shown in Figure 1-2. In addition, due to the relatively rigid rock foundation under this footing, these bearing pressures would be confined to an area surrounding the rock anchor. Consequently, the line of action of the bearing pressure force would lie close to the shear stresses at the grout-rock interface. Therefore, there is no resultant upward force on the rock to precipitate a failure in the rock.

Upon stressing the wall tendons, the upward force on the upper anchorhead of the rock anchor exerted by the wall tendon is balanced by the reaction of the wall base on the ring beam footing. Again, there is no net upward force on the rock. In fact, there is a net downward force on the rock due to the combined effects of the dead load of the containment structure and the rock itself. This and other load conditions were evaluated relative to the effect on the rock equilibrium in Reference 2. The free body diagram presented in Reference 2 for equilibrium of the rock wedge is shown in Figure 2.3-1. In Reference 2 it was shown that under normal operation R=146 kips per foot, which indicates that there is a net resultant downward force on the rock of 146 kips per foot of wall circumference. This value includes the dead weight of the rock of 67 kips per foot. The difference acting on top of the rock is a resultant downward force, $N_C + N_{DM}$, of 79 kips per foot under normal operation. Reference 2 also shows that under the 1969 Structural Integrity Test pressure of 69 psig, R=75 kips per foot. Therefore, a net downward force of 75 kips per foot existed (including the rock weight), or 8 kips per foot acting down on the top of the rock.

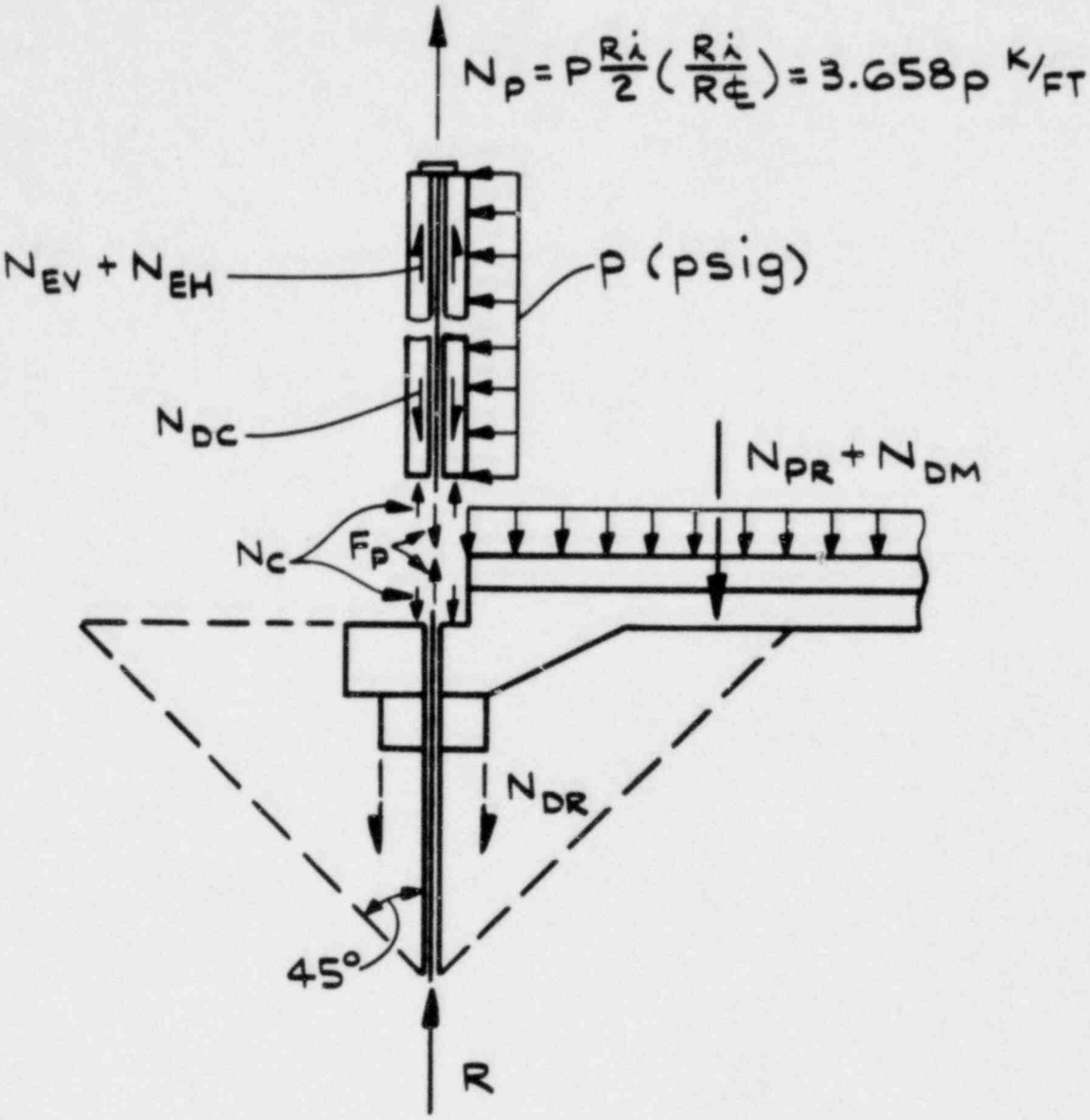
Based on these results, it is unlikely that a rock failure has occurred. This conclusion is supported by the evaluation of the tendon stressing data in Section 2.1.2, "Bond Stress and Slip of Rock Anchors". Any rock fissures large enough to produce a movement of the rock anchors would have been reflected in the wall tendon elongations; but the elongations indicated that no detectible movement of the rock anchor occurred.

2.3.2 Elevation Measurements

During the stressing of the rock anchors, survey instruments were used to measure any changes in elevation of the top rock surface which might occur. Survey points were established at 16 equally spaced locations on the circumference of the ring beam footing. No changes in elevation on top of the footing were measured that would indicate rock movement.

2.3.3 Conclusions

During the loading history of the rock anchors, there has never been a loading condition to cause a resultant tension force on the rock. Therefore, rock failure could not have occurred. Consequently, rock failure is eliminated as a cause of the larger-than-predicted tendon force losses.



P = INTERNAL PRESSURE

N_P = PRESSURE FORCE IN WALL = 3.658p K/FT

N_{PR} = PRESSURE FORCE ON ROCK = 2.638p K/FT

N_{DM} = DEAD LOAD FORCE OF MAT ON ROCK = 11 K/FT

$N_{EV} + N_{EH}$ = SEISMIC FORCE IN WALL AT BASE = { 70.3 K/FT OBE; 140.6 K/FT SSE }

N_{DC} = DEAD LOAD FORCE AT WALL BASE = 67.5 K/FT

N_{DR} = DEAD LOAD (SUBMERGED) FORCE OF ROCK WEDGE = 67.4 K/FT

F_P = TENDON FORCE = 299 K/FT + ΔF_P (TENDON FORCE INCREASE UNDER P)

N_C = RESULTANT WALL FORCE ON ROCK = $N_{DC} + F_P - (N_P + N_{EV} + N_{EH})$

R = REACTION REQUIRED FOR EQUILIBRIUM OF ROCK = $N_C + N_{DR} + N_{PR} + N_{DM} - F_P$

FIGURE 2.3-1
EQUILIBRIUM DIAGRAM

2.4 TENDON WIRE STRESSES

The Ginna tendons were initially stressed to 0.80 GUTS and locked-off at 0.70 GUTS. It was questioned whether these stress levels could have caused the wires to be stressed beyond their proportional or yield limits. If this occurred, the tendon stress relaxation property and the elastic stress-strain relationship used to predict tendon forces would be in question.

2.4.1 Investigation

Wire

The tendon fabrication records were reviewed and the stress-strain curve for each heat of wire used in the tendons was obtained. A typical curve is shown in Figure 2.4-1. Table 2.4-1 is a summary of key properties of the wire, by heat number. These data show the Yield Point-GUTS ratio for every heat to be greater than the 0.80 GUTS value to which the tendons were initially stressed. Also, the Proportional Limit-GUTS ratio for all but two (2) tests exceeds the 0.80 factor. Thus, the tests results indicate that stressing to 0.80 GUTS did not cause the wires to be stressed beyond their linear, elastic range, except for two cases which are discussed below.

For heat 30091 one value, 0.71, out of the three tested is below the 0.80 factor; and for heat 22332 the tested Proportional Limit-GUTS ratio is 0.75. The stress-strain curves for these two cases reveals that the strain value corresponding to the actual Proportional Limits is 0.6% for both. From these curves at a wire stress corresponding to 0.80 GUTS, the strain on the curves increased to 0.068%. At this strain level, the stress-strain relationship has just started to become slightly non-linear; however, a secant modulus constructed through this point on the stress-strain curve is practically no different than that constructed through the Proportional Limit. In light of this and the fact that the stress in the wires at 0.80 GUTS is well below their respective yield values, these tests also demonstrated a linear, elastic wire response for all practical purposes.

Tendon

Figure 2.4-2 is the stress-strain curve for a 90-wire test tendon, which appears in the Ginna FSAR, p. 5A-30 of Appendix 5A. The purpose of the tendon test was to demonstrate that the tendon of 90 wires is 90 times as strong as a single wire, and the test results showed this to be true. The stress-strain curve for the tendon indicates that the yield point and proportional limit values are similar to those developed in the individual wires. At 1% extension, the yield stress is 974/4.42 = 220.4 ksi. The proportional limit is 888/4.42 = 200.9 ksi. Using these two values, the ratios are:

YP/240 = 0.92

PL/240 = 0.83

Again both values are above 0.80, which indicates the tendon exhibited a linear, elastic reponse to the 0.80 GUTS initial stress level.

Unequal Wire Lengths

The above discussion assumes that each wire in the tendon is stressed, or more correctly, strained, equally. In other words, the 90 wires in a tendon are identical in length; thus, when the stressing head is displaced all wires are elongated the same length. However, in the actual tendons, there was some variation in the wire lengths. During the installation of the rock anchors, the effect of this condition was investigated.

During the full scale rock anchor tests on rock anchors 46, 61, 58, and 64, measurements were taken of all wire lengths. Using these lengths and the rock anchor elongations, the non-uniform wire stresses were calculated, with the maximum wire stress being 193 ksi. This is well below the yield values recorded in Table 2.4-1. Due to the short length of the rock anchors which protrude out of the first stage grout, their elongations were generally less than 2.00 inches. The wall tendon elongations are all greater than 9.00 inches; thus, the effect of small differences in wire length on wire stress is much smaller for the wall tendons than for the rock anchors.

2.4.2 Conclusions

Neither individual wires nor tendons have experienced stresses greater than their yield values. Moreover, most of the tendons wires were not stressed beyond their proportional limit. Some wires may have been initially stressed beyond their proportional limit, but these wires are expected to have exhibited essentially a linear, elastic response based on available test results. Thus, the possibility of a non-linear and/or inelastic stress level in the tendons is ruled out as a reason for the larger-than-predicted tendon force losses.

TABLE 2.4-1

COMPARISON OF TENDON WIRE PROPERTIES BY HEAT NUMBER

Heat No.	Yield Point @1% Strain- YP(1) (ksi)	YP/240(2)	Proportional Limit- PL(1) (ksi)	PL/240(2)	Ultimate Strength- UST (ksi)
10355	220.2	0.92	198.0	0.83	249.7
19477	221.0	0.92	200.0	0.83	249.9
	221.4	0.92	204.0	0.85	251.4
average	221.2	0.92	202.0	0.84	
21504	216.2	0.90	195.0	0.81	246.5
22332	221.9	0.92	179.8	0.75	250.6
30091	216.6	0.90	171.7	0.71	247.3
	240.4	1.00	200.0	0.83	249.7
	221.9	0.92	200.0	0.83	250.6
average	226.3	0.94	190.6	0.79	249.2
39377	223.9	0.93	198.0	0.83	252.2

(1) The first point on the stress-strain diagram to deviate from a straight line (See Figure 2.4-1.)

(2) 240 ksi is the Guaranteed Ultimate Tensile Strength (GUTS)

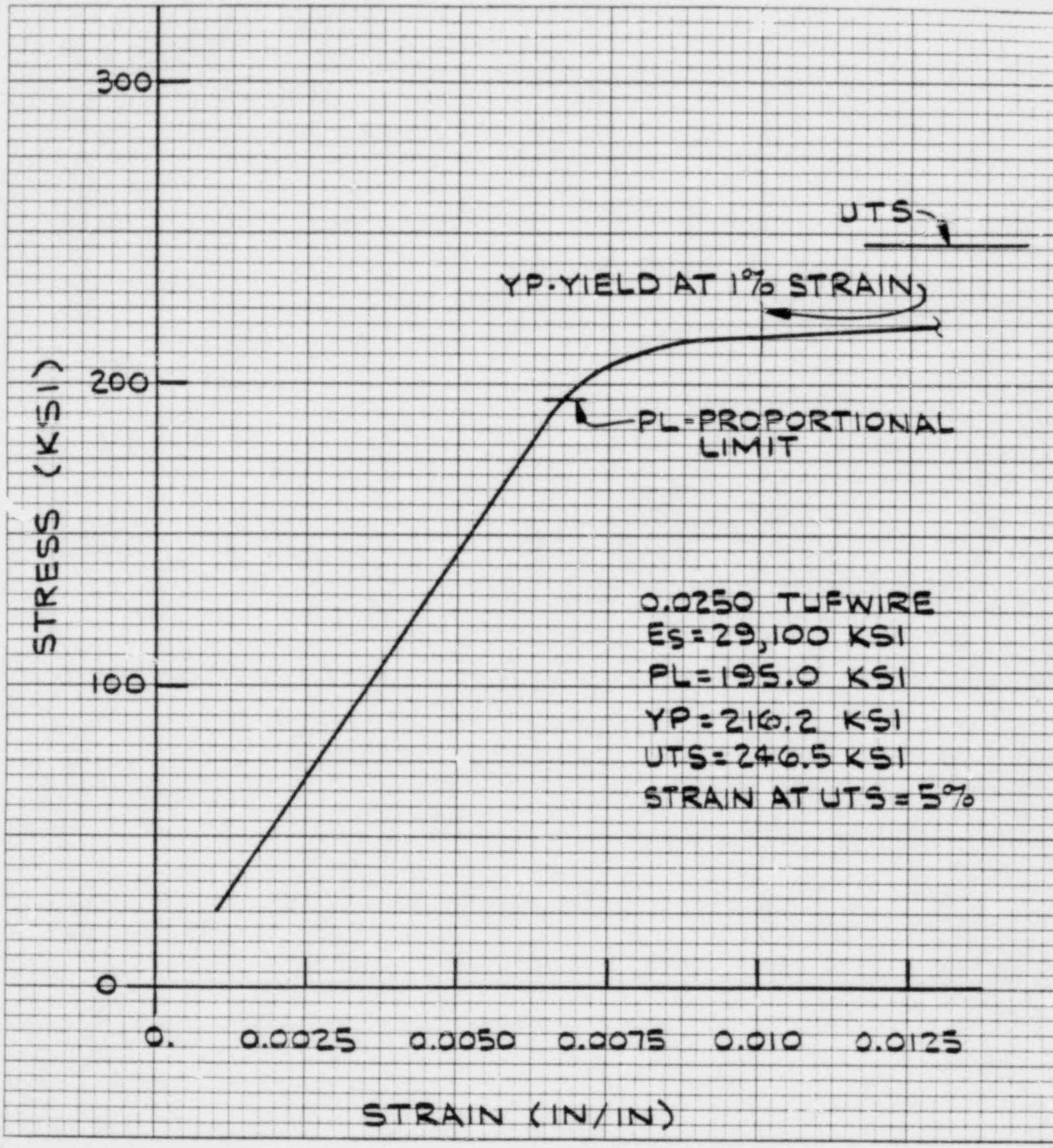


FIGURE 2.4-1
WIRE STRESS-STRAIN CURVE (HEAT 21504)

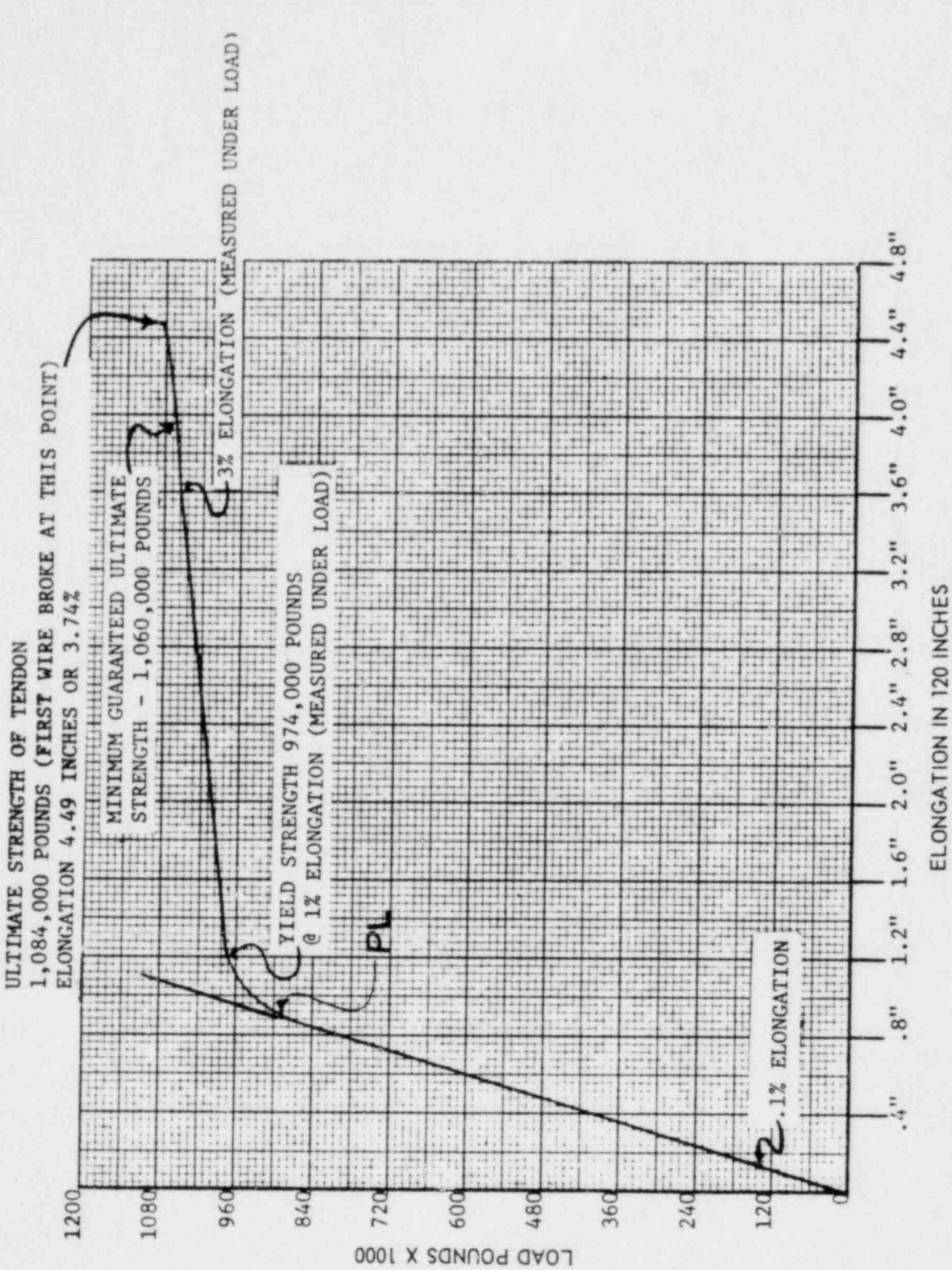


FIGURE 2.4-2
TENDON LOAD-ELONGATION CURVE

2.5 TENDON THERMAL EXPANSION

The effect of temperature differences between the tendons and the containment wall has been investigated analytically. To exhibit a force loss, the tendons would have to undergo thermal strains which exceed those in the concrete wall under the same temperature condition.

2.5.1 Analyses

For the first four tendon surveillances the average measured lift-off force was 20 kips below the average predicted value as reported in Reference 1. The 20 kip value represents about 3% of the force predicted for the tendons and, thus, it is fairly small. However, the average measured forces were at their specified minimum limit of 636 kip; therefore, several thermal effects were evaluated to determine their likelyhood of producing a 20 kip loss. This evaluation is discussed in Reference 1 and it is reviewed below.

Thermal Coefficient

First it was assumed that the average temperature across the wall and the tendon temperature were the same, and that the vertical thermal growth of the wall was solely a function of its average temperature. Thus, a force loss would be a result of the difference in thermal expansion coefficients between the tendons and the wall. The small difference in linear coefficient of thermal expansion for the concrete (5.5×10^{-6} in/in/^{o}F) and the tendon (6.5×10^{-6} in/in/^{o}F) was determined to be insignificant. If the wall and tendon were to experience a temperature increase of 40^{o}F, the tendon force would relax only 5 kips. The value of 40^{o}F was selected because this increase approximates the maximum difference in average wall temperature between ambient stressing and operating temperatures.

Temperature Difference

The effect of temperature differences between the tendon and the wall was also considered. It was determined that the average temperature difference between the tendon and the wall over their entire 115 feet of length would have to be 24°F in order to produce a 20 kip relaxation of the tendon force. At the time of the thermal evaluation described in Reference 1, such a temperature difference over the entire tendon length did not seem likely, assuming that steady state operating temperature distributions had developed in the containment wall. However, the differences in the lift-off forces measured in October 1979 and June 1980 (discussed below) indicate a larger response of the tendon to a seasonal temperature change than originally believed.

Local Areas

The effect of local hot spots on tendons curved around the main steam and feedwater penetrations was also investigated in Reference 1. To produce a relaxation of 20 kips, a typical tendon would have to be at a temperature of 92°F above its initial stressing temperature over 30 feet of length in the area of the penetration. The 30 feet length was the tendon length conservatively assumed to be heated by the penetration, without the benefit of a heat transfer analysis. If the affected length was 15 feet, the required temperature would be 184°F. The excessive length and temperature combinations would seem to rule out local hot spots as a cause. This conclusion is supported by the fact that the tendons around penetrations did do not exhibit larger losses than other tendons.

Thus, the initial thermal investigation in Reference 1 concluded that temperatures may have caused small changes in tendon force loss but were not responsible for the total force loss experienced by the tendons.

2.5.2 Seasonal Variations

Another thermal effect was considered after reviewing the difference between the October 1979 and June 1980 lift-off values. Table 2.5-1 contains these values in Columns (1) and (3) which were obtained from the figures in Appendix A. The force loss from October 1979 to June 1980 for most of the tendons was higher than expected (Column 4). This was especially true considering that the eight month time difference was relatively short, thus ruling out stress relaxation as the cause. The procedure for determining lift-off was also the same for both periods in that feeler shims were used to establish the point of lift-off. In addition, there was no correlation between the loss the various tendons experienced and their location relative to penetrations (see Column 5 of Table 2.5-1).

It was also noted that the lift-off forces measured in October 1979 are generally higher than those measured at the eight-year surveillance in June 1977. At the time of the October 1979 tests, these higher values were believed to be a result of tendon forces which were under-measured in June 1977, possibly due to the acoustical (shim-tapping) method used to determine lift off. However, the June 1980 results tended to support the June 1977 readings.

The figures in Appendix A contain eleven tendons for which lift-off tests were performed in June 1977, October 1979, and June 1980. For eight out of these eleven, the October 1979 forces are higher than would be expected relative to the two June forces. These are shown in Figures 4-1, 4-2, 4-3, 4-18, 4-24, 4-30, 4-33 and 4-37 of Appendix A. These figures indicate that the average difference between the October 1979 and June 1980 forces is approximately 30 kips, whereas the predicted difference would be about 5 kips. The unpredicted average difference of 25 kips represents approximately 4% of the average forces measured for these tendons. From these figures there appears to be a definite seasonal temperature effect which is more significant than initially expected.

2.5.3 Conclusions

A comparison of the lift-off forces measured in June 1977, October 1979, and June 1980 would seem to indicate a relationship between outside ambient temperature and tendon force, if the ambient temperature is of a sufficient duration to develop steady state temperatures in the tendon and the containment wall. The forces measured in June 1980 were an average 25 kips lower than would be expected relative to forces measured in October 1979 for the same tendons. Thus, tendon forces measured during the summer might be expected to be lower than if measured during the winter. This effect is most likely caused by a thermal expansion of the tendon which is larger than that for the wall. This would indicate a need to conduct all surveillances during the same time of the year in order to obtain consistent data. However, considering the surveillance force data collectively, the seasonal variation in tendon force is not the reason for the larger-than-predicted force losses which the tendons have generally experienced.

TABLE 2.5-1

COMPARISON OF OCTOBER 1979 AND JUNE 1980 LIFT-OFF FORCES

TENDON I.D. NO.	LIFT OFF FORCES: 10/79 FORCE (kips) (1)	LIFT OFF FORCES: GAUGE PRESSURE (psi) (2)	LIFT OFF FORCES: 6/80 FORCE (kips) (3)	LIFT OFF FORCES: DIFFERENCE (3) - (1) (4)	LOCATION RELATIVE TO PENETRATIONS (5)	TEMPERATURES: CONTAINMENT AIR TEMP[a] (°F) 10/79 (6)	TEMPERATURES: CONTAINMENT AIR TEMP[a] (°F) 6/80 (7)	TEMPERATURES: OUTSIDE AIR TEMP (°F) 10/79 (8)	TEMPERATURES: OUTSIDE AIR TEMP (°F) 6/80 (9)
133	638	3850	580	-58	In region of small pen.	92.9	102.5	43	N/A
8	641	4000	603	-38	No penetration	93.5	100.3	42	64
53	632	3950	596	-36	6 ft. from Main Steam Pen.	94.1	103.6	41	N/A
160	638	4000	603	-35	No penetration	93.5	99.2	42	54
84	609	3825	576	-33	In region of small pen.	94.1	100.3	41	64
76	593	3750	565	-28	Curves around Purge Line pen	94.1	98.9	41	48
63	600	3800	573	-27	In region of small pen.	94.1	103.8	41	N/A
150	664	4250	641	-23	Curves around pen. #140	93.5	99.2	44	N/A
110	656	4200	633	-23	No penetration	93.1	102.5	47	N/A
159	664	4275	645	-19	No penetration	93.5	99.2	42	54
45	651	4200	633	-18	6 ft. from Feedwater pen.	93.5	102.5	42	N/A
83	614	4000	603	-11	In region of small pen.	94.1	100.3	41	64
17	621	4050	611	-10	Curves around Purge Line pen	93.5	98.7	42	46
132	619	4050	610	- 9	In region of small pen.	93.1	99.2	47	N/A
142	613	4025	606	- 7	No penetration	92.9	96.4	43	N/A
60	600	3950	596	- 4	6 ft. from Main Steam pen.	94.1	96.8	41	54
100	612	4050	610	- 2	No penetration	93.1	96.4	47	N/A
51	590	3900	588	- 2	6 ft. from Feedwater pen.	93.1	99.2	47	N/A

NOTES:

a) Average of the daytime temperatures (0800-1600 hrs.) recorded by RTD Nos. 7, 8, 9, 10 on the day the tendon lift-off force was measured.

b) N/A = not available

2.6 STRESSING EQUIPMENT CALIBRATION AND LIFT-OFF PROCEDURE

Stressing equipment calibration and lift-off determination procedures were investigated as possible causes for the larger-than-predicted tendon force losses which occurred in the past and for the differences between the October 1979 and June 1980 forces.

2.6.1 Ram Area, Pressure Gauge, and Lift-Off

The history of Ginna surveillances with respect to ram area, pressure gauge calibration, and lift-off procedures was reviewed. RG&E's stressing ram was used for all the surveillances conducted through July 1981, but was not used in the tendon retensioning program of June 1980. This ram was also used for the 10 year retest conducted in October 1979. The ram area used for the surveillances through the eight year surveillance is 129.3 in^2, which was obtained when the ram was originally calibrated in 1969. In June 1979, the ram was re-calibrated for the 10 year retest in October 1979, and a ram area of 127.6 in^2 was obtained. The small difference in ram area, 1.3%, was determined not to be significant.

Two (2) stressing rams were used by Inryco, Inc. for the June 1980 retensioning program in which lift-off readings were taken prior to restressing each tendon. These rams were calibrated before and after these operations, and the ram areas were different by 1.6% at worst. Thus, the recalibration confirmed the ram area used for the lift-off readings. Therefore, after the larger-than-expected decrease in force recorded in June 1980 from October 1979, it was speculated that the effective ram area used in the October tests may have changed during the tests and could have been the apparent cause of these losses in force. However, this proved not to be the case since in the July 1981 surveillance the new calibrated effective ram area was essentially the same as the pre-October 1979 value. Section 5.3.3 explains the method of determining ram area used for the July 1981 surveillance. This method includes the pressure gauge and thus calibrates both the ram and gauge as a unit. Comparing these latest values with the effective ram areas previously used, it is concluded that the differences are not large enough to account for the lower-than-predicted tendon forces measured in the past.

Other possible errors include hydraulic system effects and gauge reading accuracy. To investigate these, the stressing rod was instrumented to determine the lift-off forces during the July 1981 surveillance (see Section 5.3.3). The results of these tests indicated that the force determined by pressure gauge is within ±3% of the actual force. This is approximately ± 18 kips at a lift-off of 600 kips. Table 2.5-1, Column 4, lists the difference in lift-off values between October 1979 and June 1980. Ten (10) of the eighteen (18) tendons listed had differences greater than the 18 kips possible error in pressure gauge reading. Therefore, it is concluded that error in pressure gauge reading cannot explain the October to June losses nor the general force loss which has occurred over the life of the structure.

The determination of actual lift-off is critical in the surveillance procedure. Until the 10-year retest in October 1979, Ginna procedures specified the use of the acoustical method. This method calls for the operator to tap the shim stack with a hammer until the sound changes. When the sound changes, all compression is assumed to be removed from the shim stack, or in other words, lift-off has occurred. The accuracy depends heavily upon the experienced ear of the operator. In October 1979, a new method was introduced, referred to as the feeler shim method. This method requires that the tendon head be lifted-off the shim stack until two thin (1/32 inch) feeler shims can be inserted into the shim stack on opposite sides. The tendon head is then set back down on the shims. Pressure is then increased until both feeler shims can be removed, which defines lift-off.

The 10-year retest in October 1979 used both methods, and it was concluded that both methods determined approximately the same lift-off force. However, it should be noted that the operator was very experienced in using the acoustical method. In this case it was concluded that the lift-off determination method has no effect on the value recorded.

As a check on lift-off determination using the feeler shim method, four tendons with load cells were monitored during the July 1981 surveillance. For each load cell tendon, the load cell reduced to zero indicating lift-off at the same load as the feeler shims were removed.

2.6.2 Conclusions

The accuracy in measuring the tendon forces depends on (1) the calibration accuracies of the ram and pressure gauge, (2) the ability to measure the actual point of lift-off, and (3) the error in reading the pressure gauge.

The results of the July 1981 surveillance from the load cell tendons demonstrated that the point of lift-off determined using feeler shims is very accurately established. These results also demonstrated that the application of the gauge pressure to the effective ram area produces a tendon force which is within ± 3% of that measured with the strain gaged stressing rod. Since both the lift-off tests conducted in October 1979 and June 1980 used these test methods, these tendon forces measured are considered to be reasonably accurate. Therefore, the larger-than-predicted force losses which the tendons exhibited through June 1980 cannot be explained by equipment or procedure inaccuracies.

2.7 6% OVERSTRESSING

On all previous tendon surveillances, after the lift-off force was measured for each tendon, the tendon was stressed 6% above the lift-off force for the purpose of verifying its ability to withstand the stress increase associated with the postulated accident condition. This temporary 6% overstressing was investigated as possibly having a detrimental effect on the tendon force.

2.7.1 Tests

Two investigations were conducted. The Lehigh testing program included a 6% overstressing of one wire, and at the July 1981 surveillance two load cell tendons were overstressed by 6%.

The Lehigh test results are presented in Section 3.3.1 of this report. There it is concluded that the 6% overstressing did not cause any unusual stress relaxation. In fact, the data scatter at that level appears to be larger than any effect the 6% overstressing had on steel stress relaxation.

The surveillance results are detailed in Section 5.3.4. Two of the load cell tendons (13,133) had the 6% overstress applied as in previous surveillances and two tendons (53, 93) were re-seated without overstressing. Observation of the all load cell data after their lift-off values were determined indicates no change in force. Therefore, it is concluded that the 6% overstressing had no noticeable effect on the load cell readings.

2.7.2 Conclusion

The 6% overstressing had no overall effect on tendon force loss, as demonstrated by the surveillance results. Also, the 6% overstressing had no measureable effect on the steel stress relaxation, as seen by the Lehigh tests. Therefore, the 6% overstressing procedure used in past surveillances does not appear to have caused the larger-than-predicted losses the Ginna tendons have experienced.

2.8 ELASTROMERIC PAD CREEP

The containment wall is designed to have a hinge at its intersection with the base mat. This hinge is developed with elastomeric pads between these structural components. Each pad consists of two 11/16 inch thick layers of 55 durometer hardness neoprene, seperated by and epoxy bonded to a 10 gauge (0.135 inch) steel shim. In addition, a 16 gauge (0.06 inch) steel shim is epoxy bonded to the top and bottom of the composite pad set. The total pad thickness is 1.63 inches, including the steel shims and 9 inch by 42 inch in plan. The combined neoprene thickness is 1 3/8 inches. The details and location of these pads are shown in Figure 2.8-1. As the figure indicates, there are two pads associated with each tendon.

The possibility of pad creep, which would reduce the tendon forces with time, was investigated by reviewing the design information presented in the Ginna FSAR and by attempting to inspect the in-place pads.

2.8.1 FSAR Review

From page 5.1.2-38 of the Ginna FSAR, a design load of 371 tons or 742 kips is given for each pair of 9 inch x 42 inch pads. This results in a bearing stress of 980 psi on the pads. An upper limit on pad displacement (elastic) of 15% of its thickness is also given, and a test on one pad demonstrated that this limit was not exceeded. The test results are shown in Figure 5.6.1-4 of the Ginna FSAR, which indicate that under the 742 kip total load, or 371 kips per pad, the elastic displacement of the pad was approximately 0.11 inches.

The creep displacement of the pads is stated to be 13% of the intial (elastic) displacement. A 72 hour creep test was conducted on another pad, under 1000 psi compression. The results are shown in the Ginna FSAR in Figure 5.6.1-3. The percent of initial strain (or elastic displacement) is a constant value of 11% after 46 hours under load, which is slightly less than the stated value of 13%.

Although not specifically stated in the Ginna FSAR, the tests on the two pad specimens are believed to have been at a room temperature condition. Page 5.6.1-4 of the Ginna FSAR contains a brief dicussion of the tests.

The design load of 742 kips given in the Ginna FSAR is based on the initial tendon force, and it does not include the dead load of the containment. For an estimate of the creep displacement of the pads this should be included, which adds 151 kips to each pair of pads. This increases the load on each pad to 447 kips or 1181 psi bearing stress. Under this stress an elastic displacement of 0.12 inches would result, based on the test results of Figure 5.6.1-4. As shown on Figure 5.6.1-3, the maximum creep deflections would be 11% of the elastic displacement, which is a creep displacement of 0.013 inches. The effect of this on tendon force loss would be minor:

$$\Delta F_{ps} = (0.013")/(115' \times 12)\ (29 \times 10^6 \text{ psi})\ (4.42 \text{ in}^2)$$
$$= 1.2 \text{ kips.}$$

If the results of the creep test shown in Figure 5.6.1-3 are plotted as a function of ln (time) and fitted with a line, then the creep strain would exhibit a linearly increasing property. The creep results of Figure 5.6.1-3 were evaluated in this manner, which resulted in creep strain (or displacement) values, expressed as a percent of initial strain (or displacement), of approximately 17% at 100,000 hours (11.4 years) and 18% at 40 years. These values are to be compared with the 11% maximum value indicated in Figure 5.6.1-3. Thus, at 11.4 years a creep displacement of 0.17 x 0.12" = 0.020" results. This would produce a corresponding tendon loss of approximately 2 kips which is still of no practical consequence.

Based on the above evaluation, which relies on existing test results, the creep displacement of the pads is very small and the corresponding effect on tendon force loss is minor.

The 72 hour duration of the creep test reported in the Ginna FSAR is brief; therefore, it was considered to be important to further define the creep properties of the elastomeric pads. E.I. duPont de Nemours & Company was contacted and suggested that their publication entitled "Design of Neoprene Bearing Pads," Reference 4, is still considered the best available guide to the design and use of neoprene pads. This document contains information on creep in Figures 1 and 3, which are reproduced as Figure 2.8-2 in this report.

The compressive stress versus strain curves of Figure 2.8-2 can be used to calculate the initial compressive strain and then the deflection. Using the previously determined pad compressive stress of 1181 psi, a shape factor of 5.39* and a hardness of 55, the curves can be extrapolated to obtain an initial compressive strain of 11%. This 11% initial strain applied to the total neoprene thickness of 1-3/8 inches gives a deflection of 0.15 inches. The creep curves of Figure 2.8-2 can be interpolated to a 55 hardness to obtain a creep strain at 10 years of 30% the initial strain. The tendon force loss due to pad creep can easily be determined as follows:

$$\Delta F_{ps} = \frac{(0.3)(0.15")}{115' \times 12}(29 \times 10^3 \text{ ksi})(4.42 \text{ in}^2) = 4.2 \text{ kips}$$

Considering the neoprene creep results reported in both the Ginna FSAR and the duPont publication, the force loss due to elastomeric pad creep is very small and cannot account for the tendon force losses measured at Ginna.

$$\text{*Shape Factor} = \frac{\text{one loaded surface area}}{\text{total free-to-bulge area}} = \frac{9"\text{x}42"}{2(9"+42")(11/16)} = 5.39$$

2.8.2 Inspection

During the July 1981 surveillance an attempt was made to visually inpsect the in-place pads. Much of the circumference of the containment wall at the elevation of the pads is inaccessible, being covered by concrete on top of the base mat which serves as part of the floor slab for the adjacent buildings. The areas where this slab did not exist were sumps and these contained water at the time of the inspection. Grout and mastic material also cover the pads. Consequently, visual inspection of the pads could not be performed.

2.8.3 Conclusions

Based on the one creep test reported in the Ginna FSAR, the results indicate very little pad creep and the corresponding tendon force loss would be 2 kips. This creep test was of the relatively short duration of 72 hours.

However, ten-year neoprene creep data is reported in Reference 4. This information was used to determine the pad creep and resulting tendon force loss of 4 kips. This value is still very small relative to the larger-than-predicted force losses which the tendons have exhibited in the past.

The pads were inaccessible for visual inspection. Consquently, no conclusion can be reached on the actual displacement that they have undergone over the past 12 years.

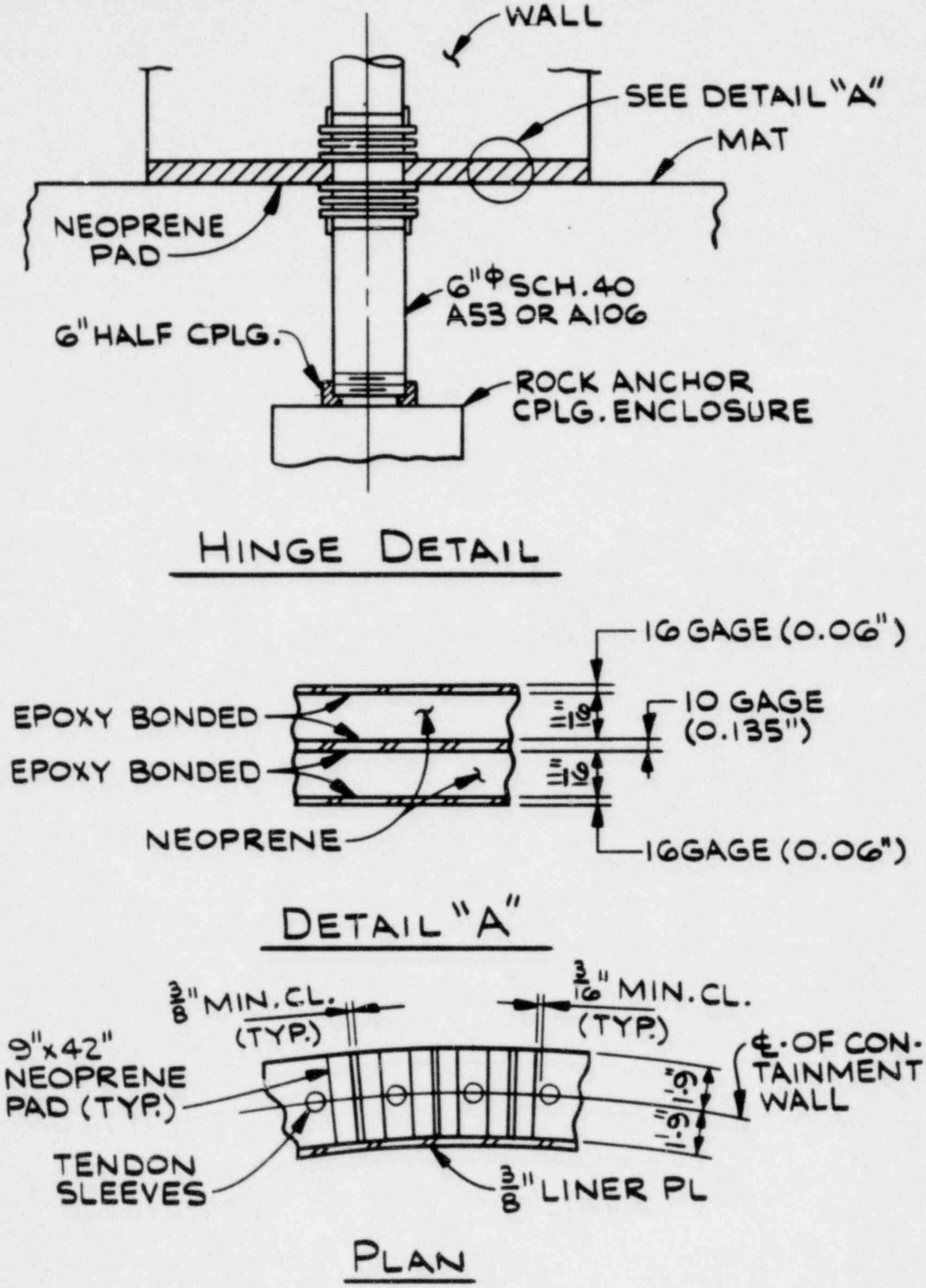


FIGURE 2.8-1
ELASTOMERIC PADS

Figure 1. Stress/Strain in Compression *(Typical Neoprene Bearing Compositions)*

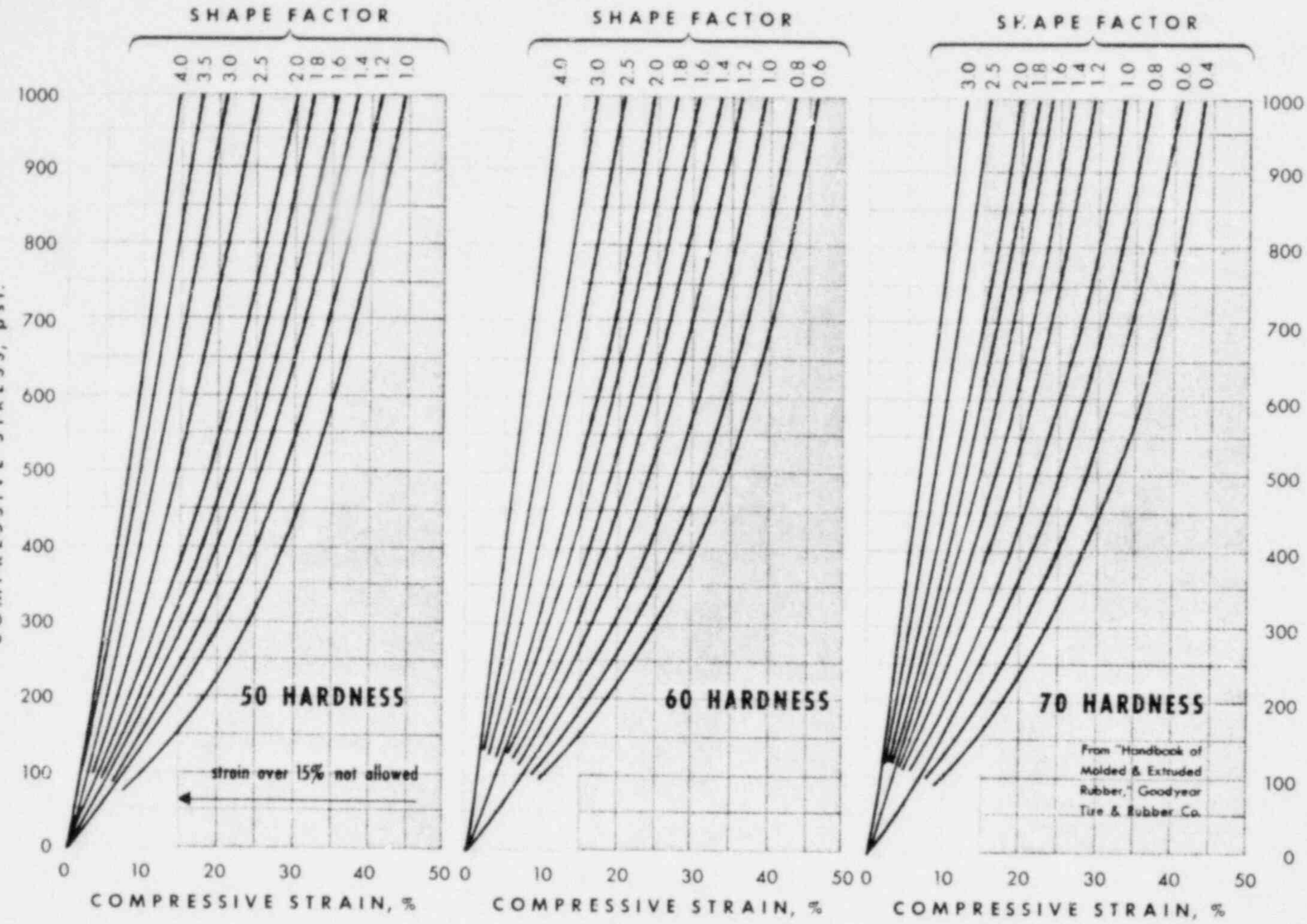


Figure 2. Modulus of Elasticity in Shear *(Typical Neoprene Bearing Compositions)*

50 HARDNESS	60 HARDNESS	70 HARDNESS
110 psi at 70°F.	160 psi at 70°F.	215 psi at 70°F.
1.1 x 110 psi at 20°F.	1.1 x 160 psi at 20°F.	1.1 x 215 psi at 20°F.
1.25 x 110 psi at 0°F.	1.25 x 160 psi at 0°F.	1.25 x 215 psi at 0°F.
1.9 x 110 psi at −20°F.	1.9 x 160 psi at −20°F.	1.9 x 215 psi at −20°F.

Figure 3. Creep in Compression *(Typical Neoprene Bearing Compositions)*

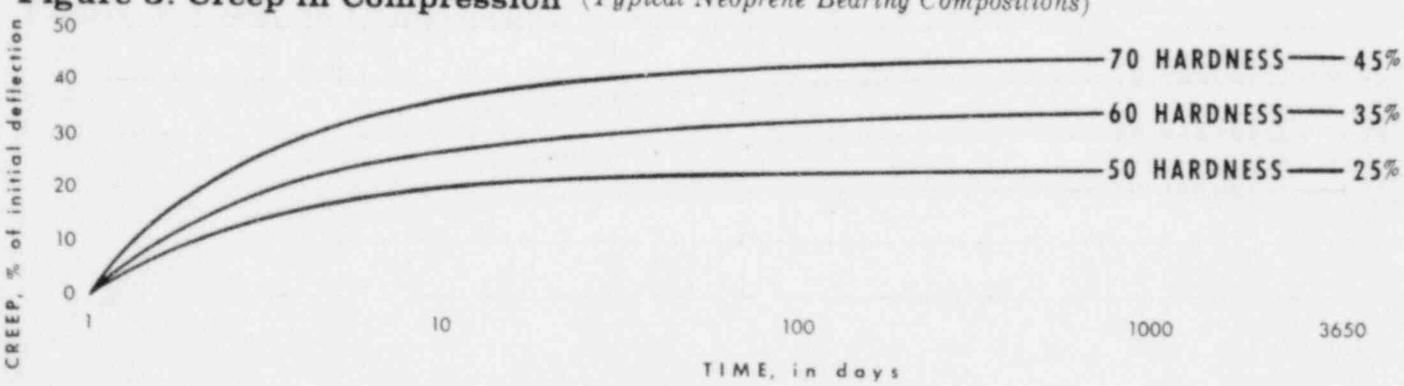


FIGURE 2.8-2
NEOPRENE CREEP DATA
(FROM DUPONT PUBLICATION, REFERENCE 4)

2.9 STRESS RELAXATION

Excessive stress relaxation of the tendon wires, as a cause of the larger-than-predicted tendon force losses, has been thoroughly investigated. Stress relaxation tests on wires extracted from three tendons were initiated in April 1980 at the Fritz Engineering Laboratory of Lehigh University. The test conditions, results, and conclusions of these tests are discussed in detail in Section 3.0. That section should be reviewed, particularly the conclusions, to fully understand the basis for the discussion that follows.

2.9.1 Tendon Heats

The wires tested represented three out of the six known wire heats which made up 147 of the 160 tendons. For the remaining 13 tendons, the tendon heat records were not found; consequently, the heats of wires comprising these tendons are not known. Records indicate that 129 of 147 tendons are represented by single heats, i.e., for 129 tendons only one heat of wire comprises a tendon. Of these 129 tendons, 74 are comprised of wires from the same heats as those wires tested at Lehigh. Thus, the stress relaxation test results represent 74 out of 160, or approximately 46% of all the tendons in the containment. The three heats and the tendons from which the test wires were obtained are: #30091 (tendon 76), #19477 (tendon 51), and #10355 (tendon 150).

2.9.2 Tendons Versus Test Wires

The conclusions of Section 3.0 are that all the wires from heats #30091, #19477, and #10355 tested at 104°F exhibit stress relaxations properties much greater than that of the Theoretical

(Nominal) 12% wire*, which had been used for the original design and the predicted tendon force curves of Appendix A. In addition, when tested at 68°F the wires from tendons 76 and 51 exhibited stress relaxations which also exceeded that of the 12% wire. Figures 3-1 and 3-2 contain the test stress relaxation curves along with the 12% wire curve, showing that most test curves are above the 12% curve. However, it is necessary to determine if these differences are significant enough to account for the past surveillance tendons generally having measured forces which were less than predicted (based on 12% wire stress relaxation), as indicated in Figures 2.9-1 through 2.9-4.

Figures 2.9-1 through 2.9-4 contain the results of the stress relaxation tests reported in Section 3.0. Superimposed on these results are the effective stress relaxations, indicated by dots, that the tendons have exhibited from past lift-off tests. Here, effective stress relaxation refers to the amount of force loss (expressed as a percent of initial stressing force) that a tendon would have to have experienced to make-up the difference in measured and predicted lift-off forces. Before comparing the results, the details of the determination of the effective stress relaxation are presented.

2.9.3 Effective Tendon Stress Relaxation

The effective stress relaxation, $SR_i(t)$, for any tendon at time, t, after stressing is:

$$SR_i(t) = \frac{\Delta F_i(t)}{LOF_i}$$

*The 12% value represents the percent of stress relaxation occurring after a wire has been under load for 40 years. This value is applicable to a wire that is initially loaded to 70% of GUTS (Guaranteed Ultimate Tensile Strength) and is at a constant temperature of 68°F.

where:

LOF_i = Original tensioning lock-off force for tendon i, occurring in March and April 1969

$\Delta F_i(t)$ = The stress relaxation force for tendon i that when added to the predicted creep, shrinkage, and elastic shortening losses gives a total force loss equal to the original tensioning lock-off force minus the measured lift-off force at time t.

Thus, the expression for $\Delta F_i(t)$ is

$$\Delta F_i(t) = LOF_i - \Delta F_i^{es} - \Delta F_i^{cr}(t) - \Delta F_i^{sh}(t) - MF_i(t)$$

where: ΔF_i^{es} = Concrete elastic shortening

$\Delta F_i^{cr}(t)$ = Concrete creep predicted at time t.

$\Delta F_i^{sh}(t)$ = Concrete shrinkage predicted at time t.

$MF_i(t)$ = The measured lift-off force in tendon i at time t after original tensioning

For the Ginna tendons, values for these losses were discussed in Reference 1. The elastic shortening loss is

$$\Delta F_i^{es} = 20.1 \text{ kips} \left[\frac{N-n_i}{N}\right]$$

where:

N = Total number of stressing sequences = 40

n_i = Sequence number of tendon i

As discussed in Reference 1, the shrinkage losses are based on a concrete shrinkage strain of 100 micro inches per inch at 40 years. However, only the concrete shrinkage strain which occurs subsequent to the average stressing date (4-1-69) contributes to the tendon losses. The value of strain is 74 micro inches per inch at the average stressing date. Therefore, the shrinkage strain which affects tendon force is:

$$\varepsilon_{sh}(t) = 7.752 \ln(t/0.0365) - 74 \text{ micro inches per inch}$$

and the corresponding force loss due to shrinkage is

$$\Delta F_{sh}(t) = \varepsilon_{sh}(t)\,(29 \times 10^6 \text{ psi})\,(4.42 \text{ in}^2)$$
$$= \left[128.2 \times 10^6\right] \varepsilon_{sh}(t)$$

where t is the time of interest in days after the average wall placement date, and 4.42 in^2 represents the tendon area.

The concrete creep strain at time t after the average wall placement date is based on the specific creep curves of Reference 5. This information was used to construct a specific creep curve for a concrete age of 515 days, which corresponds to the average of the Ginna containment wall concrete at tendon tensioning in March and April of 1969. This curve is shown superimposed on the curves from Reference 5 and included herein as Figure 2.9-5. The specific creep (sc) from the Ginna curve is used to obtain the tendon force loss:

$$\Delta F_{cr}(t) = sc(t)\,(628 \text{ psi})(29 \times 20^6 \text{ psi})(4.42 \text{ in}^2)$$
$$= \left[8.0497 \times 10^{10}\right] sc(t)$$

where the specific creep, sc(t), is in units of micro inches per inch per psi of wall stress. The value of wall stress is 628 psi.

Based on the above, the following values for creep and shrinkage tendon force losses at all previous lift-off periods were obtained:

FORCE LOSSES (KIPS)

	6 MO.*	1 YR*	3 YR*	8 YR*	10 YR*	June 1980
ΔF_i^{cr} (t)	6.2	7.2	9.4	13.7	14.7	15.0
ΔF_i^{sh} (t)	0.4	0.6	1.2	1.9	2.2	2.2
TOTAL	6.8	7.8	10.6	15.6	16.9	17.2

* Refers to time after original tensioning

Therefore, the value for effective stress relaxation, $SR_i(t)$, was obtained at each previous surveillance based on the losses discussed above and the tendon force measured at original tensioning.

2.9.4 Results

In Figure 2.9-1 the effective stress relaxation values obtained from all previous lift-off tests are shown for all 137 tendons which had not been retensioned prior to June 1980. These values, represented by the dots, are superimposed on upper and lower bound stress relaxation curves for the wire specimens. The upper bound curve corresponds to the 0.75 GUTS and 104°F test condition and the lower bound curve to that of 0.70 GUTS and 68°F. It is seen that practically all of the data points lie between the test bounds, and most of the tendons exhibit an effective relaxation which exceeds that of the 12% wire. The latter result would be expected since the measured forces in the tendons have been generally less than those predicted using the relaxation properties of the 12% wire.

To specifically relate the tendons to the test results, Figures 2.9-2, 2.9-3, and 2.9-4 were constructed. Superimposed in each figure are the effective stress relaxations of only those tendons which are comprised solely of wires which are of the same heat as the test heat. There are 18 such tendons for heat #30091, 38 tendons for heat #19477, and eight tendons for heat #10355. Ten (10) additional tendons are also made-up of wires from these heats. However, these tendons were retensioned at 1000 hours after original stressing in May 1969, and subsequent lift-off forces have not been plotted for these 10 tendons.

Tendons for Heat #30091

Referring to Figure 2.9-2 for heat #30091, most of the effective stress relaxation values of the tendons range from somewhat below curve 76-C up to curve 76-B2. These curves represent the 0.70 GUTS stress level and temperatures of 68°F and 104°F, respectively. The applicability of elevated temperature data to the actual tendons is discussed below.

During plant operation when the air temperature inside the containment is approximately 100°F, the temperature of the tendons is expected to range as high as 85°F to 95°F, depending on their location, over much of their length. The 85°F value would result from a 70°F air temperature in an adjacent building; some areas would be higher, such as the main steam penetration area of the intermediate building. The estimated stress relaxation of the test wires at 85°F and 95°F is marked at 100,000 hours for comparison with the June 1980 tendon values. This comparison indicates that the higher range of tendon effective stress relaxation values is in the neighborhood of the stress relaxation property exhibited by the wire. Therefore, test results at reasonable estimates of the actual tendon temperatures are generally consistent with the effective stress relaxations of the tendons which exhibit the greatest values. The wire stress relaxations of 16.5% and 17.5% at 85°F and 95°F, respectively, resulted from a linear interpolation between the 68°F and 104°F data at 100,000 hours. The linear relationship appears to be reasonably accurate based on a review of the results for heat #19477 which had test temperatures of 68°F, 78°F, and 104°F.

The average of the effective stress relaxations at 100,000 hours of all the 18 tendons is 14.9%, which is indicated in Figure 2.9-2. Also indicated are the values of effective stress relaxation of the tendons if the measurement error of the June 1980 lift-off forces is ±3%. This would result in a range of effective stress relaxations of 12.3% to 17.4%; thus, much of the variation in effective stress relaxation could be due to this measurement error. The basis for a ±3% accuracy was established from tests conducted during the July 1981 surveillance (Section 5.3.3) to determine the accuracy of a pressure gauge determined force. In these tests, the lift-off force determined from the pressure gauge was undermeasured approximately 40% of the time and overmeasured 60% of the time.

The fact that some of the tendons exhibited effective stress relaxations outside the 12.3% to 17.4% range could be due to the different temperature histories which the tendons have experienced over their 10 year life. Also, there is to be some expected variation in stress relaxation properties among wires, even though they are from the same heat, considering the variation exhibited among three test specimens which were all cut from the same wire (curves 76-B, 76-B1, and 76-B2).

Finally, from Figure 2.9-2 it is noted that the 85°F and 95°F curves appear to give 40 year extrapolated stress relaxation values which are in the 17.5% to 18.5% range, and this significantly exceeds the 12% design value.

Tendons from Heat #19477 and Heat #10355

Comparisons similar to those discussed above were made for heat #19477 and heat #10355 and the results are shown in in Figures 2.9-3 and 2.9-4, respectively. For heat #19477, a higher percentage of its tendons have an effective stress relaxation at 100,000 hours which exceeds the interpolated test values of 14% and 15.5% corresponding to the 85°F-95°F range. This is because the average effective stress relaxation (15.1%) of the tendons is also higher relative to this temperature range. Nevertheless, a -3% measurement error above the average would account for most of the excess values. The effective stress relaxation values for about 67% of the 38 tendons lie within ±3% of the average value. The values which lie outside this range could be a result of the historical temperature variation or wire property variation discussed above.

Figure 2.9-3 shows that the 40 year stress relaxation of the wire from heat #19477 appears to be in the 15% to 16.5% range for the 85°F and 95°F temperatures.

The results for heat #10355 are shown in Figure 2.9-4. The effective stress relaxation values for the eight tendons lifted-off at 100,000 hours lie far above the 68°F test results (curves 150-C1 and 150-C2). However, it is not unreasonable to expect this considering the elevated temperatures which the tendons have experienced over most of their history. For the reasons discussed in Section 3.0, the 104°F test results on wire specimen 13, curve 150-B, appear to be too low. Consequently, a relaxation curve was approximated for this test condition (calculated 150-B). The average of the effective stress relaxations is 15.0%, which lies some what below the stress relaxation estimated for the 104°F condition. A ±3% error in measuring the 1980 lift-off forces would account for practically all of the variation in effective stress relaxation exhibited by the tendons. It is noted that due to the lack of valid data for wire specimen 13, an interpolation of the stress relaxation data was not made for heat #10355 to the 85°F and 95°F temperature range. For this reason, estimated relaxation curves for these two temperatures do not appear in Figure 2.9-4.

All Three Tendon Groups

In comparing the effective stress relaxation values of the tendons at 100,000 hours for all three heats (Figures 2.9-2 through 2.9-4), their average values are very close: 14.9% (#30091), 15.1% (#19477), and 15.0% (#10355). Therefore, the average stress relaxations of the three groups of tendons were not effected by the different heats of wire which comprised them. This conclusion is similar to that reached for the relaxation test specimens from different heats, but it is applicable to only those specimens at the 104°F temperature condition and not those at 68°F (see Section 3.4, item 3). Therefore, it is a reasonable conclusion that the tendons exhibited nearly equal average values of stress relaxation because they have been generally at elevated (average) temperatures, which in view of high wire relaxation properties at these temperatures, explains why the tendons have incurred force losses much greater than that corresponding to the Theoritical 12% wire.

2.9.5 Conclusions

The force losses which the tendons have generally experienced in the past are consistent with the stress relaxation properties of the wires which comprise the tendons, and these properties are significantly greater than those for the nominal 12% relaxation wire used for the design and subsequent tendon force predictions.

The operational temperature range believed to be applicable for most of the tendons is 85°F to 95°F. For comparison with the effective stress relaxations of the tendons in June 1980, the tested wire stress relaxations were interpolated to 85°F and 95°F. At these temperatures the interpolated test values ranged from a minimum value of 14.0% (heat #19477) to a maximum of 17.5% (heat #300910). These values are significantly greater than the 10% value associated with the 12% relaxation grade of wire used in all previous tendon force predictions. Consequently, the tendon forces would be over-predicted using the relaxation property of the 12% wire. For example, the 39 kip average value by which the forces for a 35 tendon sample were over-predicted in June 1980 (Section 1.2 of Introduction) can be generally accounted for by the differences above. A four (4) percentage point difference in stress relaxation corresponds to a 30 kip force for the Ginna tendons, and a 7.5 percentage point difference in stress relaxation corresponds to 56 kips of tendon force. Therefore, the 39 kips previously unaccounted for in the June 1980 is consistent with these values.

The average value of the effective stress relaxations exhibited by the 64 tendons in June 1980, which were comprised solely of wires for the same heats as the test wires, was approximately 15%. Most of the variation about the average value could be explained by a ±3% force measurement error. More importantly, a 15% stress relaxation for the tendons in June 1980 does not appear to be unrealistically high in light of the test values discussed above, which are in the 14.0% to 17.5% range.

In the operational temperature range believed to be generally applicable for the tendons, the 40 year stress relaxations could be as high as 15% to 18.5% based on the interpolated test results for 85°F and 95°F. These values are significantly greater than the 12% design value.

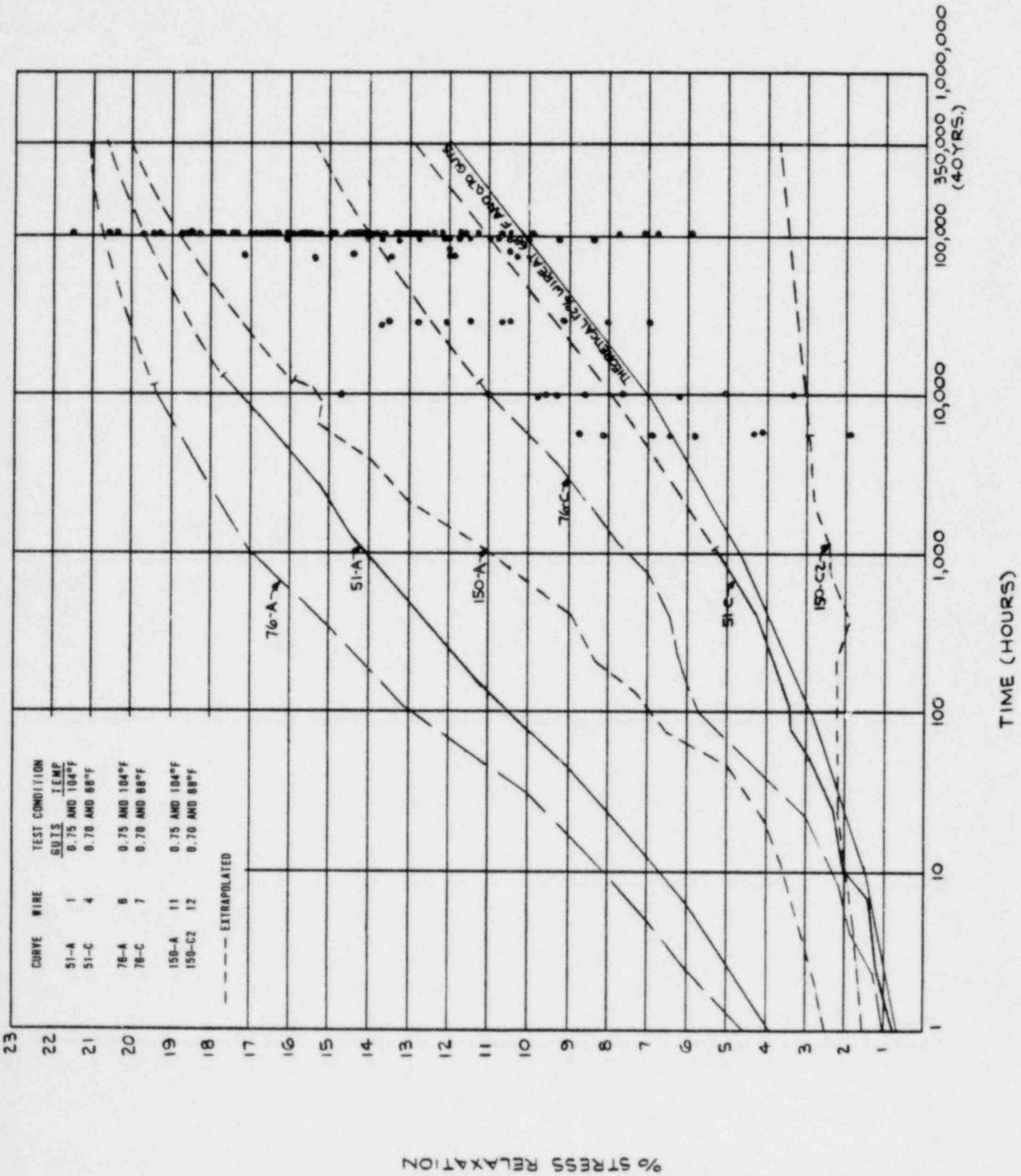


FIGURE 2.9-1
EFFECTIVE STRESS RELAXATION OF ALL SURVEILLANCE TENDONS, WITHOUT REGARD TO WIRE HEATS

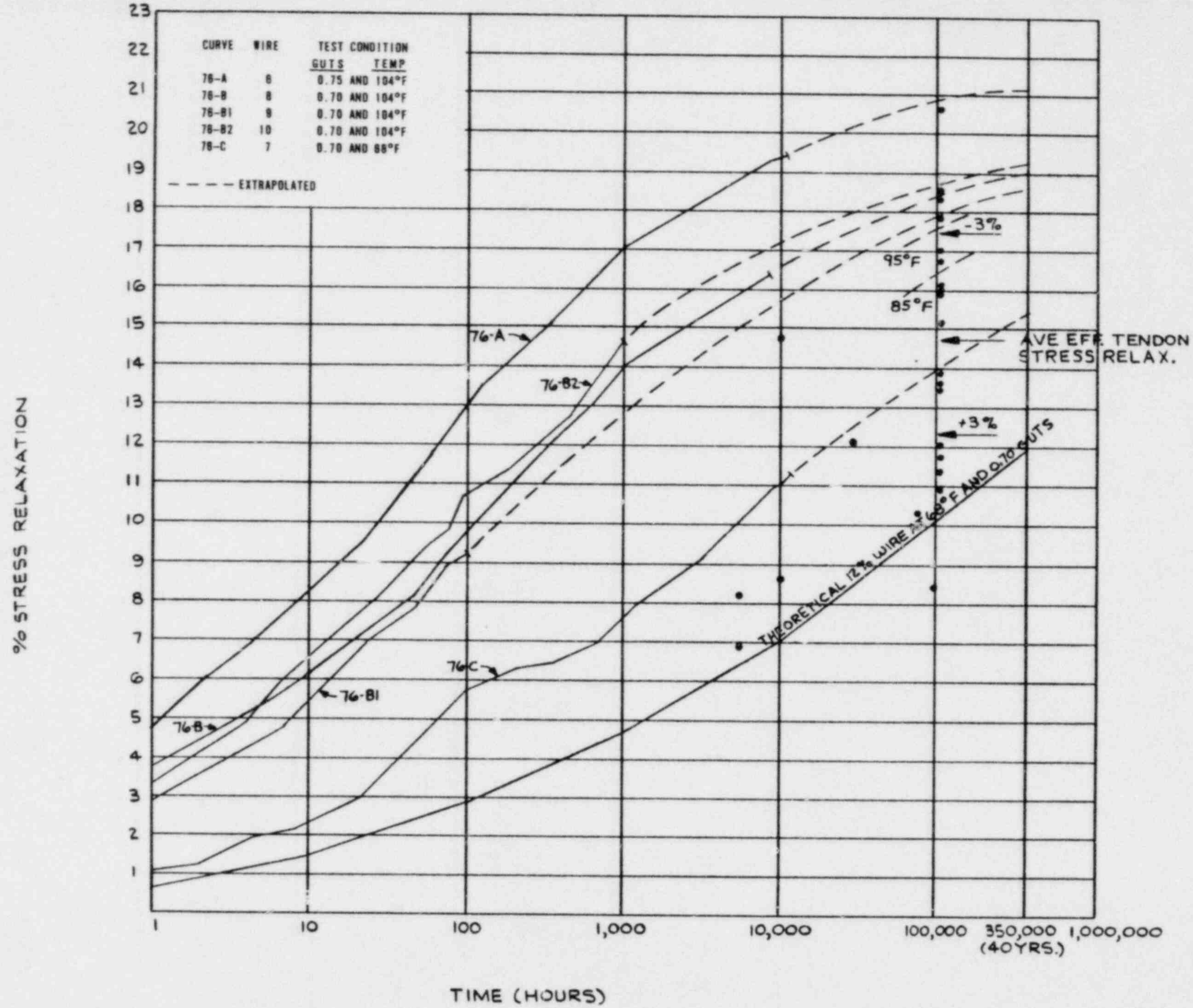


FIGURE 2.9-2
EFFECTIVE STRESS RELAXATION OF SURVEILLANCE TENDONS
COMPRISED ENTIRELY OF WIRES FROM HEAT #30091

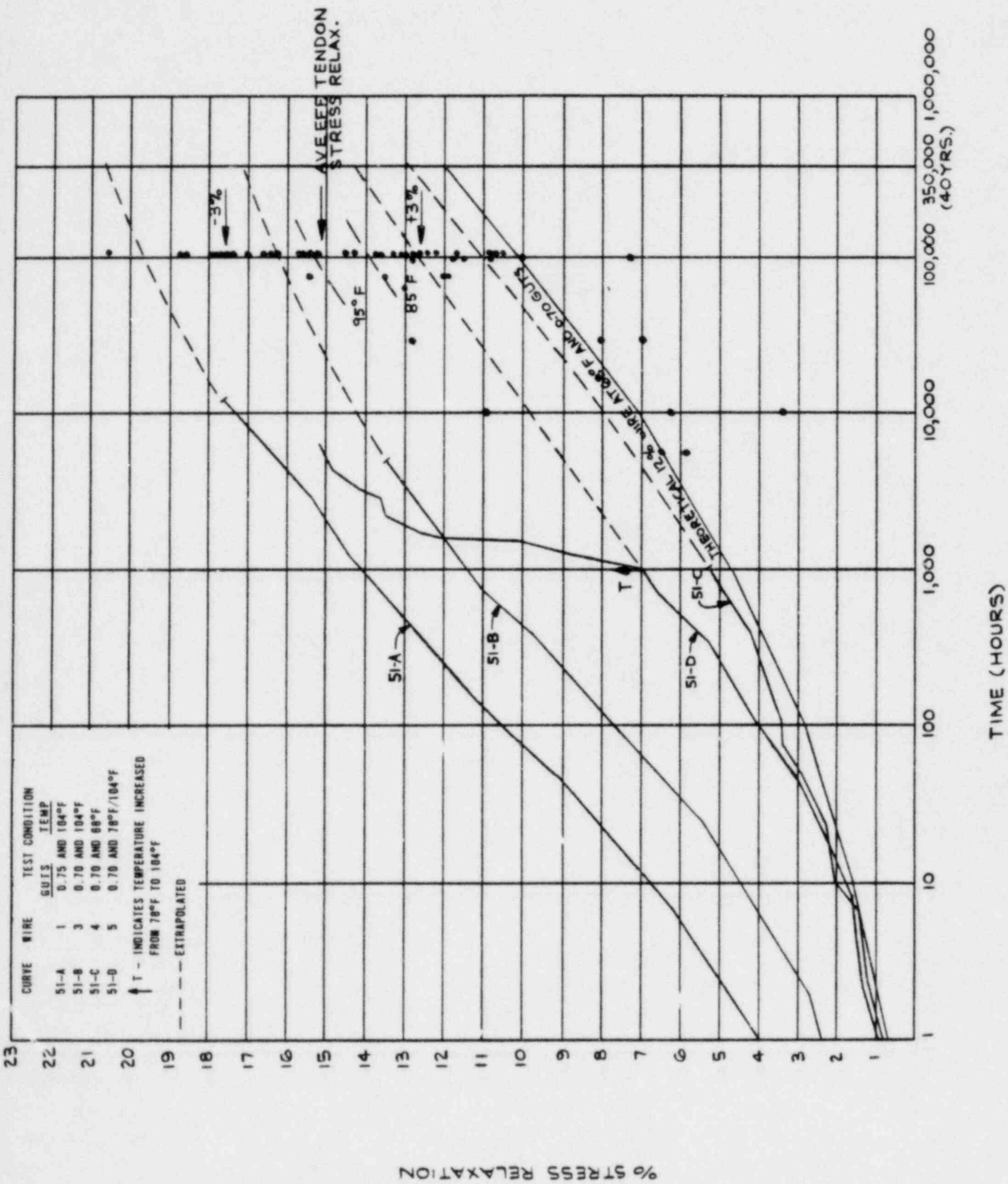


FIGURE 2.9-3
EFFECTIVE STRESS RELAXATION OF SURVEILLANCE TENDONS
COMPRISED ENTIRELY OF WIRES FROM HEAT #19477

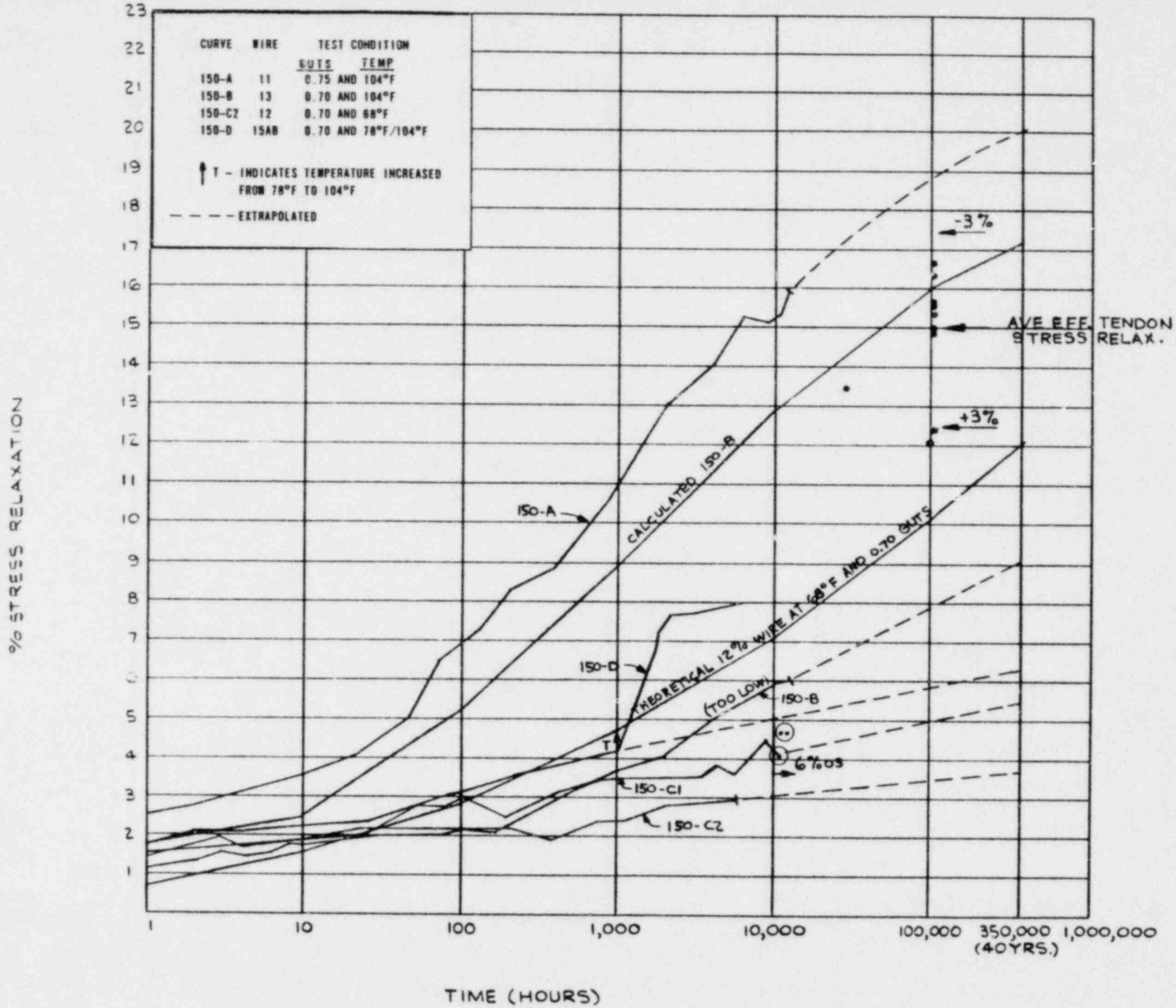
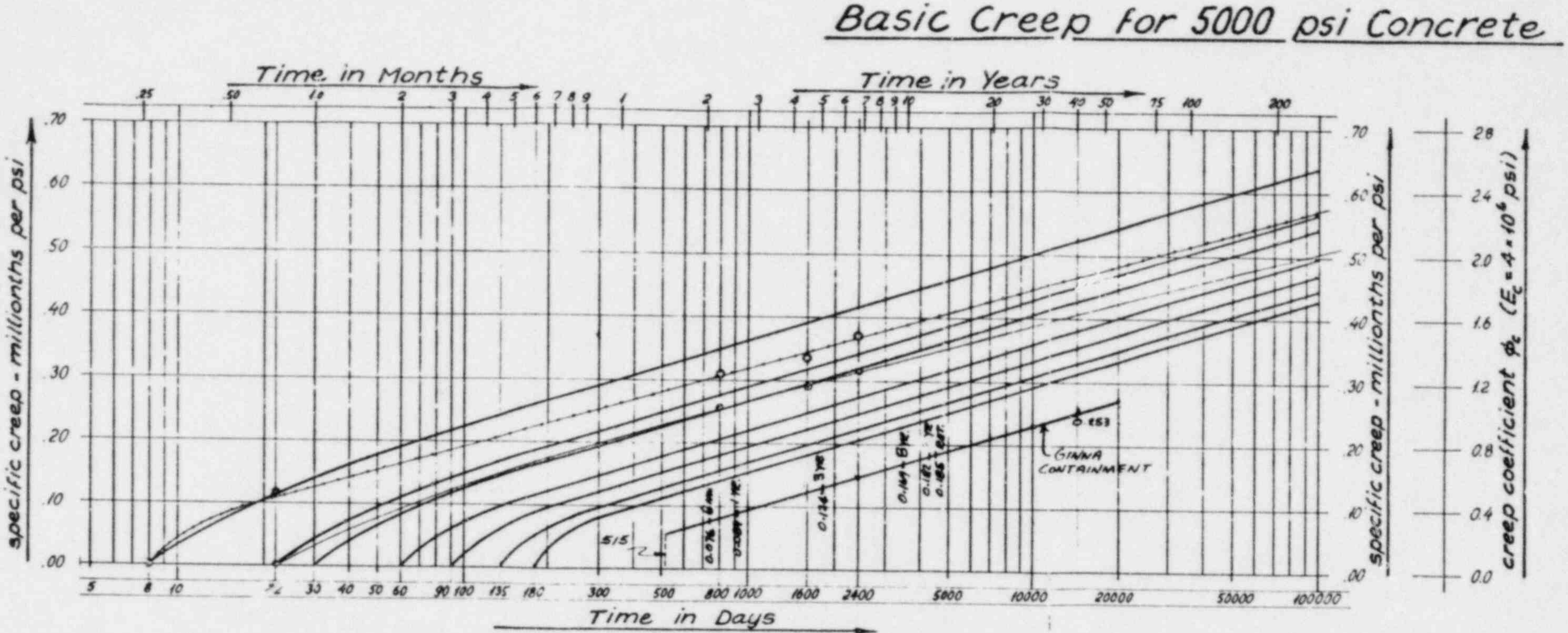


FIGURE 2.9-4
EFFECTIVE STRESS RELAXATION OF SURVEILLANCE TENDONS
COMPRISED ENTIRELY OF WIRES FROM HEAT #10355



Total creep @ cgs . . . . , Port Hueneme Tests[1]; age @ loading: 8 days;

Differential creep, top fibre, " " "[1]; " @ " : 22 ";

Estimated basic creep[2] for loading ages: 8 & 22 days and 1, 2, 3, 4½ & 5 months

[1] Technical Report R212, U.S. Naval Civil Engineering Laboratory, see also Appendix B.

[2] Formula for basic creep: $\frac{\epsilon_{creep}}{\sigma} \times 10^6 = \frac{0.18\,g(t_0)+0.28}{g(t_0)}(1-e^{-(t-t_0)/30}) + 0.6\ln(\frac{t}{t_0})$, ref. equation [S], Appendix A.

FIGURE 2.9-5
SPECIFIC CREEP CURVES

2.10 TENDON TYPE

The possibility was investigated that the larger-than-predicted tendon losses could be related to the curvatures of the tendons. It was speculated that tendons with the largest curvatures might exhibit a gradual "slackening" if the friction forces along these tendons undergo a redistribution and reduction. Thermal changes in the tendon might tend to cause this.

2.10.1 Approach

The approach taken was to determine if the largest unpredicted losses from the June 1980 lift-off tests were associated with the tendons with the largest friction forces. The various friction factors for the tendons are related to the tendon types indentified in Figure 1-2. For example, Type A tendons are straight; therefore, they exhibit the least friction forces relative to the other types. Also the effective stress relaxations, shown by the data points at 100,000 hours in Figure 2.9-1, are a measure of the unpredicted losses for the tendons. A specific tendon is associated with each data point.

2.10.2 Conclusions

A comparison of effective stress relaxation with tendon type revealed no correlation. Therefore, tendon type was eliminated as a reason for the larger-than-predicted tendon losses.

3.0 STRESS RELAXATION TESTS

3.1 OBJECTIVES

The original purpose of the tests was to determine if the larger-than-predicted force losses in the tendons were caused by excessive stress relaxation of the tendon wires. For this purpose, stress relaxation tests were initiated at the Fritz Engineering Laboratory of Lehigh University in April 1980. The test specimens were obtained from actual tendon wires. The tests were designed to determine the effects of initial stress level and temperature since the tendons were not all initially stressed to the same level and since the tendons had been exposed to temperatures greater than 68°F during plant operation.

One test condition of particular interest was an initial stress level of 0.70 GUTS (Guaranteed Ultimate Tensile Strength) and 68°F. These are standard conditions which were generally used by the nuclear industry as a basis for classifying relaxation properties of prestressing wire. Thus, the wire for Ginna was supplied on this basis. The Ginna wire was stated to have a 40 year stress relaxation of 12%; this relaxation grade being the only grade of wire which was generally commercially available at the time of the Ginna design.

After the test program was underway, it was decided to retension the tendons in the containment building. Therefore, the objective of the test program was modified to include determination of retensioning effects on the stress relaxation behavior of the tendon wires.

3.2 TESTS

3.2.1 Introduction

Each of the 160 tendons contains an extra (sacrificial) wire, 115 feet long, which is unstressed. The extra wire was removed from three tendons (numbers 76, 51, and 150) and was cut into 23 feet lengths on site for shipment to Fritz Engineering Laboratory for stress relaxation testing in April 1980. A total of 14 specimens was tested at temperatures of 68°F, 78°F, and 104°F and at initial stress conditions of 0.70 GUTS and 0.75 GUTS (GUTS is the Guaranteed Ultimate Tensile Strength of 240 ksi). During these tests, seven specimens were retensioned. The test condition for each specimen is given in Table 3-1. The Tendon Mark indicates tendon number and a letter designation for specimen, which is used in identifying the relaxation curves to be presented later. The Specimen Number is the designation established at the Ginna site when the wires were cut and shipped.

3.2.2 Test Equipment

The test equipment is shown in Figures 3-12A and 3-12B. The environmental chambers in which relaxation tests were conducted were originally designed and used for relaxation tests on 1/2 inch diameter seven-wire prestressed strand. Supreme chucks were used to anchor the strands and shims were used to hold the correct strain in the specimens during periods between readings.

After some experimentation in a testing machine, a satisfactory procedure for using supreme chucks with two of the three jaws was developed for anchorage of the 1/4 inch diameter wires. It is not absolutely necessary to have the chucks hold the load without slip, but it is very helpful if no slip occurs after tensioning. With the chucks used, there was no trouble with slip of the chucks for loads greater than 1000 lbs.

Each specimen was placed in a separate frame consisting of two steel angles 5 inch x 3-1/2 inch x 3/8 inch back to back with a 3/4 inch thick steel bearing plate at each end. The bearing plates were provided with a 3/4 inch diameter drilled hole and positioning lugs on the back side to hold the specimen in position at the c.g. of the pair of angles. The frames were supported on steel racks so that each frame was free to shorten as the specimen was tensioned. Three compartments were provided for the relaxation testing. The compartment for 68°F was air conditioned. The length of the test frame in this compartment was 21 feet. A double compartment unit was provided with heaters on the floor and circulation fans at one end for elevated temperature. One compartment was maintained at 104°F throughout the test. The other began at 78°F, but was increased to 104°F after 1008 hours for test specimens 5 and 15AB. In the studies on 1/4 inch diameter wire, both sides were used at 104°F with one side being used to cycle temperature. The length of test frames in the heated compartments was 16 feet.

Each specimen had a 10 feet gage length marked off in the center of the span. This gage length was used to be certain that the length of wire between gage points was exactly the same length each time load readings were taken. To make the gage length, clamps were attached to the specimen by bolting spring loaded plates on the specimen. At the fixed end, the plates were bolted to a 3/4 inch diameter rod approximately 9'-8" in length, which was supported by rollers above the pair of angles. At the jacking end, a dial gage reading to 0.001 inch was bolted to the rod. The plunger of the dial gage bears on a plate bolted to the clamp at the opposite end of the gage length.

Loads were read by a BLH 20 kip load cell incorporated in the pulling rod of the hydraulic ram. Loading was acomplished by a 30 ton capacity center hole hydraulic ram mounted in a chair designed to accommodate the load cell and ram. A threaded lug was connected to the chuck and a mating fixture was attached to the load cell.

During initial tensioning of each specimen, the specimen was loaded over a five (5) minute period in increments of 20% of the final load per minute. At the end of five minutes, timed by a stop watch, the load was adjusted to exactly the required load and the dial gage on the 10 feet gage length was read. This marked the start of the relaxation test. After this, all readings were taken by adjusting the load so that the 10 feet gage length was exactly correct and the corresponding load was read on the load cell.

During the first 24 hours the load was held by the jack with the load cell under load. After the 24 hour reading was taken, shims were fitted between the frame and chuck so that when load was released by the jack the dial reading was within ± 0.002 inch of the correct reading for measuring load.

Each time the readings were taken, the load cell zero was checked before starting the test. The specimen was loaded by the ram and load cell a sufficient amount to release the shims. This required a change in dial gage reading of 0.015 inch or an overload of 225 lbs. Load was then released back to the correct dial reading and the load was recorded. The specimen was then overloaded slightly to fit the shims back in place and the load released. Temperature was maintained within 2°F of the designated temperature when readings were taken. It was not necessary for the temperature to be so exact, but it was found that wire and angles did not change length simultaneously. Therefore, the procedure was to have the temperature very close to the designated temperature when taking readings. It was found that a very rapid changing temperature could produce an error of up to 12 lbs per $^{\circ}$F in the load.

The following information was recorded each time data was taken:

- Date
- Watch Time
- Time from Start of Test (calculated) (hours)
- Dial Gage Reading
- Load (Kips)
- Temperature (°F)
- % Loss of Load (calculated)

The last item was checked against all previous values to be sure that the data obtained was reasonable.

3.2.3 Original Tests

Refer to Table 3-1 for the following discussion. One objective of the tests was to determine the stress relaxation property, at a condition of 68°F and 0.70 GUTS, of the production wire provided for Ginna since its relaxation grade of 12% at 40 years was based on these conditions. A total of four specimens was allocated for these tests, at least one from each of the three tendons.

Another objective was to determine the influence of temperature and initial stress levels which are greater than the standard condition of 68°F and 0.70 GUTS. Investigation of these effects was considered to be important since the tendons in the containment building have been exposed to temperatures greater than 68°F for prolonged time periods; for example, in the neighborhood of 90°F during plant operation. Also, some tendons were originally stressed greater than 0.70 GUTS, a few as high as 0.74 GUTS. Thus, one specimen from each of the tendons was subjected to an initial stress level of 0.75 GUTS; and a total of eight specimens was tested at a constant elevated temperature of 104°F. In addition, two specimens had their temperature increased from 78°F to 104°F at 1,000 hours after initial stressing. The purpose of this test was to determine the effect on stress relaxation of an elevated temperature (104°F) after substantial stress relaxation had already occurred.

One specimen was tested to determine the effect of applying a temporary 6% overstress, similar to that performed on the tendons at previous surveillances. After being under load for 10,000 hours, an incremented force was applied to temporarily stress the specimen to 1.06 times its existing stress level, then the specimen was reseated to its existing value. This so-called overstressing was performed several times at specified intervals.

The results of the tests described above were evaluated with respect to the stress relaxation values used in the original design and also in the tendon force predictions in Reference 1, which were based on a wire with a 40 year stress relaxation of 12%. The 12% valve is applicable to a wire that is initially loaded to 0.70 GUTS and is at a constant temperature of 68°F. The stress relaxation curve for this wire is shown in Figure 3A of Reference 1, and it appears in the figures in Section 3.3 labeled "Theoretical 12% Wire at 68°F and 0.70 GUTS."

3.2.4 Retensioning Tests

After the specimens had been under load for a specified duration, seven were restressed to their initial stress level. These test modifications were intended to develop data which would enable an estimate of future stress relaxation in the 137 tendons retensioned in June 1980 and in the 23 tendons retensioned in May 1969.

The seven specimens were allocated to assess three effects: (1) duration under load prior to restressing, (2) variation between tendons, and (3) temperature. Specimens from tendon 76 were retensioned at three time decades: 100 hours, 1,000 hours, and 10,000 hours. Three of the seven specimens were tested at 68°F and four were tested at 104°F. Tendon 76 had four retensioned wire specimens, tendon 51 had two; and tendon 150 had one retensioned specimen. The retensioning test conditions are summarized in Table 3-1. From the table, it is seen that five of the specimens have been monitored for at least 5000 hours after retensioning. The remaining two specimens have been tested for 1,000 hours and 1,656 hours. These tests are still in progress.

3.3 RESULTS

The results of the original tests are presented in Figures 3-1 through 3-4. These results are evaluated below since they specifically relate to the tendon loss investigation. The data obtained from the retensioned wires are presented in Figures 3-5 through 3-11. They are evaluated in Section 4.0 relative to the relaxation prediction techniques discussed in that section of the report.

3.3.1 Original Tests

Figures 3-1 through 3-4 present the results of the stress relaxation tests. In the figures, the solid portion of each curve represents the actual data. The dashed line is the extrapolation of the data out to 350,000 hours (40 years). The results are shown as starting after the wires had been under load for one hour, although data was recorded prior to this time.

A visual method of extrapolation was used. This method is justified since many of the curves had sufficient data points to establish the characteristic "S" shapes. Generally the stress relaxation, when plotted on a semi-log graph, will exhibit an "S" shape if the test is of sufficient duration. However, the "S" shape will become evident for shorter times if the tests are conducted at higher initial stress levels and temperatures. From the figures it is seen that the wires at the highest initial stress level (0.75 GUTS) and temperature (104°F) had developed "S" shapes, whereas the wires tested at 0.70 GUTS and 68°F exhibited stress relaxation still in the beginning part of the "S".

The Theoretical 12% wire curve is also shown in the figures for purposes of comparison.

Wire Specimen Heats

Once the tests had begun and had been in progress for at least 1,000 hours, a variation of the stress relaxation properties became apparent in specimens at the same test condition but from different tendons. At this point, the heats of wire which comprised tendons 76, 51, and 150 became another parameter to be considered in evaluating the test data. From the tendon records, the following information was reported regarding the heats of wire which comprised these tendons. Two different heats of wire comprised tendon 76: #10355 and #30091. Tendons 51 and 150 were each comprised of wires from only one, but different, heats: wires from heat #19477 entirely made up tendon 51 and wires from heat #10355 entirely made up tendon 150. However, this raised another question concerning the extra (sacrificial) wires from which the relaxation specimens were obtained: Did these wires also come from the same heat, or were they from different and unknown heats? This question was asked to the tendon supplier, Inryco Inc., who responded that the extra wire contained in a tendon was fabricated from the same wire as the material in the tendon. Based on this information, all stress relaxation data were evaluated under the presumption that the test specimens are identifiable from the heats above. Thus, all specimens from tendon 51 are from heat #19477, and those from tendon 150 are from heat #10355. It cannot be determined for sure whether the specimens from tendon 76 came from heat #10355 or heat #30091. However, the marked difference in 68°F data between tendon 76 and

150 makes it reasonable to assume the specimens from these two tendons are not from the same heat. Therefore, specimens from tendon 76 are assumed to be from heat #30091. In summary then, the specimens are from three different and identifiable heats.

Wire Specimens from Tendon 76 and Tendon 51

Figure 3-1 shows that all of the wire specimens from tendon 76 and tendon 51 exhibit stress relaxation properties greater than that of the 12% wire. Moreover, for all of the specimens except one (curve 51-C) the difference above the 12% wire is significant. The 68°F specimen from tendon 76 (curve 76-C) exhibits a stress relaxation property which is generally four percentage points above the 12% wire. The 40 year stress relaxation of this specimen would be almost 16%. By comparing curves 51-C and 51-D in Figure 3-1, the effect of an increased ambient temperature of 10°F is to increase the stress relaxation property by about two percentage points beyond 1,000 hours. For the specimens tested at 104°F, the extrapolated stress relaxation is greater than the 12% wire by a factor of at least 2.0 at 10,000 hours and by a factor of at least 1.6 at 100,000 hours. These times would correspond to about one year and 11 years after original tendon stressing. Comparing curves for the same test condition, the specimen from tendon 76 appears to exhibit a somewhat greater relaxation property than does the wire from tendon 51. However, this difference decreases as the time under stress increases, and for the 104°F specimens, the maximum percent difference has been reduced to about 15% for times greater than 10,000 hours.

Wire Specimens from Tendon 150

Figure 3-2 shows that all the specimens tested at 68°F and 78°F from tendon 150 have confirming relaxation properties which are less than the 12% wire (curves 150-C1, 150-C2, and 150-D). The curve for specimen 13 (150-B), which was tested at 0.70 GUTS and

104°F, also lies below the 12% wire curve. However, the data for specimen 13 appears too low with respect to the data from specimen 11 (curve 150-A) when considering the results at similar test conditions for the tendon 76 and 51 specimens. Consequently, an adjustment is made to curve 150-B in subsequent figures.

Figure 3-2 also shows that specimen 11, tested at 0.75 GUTS and 104°F (curve 150-A), exhibits the high stress relaxation also seen for the specimens at the same test condition from tendons 76 and 51.

To examine this similarity, stress relaxation values for the specimens tested at 0.75 GUTS and 104°F are compared in Table 3-2 at various durations under load. This table shows that the difference in stress relaxation between the tendons is still significant at 1,000 hours and 10,000 hours, but by 100,000 hours (11.4 years) the values are within 10% of each other. However, this situation does not exist for the specimens tested at 68°F, as can be noted from the comparison in Table 3-3. Therefore, it appears that, whereas the 68°F results indicate a significant difference in the relaxation property of wire from tendon 150 versus that from tendons 76 and 51, at the elevated temperature of 104°F this difference is much less, such that after 100,000 hours (11.4 years) under load, the difference (10%) might be considered insignificant.

<u>6% Overstress</u>

The effect of the 6% overstress is shown in Figure 3-2 by curve 150-C1. The three data points beyond 10,000 hours indicate the stress relaxation recorded after applying the temporary stress increase. These stress increases were applied at 9,960, 10,269, 10,632 and 11,376 hours. Immediately before applying the 6% overstress at the last three times, the stress in the wire was measured; thus reflecting the effect of the previous 6%

overstressing. From these results it cannot be determined whether the slight increase in stress relaxation indicated by the data points is due to the 6% overstress or to the data scatter, especially considering the sharp changes in this curve in the neighborhood of 10,000 hours. Regardless of the reason, the increase in stress relaxation subsequent to the 6% overstress is small, approximately 1 percentage point.

Temperature Increase

Figures 3-3 and 3-4 show the effect of a temperature increase after a wire has been under load at a lower temperature.

In Figure 3-3 the first part of curve 51-D indicates the stress relaxation in specimen 5 up to 1,000 hours at a test condition of 0.70 GUTS and 78°F. This specimen exhibits a somewhat greater relaxation than specimen 4 (curve 51-C), tested at 0.70 GUTS and 68°F, which is to be expected considering the 10°F temperature difference. At 1,000 hours, the temperature of specimen 5 was increased to 104°F, and the resulting increase in stress relaxation was dramatic as seen by curve 51-D. It is obvious from the figure that this stress relaxation now greatly exceeds that of the Theoretical 12% wire. In fact, the stress relaxation beyond 2,000 hours due to this temperature increase is greater than that of specimen 3 which had been at 0.70 GUTS and 104°F throughout its test history (curve 51-B).

In light of these results, the question was raised if a portion of this apparent stress relaxation in specimen 5 was due to the increased thermal strain in the specimen due to the 26°F increase. However, from a review of the test equipment, this was considered not to be the case. The steel angle frame which fixed the ends of all the specimens was unrestrained; consequently, it would experience the same thermal strain change as the specimen. Therefore, it was concluded that the large stress drop in specimen five was entirely due to its increased stress relaxation.

Figure 3-4 indicates the temperature increase effect on specimen 15AB from tendon 150. Similar to that discussed above, the 10°F difference in test temperature between specimen 15AB (curve 150-D) and specimen 12 (curve 150-C2) is reflected in the difference in the stress relaxation property of the two specimens. The effect of increasing the temperature on specimen 15AB is shown in curve 150-D beyond 1,000 hours. A sharp increase in stress relaxation is seen. The percentage increase in stress relaxation at the end of its sharp increase (approximately at 2,000 hours) is about the same for specimen 15AB as it is for specimen 5 from tendon 76 - in the neighborhood of 90%. However, the response from specimen 15AB differs from specimen 5 in that specimen 15AB exhibits a stress relaxation which would appear to be less than that estimated from a specimen which had been at 0.70 GUTS and 104°F throughout its test history. This estimated curve is indicated by "calculated 150-B", which is explained below.

For specimen 13 (curve 150-B), the test data was believed to be too low, as explained previously. Therefore, for purposes of obtaining a comparison, a curve for the 0.70 GUTS and 104°F test condition was calculated. The basis for the calculation was to maintain the same percent below curve 150-A (specimen 11 @ 0.75 GUTS and 104°F) as the averages of the curves from tendon 76 and 51 at the same test conditions.

Recognizing the approximate nature of the calculated 150-B curve, the only firm conclusions on specimen 15AB are that the temperature change sharply increased its stress relaxation, which had been below the Theoretical 12% wire, to the point that it significantly exceeded the 12% wire. However, it is noted that the relaxation rate beyond 2,000 hours, again referring to curve 150-D, has decreased to the point that the stress relaxation appears to be approaching that of the 12% wire.

3.3.2 Retensioning Tests

The results for the retensioned wire specimens are indicated in Figures 3-5 through 3-10. The stress relaxation history before and after restressing is shown. From these results, it is apparent that the effect of retensioning is to cause a much lower stress relaxation in the wire as expected. Figure 3-11 superimposes the retensioned stress relaxations of specimens 8, 9, and 10 for tendon 76. These specimens were all at the same test condition of 0.70 GUTS and 104oF but were retensioned one time decade apart at 100 hours, 1,000 hours, and 10,000 hours. These results indicate that the retensioned stress relaxation property decreases as time of retensioning increases. Therefore, wires which have relaxed for a long period of time prior to retensioning will exhibit less relaxation subsequent to retensioning than wires which were retensioned at earlier times. For tendon retensioning, the time of retensioning was 11.4 years or 98,988 hours, which is one time decade beyond the longest test retensioning time (10,192 hours for specimen 8). Thus, the test results must be evaluated to allow a projection of the stress relaxation in a wire restressed 10 years after initial stressing. This projection must extend to 30 years after restressing to be applicable to the actual condition of the containment tendons. Section 4.0, "Predicting Retensioned Tendon Forces," describes an evaluation procedure, which is referred to as the "Factor Method" in that section.

3.4 CONCLUSIONS

Based on the results presented in Section 3.3.1, the following conclusions are drawn:

1A. The wire from tendons 76 and 51 exhibited stress relaxation properties at all test conditions greater than that of the Theoretical 12% wire; and for all wire specimens, except one, the difference was significant. For the test condition comparable to that of the 12% wire (0.70 GUTS and 68°F), the 40 year relaxation values are 15.5% (tendon 76) and 13% (tendon 51).

1B. At the elevated temperature of 104°F, the test wires from tendons 76 and 51 had a stress relaxation after one year under load of at least two times the 7% value of the 12% wire. By 10 years under load, these wires would be expected to have relaxed at least 1.6 times the 10% value of the 12% wire. After 40 years under load, the stress relaxation of these wires would be expected to range from 17% to 21% instead of 12%.

2. The wire from tendon 150 appears to have a stress relaxation which was less than that of the wires from tendons 76 and 51. In fact, the stress relaxation property at 68°F of the wire from tendon 150 was even less than the 12% wire. However, the one wire specimen from tendon 150 for which valid elevated temperature data (104°F) was available, specimen 11, exhibited a significantly greater stress relaxation than that of the 12% wire. The sress relaxation of specimen 11 was greater than the 12% wire by a factor of 2.0 at one year under load and by a factor of 1.9 (extrapolated) at 10 years. The 40 year stress relaxation at this condition is estimated to be 20%.

3. The difference among all three tendons in the stress relaxation properties of wires tested at 104°F decreased with duration under load to the point where after ten years under load the maximum difference was within 10%. Therefore, it appears that even though wires from different heats may initially exhibit significantly different stress relaxation properties (at the same test conditions), if the wires are at elevated temperatures and have been under load for 10 years

or more the difference in stress relaxation between heats becomes small.

4. The effect of increasing the temperature from 78°F to 104°F after the wire has been under load at the lower temperature was to cause a sharp increase in the stress relaxation. It also appears that it is possible for the increased relaxation to approach, or even exceed, the constant 104°F data. Therefore, it appears to be possible for a wire initially stressed at an ambient temperature, which increased later, to eventually exhibit the same stress relaxation as that of a wire which had been under the elevated temperature throughout its load history.

5. The effect of applying a temporary 6% overstress to the wire may result in a slight increase in the stress relaxation; however, this increase is small and insignificant.

6. The stress relaxation property of the wire increases with initial stress level and temperature, as expected.

TABLE 3-1

STRESS RELAXATION TEST CONDITIONS

Tendon Mark	Specimen Number	Test Conditions: Original Stressing: Stress (% GUTS)	Temperature (°F)	Duration (Hours)	Retensioning: Stress (% GUTS)	Temperature (°F)	Duration(3) (Hours)
51-A	1	75	104	11,376	N/A	-	-
51-B	3	70	104	6,000	70	104	5,688
51-C	4	70	68	1,000	70	68	6,551
51-D	5	70	78/104(1)	6,192	N/A	-	-
76-A	6	75	104	12,096	N/A	-	-
76-C	8	70	104	10,192	70	104	1,656
76-B1	9	70	104	100	70	104	6,498
76-B2	10	70	104	1,008	70	104	6,653
76-B	7	70	68	11,230	70	68	1,000
150-A	11	75	104	11,712	N/A	-	-
150-B	13	70	104	12,072	N/A	-	-
150-C1	15AB-10	70	68	9,960(2)	N/A	-	-
150-C2	12	70	68	5,520	70	68	5,686
150-D	15AB	70	78/104(1)	6,192	N/A	-	-

NOTES:

1. Temperature raised to 104°F at 1008 hours.
2. After 9,960 hours a 6% overstress was applied. See Section 3.3.1 for details.
3. Tests in progress.

TABLE 3-2

COMPARISON OF SPECIMENS AT 0.75 GUTS AND 104°F

	Stress Relaxation (SR)							
	1000 hrs		10,000 hrs		100,000 hrs		40 yrs	
Curve	SR (%)	% Diff.	SR (%)	% Diff.	SR (%)	% Diff.	SR (%)	% Diff.
76-A	17.0	0	19.4	0	20.8	0	21.0	0
51-A	14.1	-17	17.3	-11	19.8	-5	20.6	-2
150-A	11.0	-35	15.2	-22	18.8	-10	20.0	-5

TABLE 3-3

COMPARISON OF SPECIMENS AT 0.70 GUTS AND 68°F

	Stress Relaxation (SR)							
	1000 hrs		10,000 hrs		100,000 hrs		40 yrs	
Curve	SR (%)	% Diff.	SR (%)	% Diff.	SR (%)	% Diff.	SR (%)	% Diff.
76-C	7.5	0	11.0	0	14.0	0	15.4	0
51-C	5.3	-29	8.0	-27	11.1	-21	13.0	-16
Ave. of 150-C1 and 150-C2	2.9	-61	3.5	-68	4.3	-69	4.6	-70

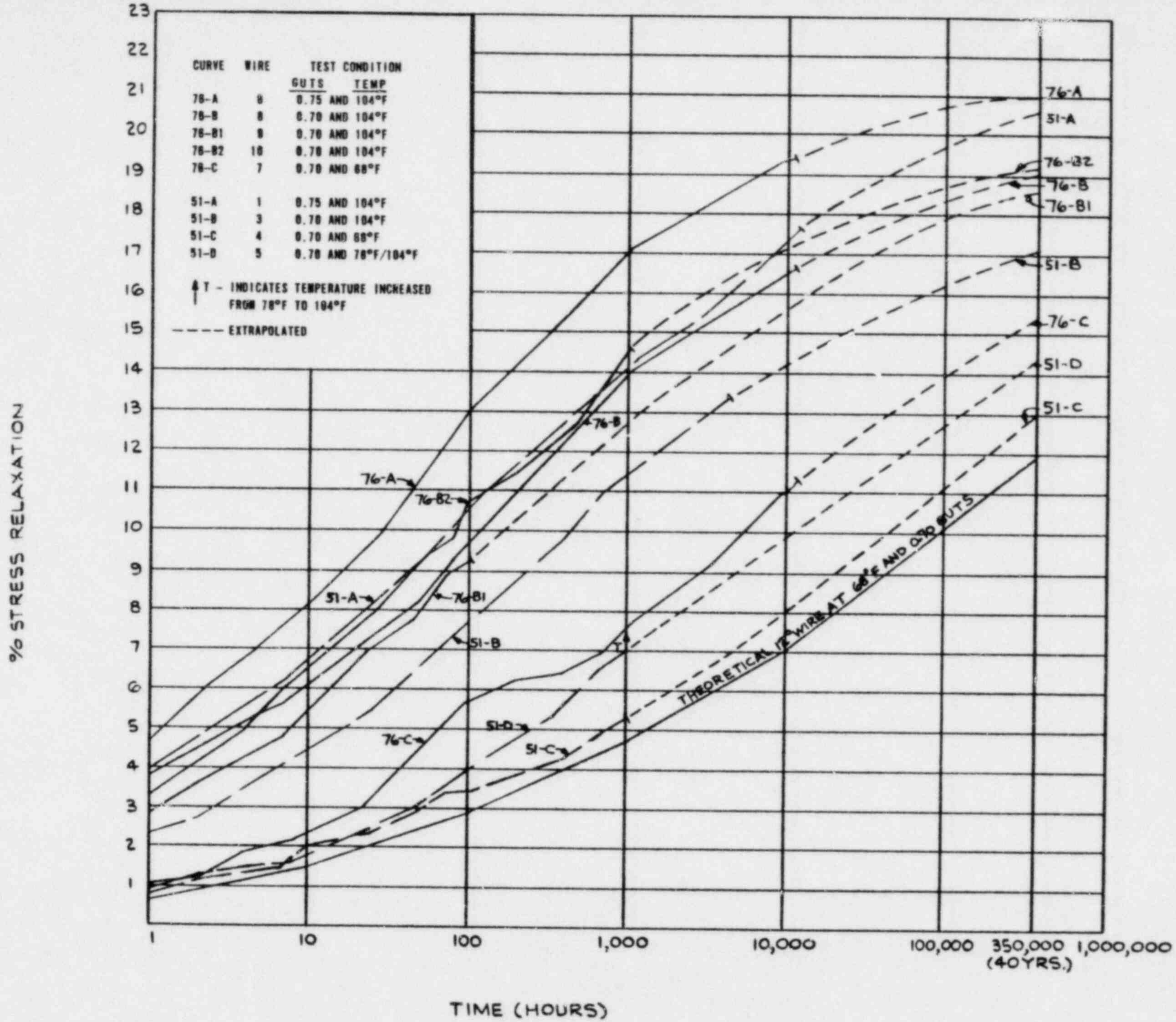


FIGURE 3-1
STRESS RELAXATION OF WIRES FROM TENDONS 76 AND 51

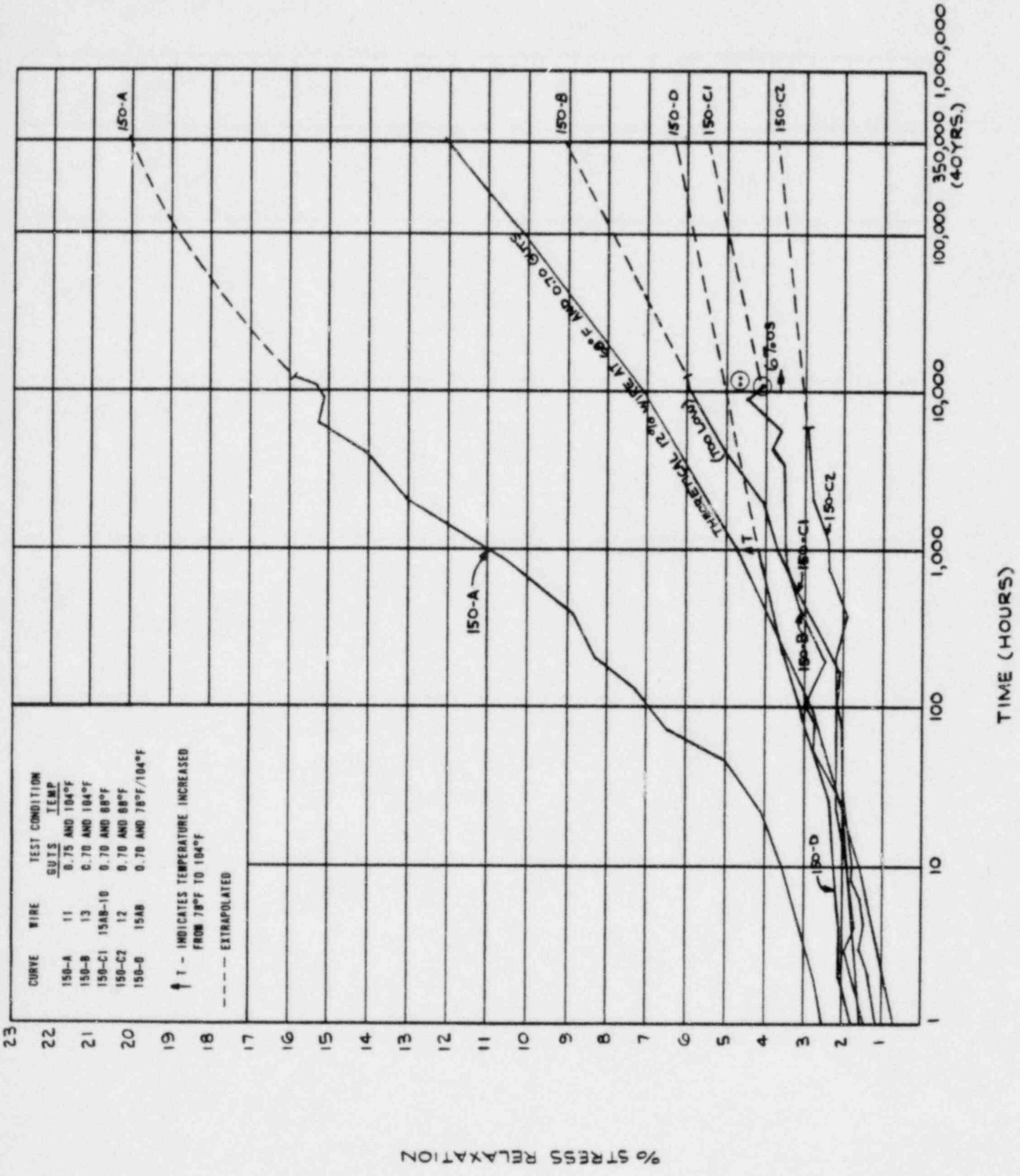


FIGURE 3-2
STRESS RELAXATION OF WIRE FROM TENDON 150

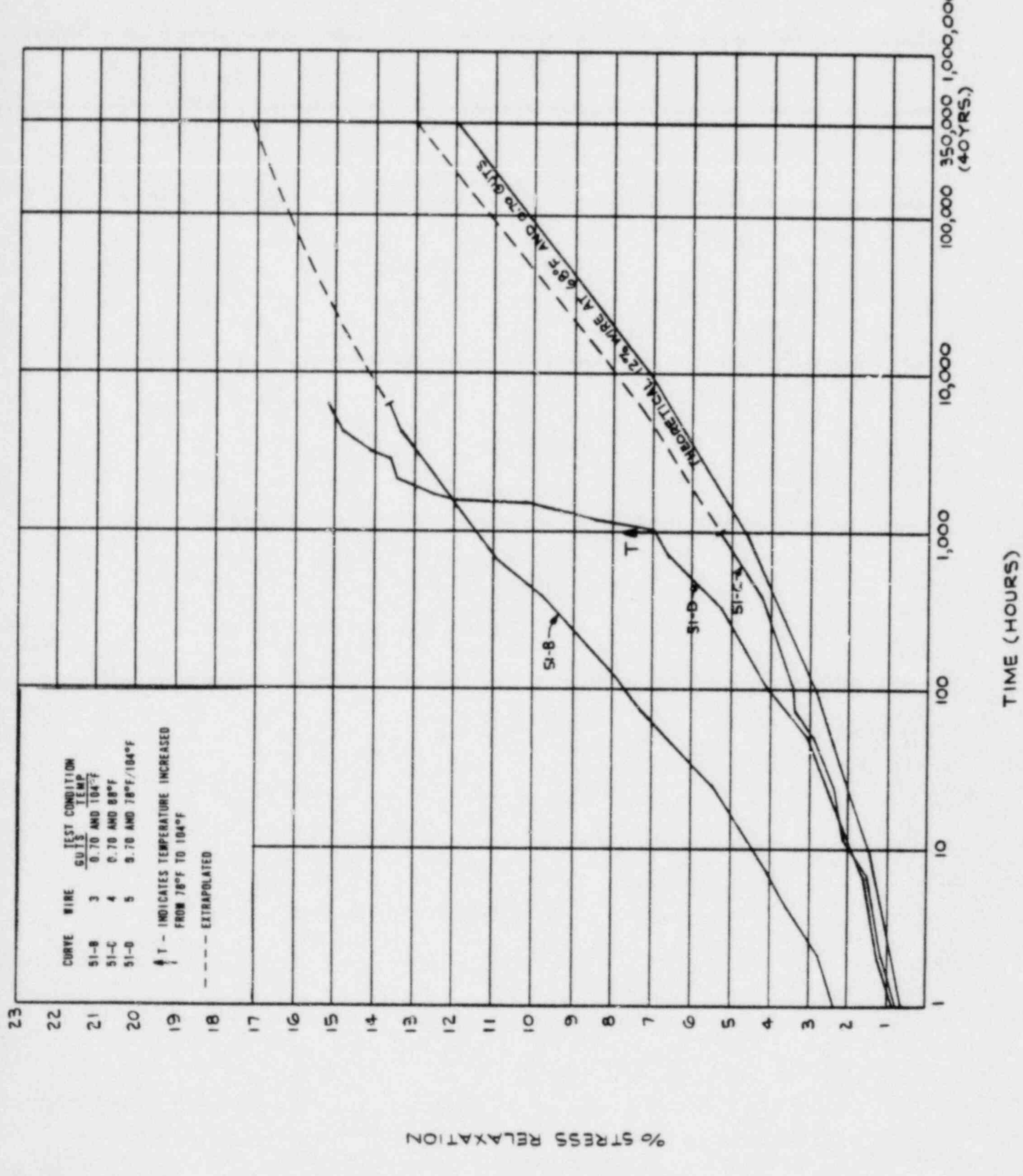


FIGURE 3-3
EFFECT OF TEMPERATURE INCREASE ON
STRESS RELAXATION OF WIRE FROM TENDON 51

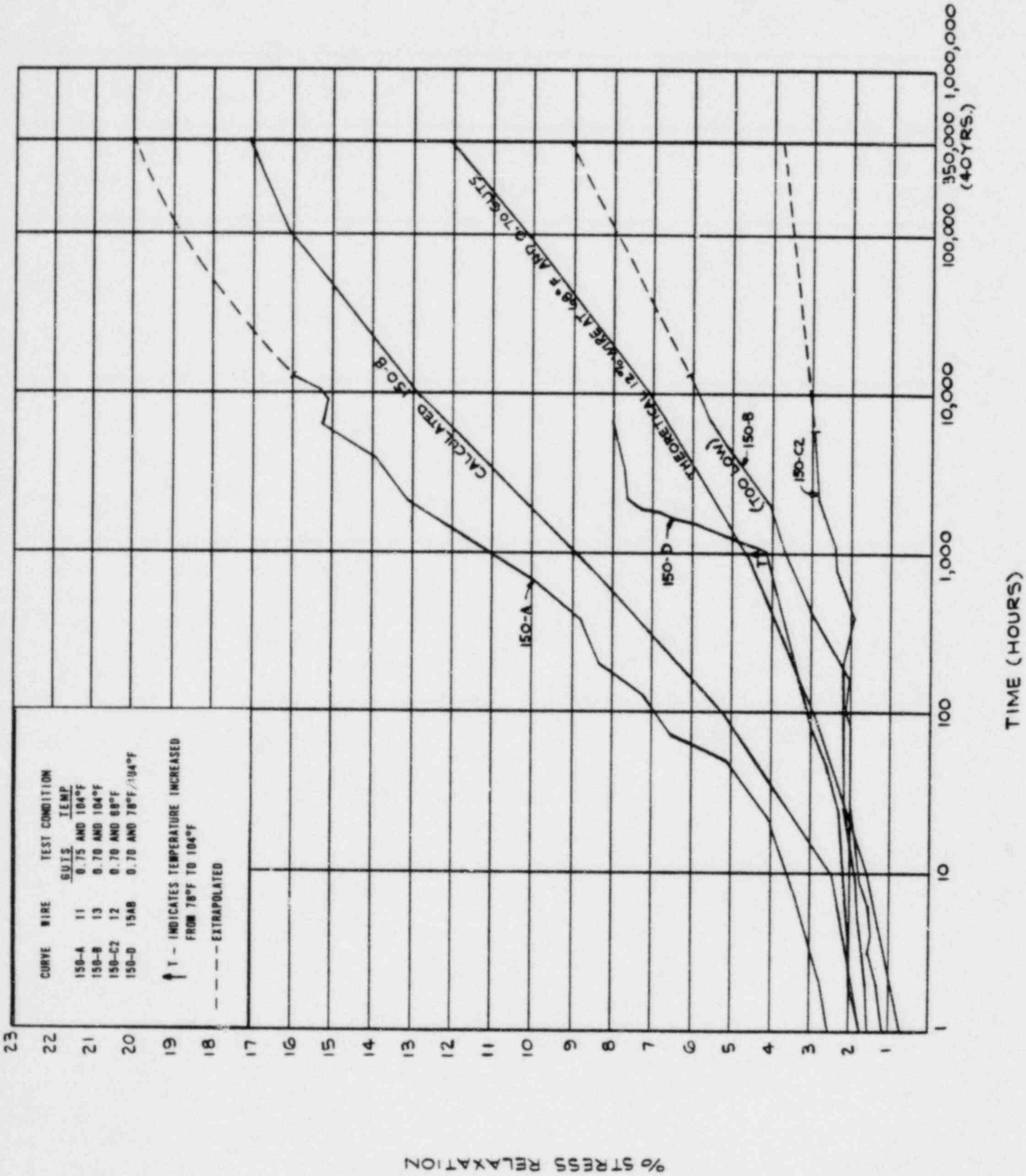


FIGURE 3-4
EFFECT OF TEMPERATURE INCREASE ON
STRESS RELAXATION OF WIRE FROM TENDON 150

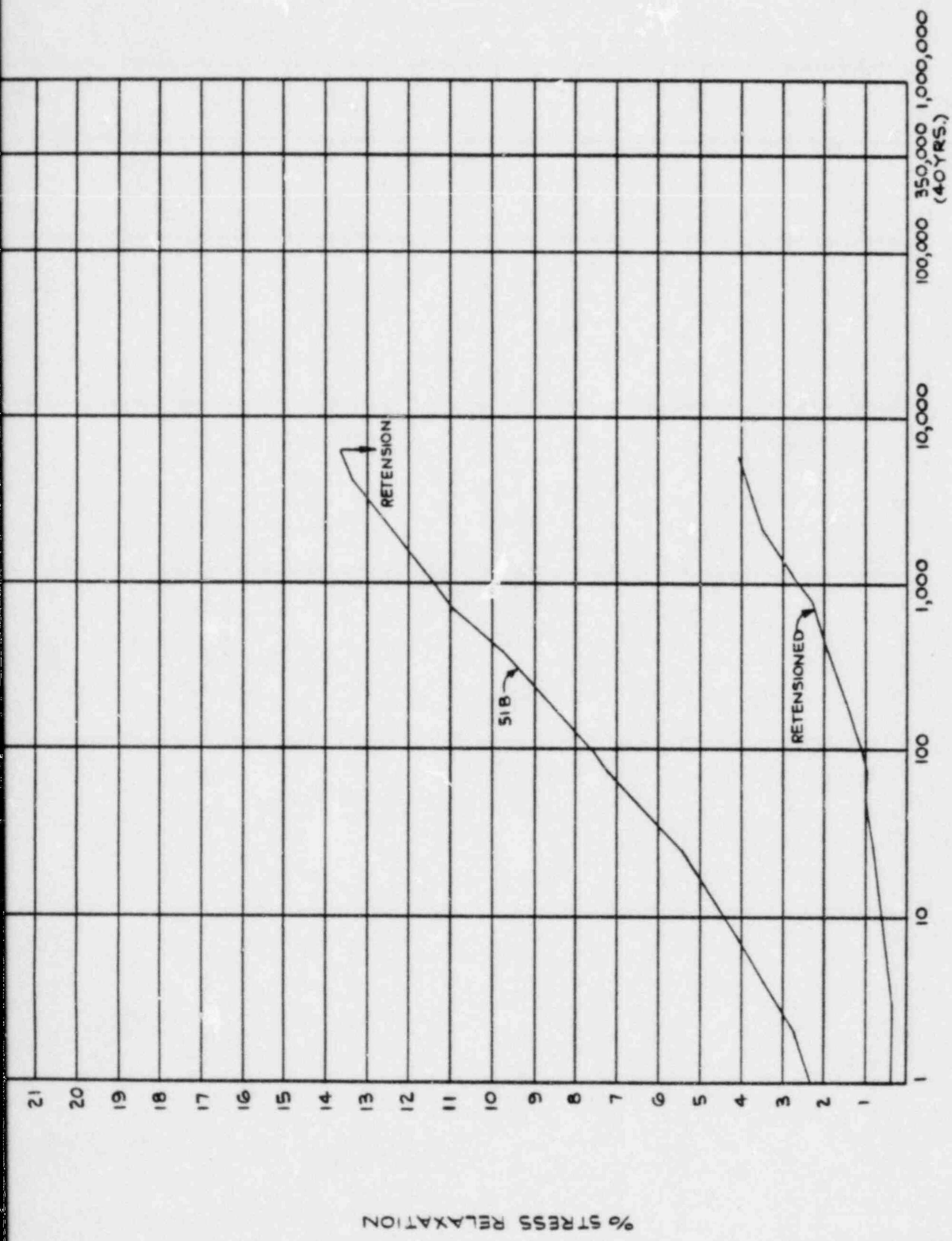


FIGURE 3-5
EFFECT OF RETENSIONING SPECIMEN #3 (TENDON 51)

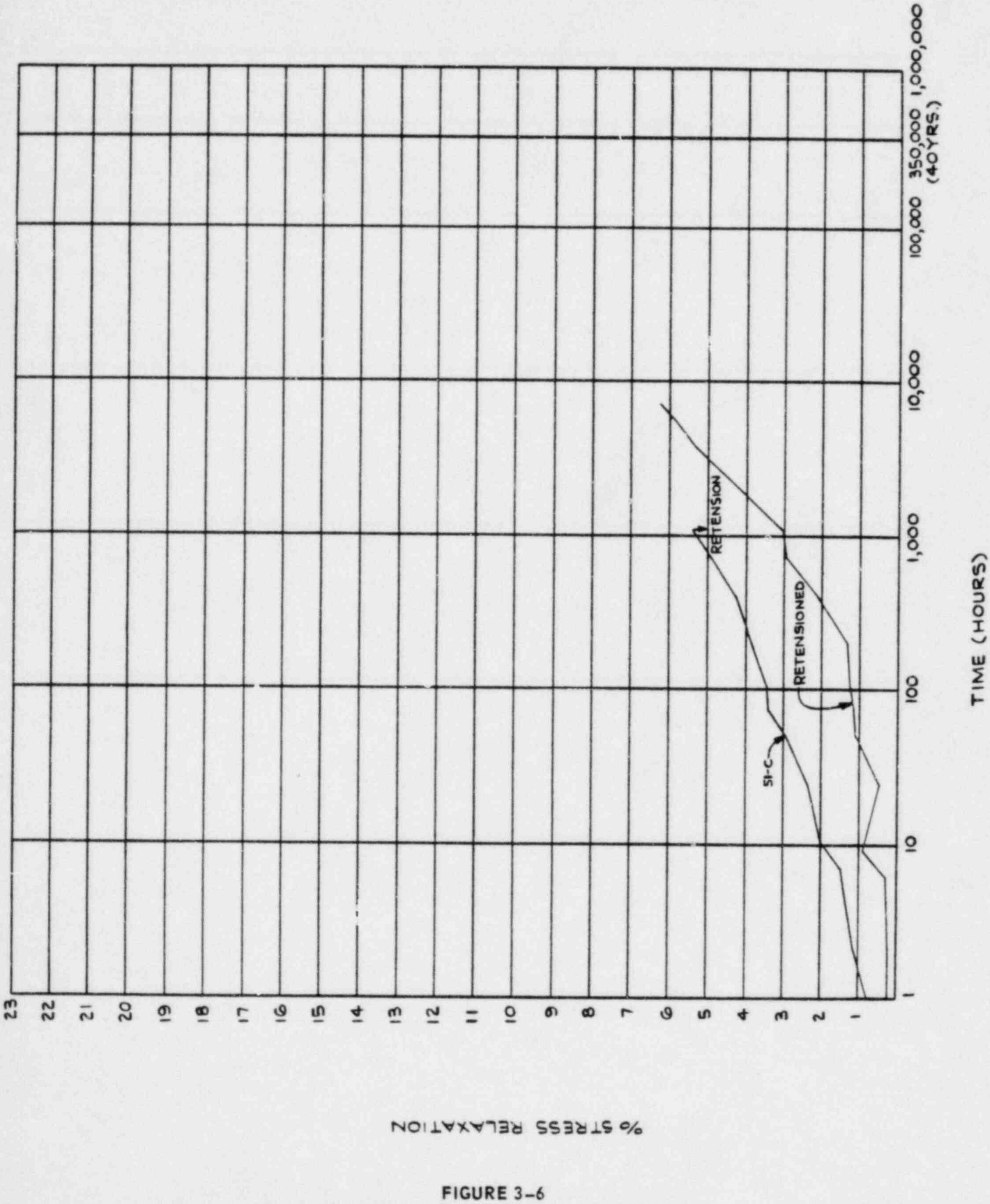


FIGURE 3–6
EFFECT OF RETENSIONING SPECIMEN #4 (TENDON 51)

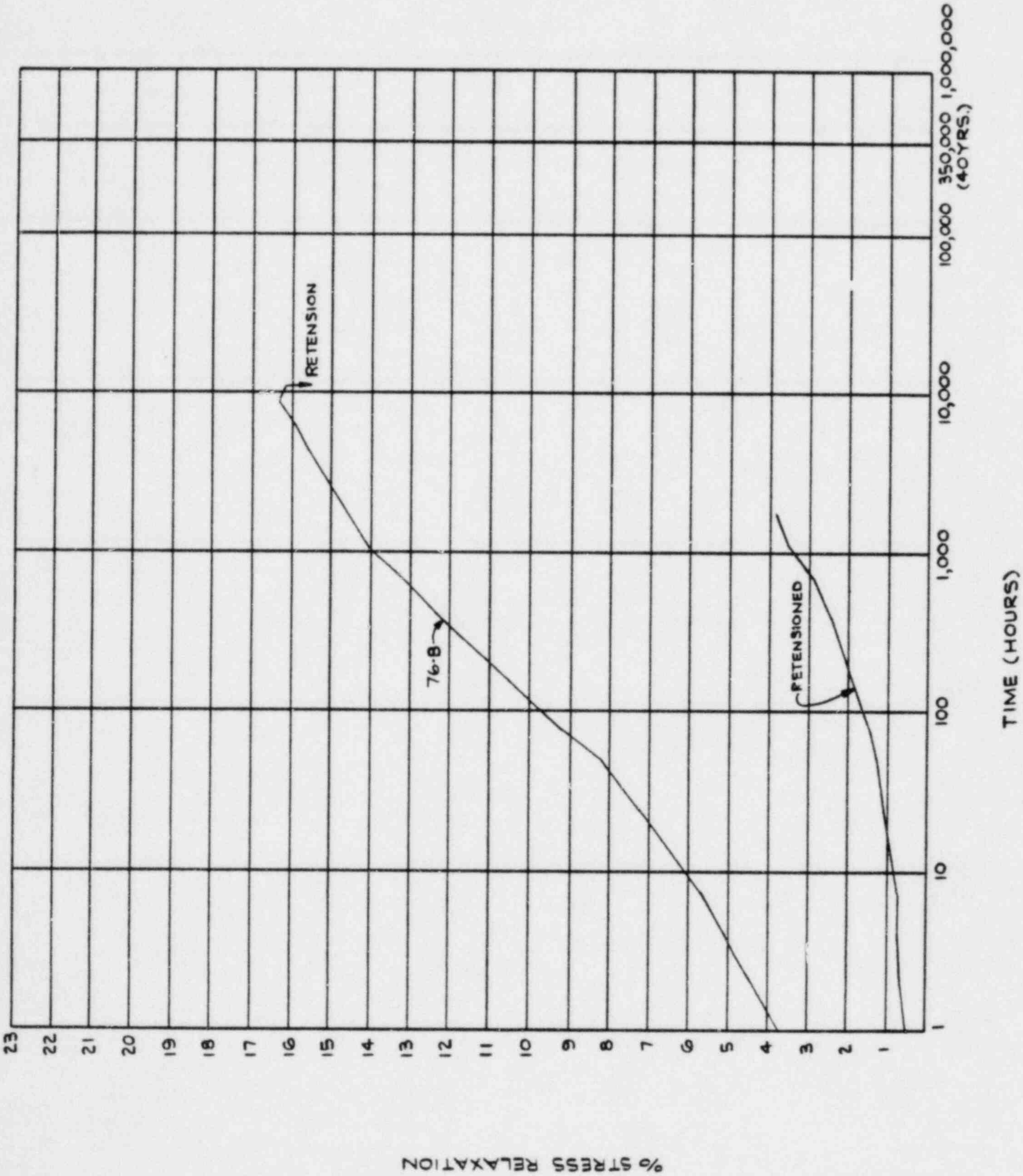


FIGURE 3–7
EFFECT OF RETENSIONING SPECIMEN #8 (TENDON 76)

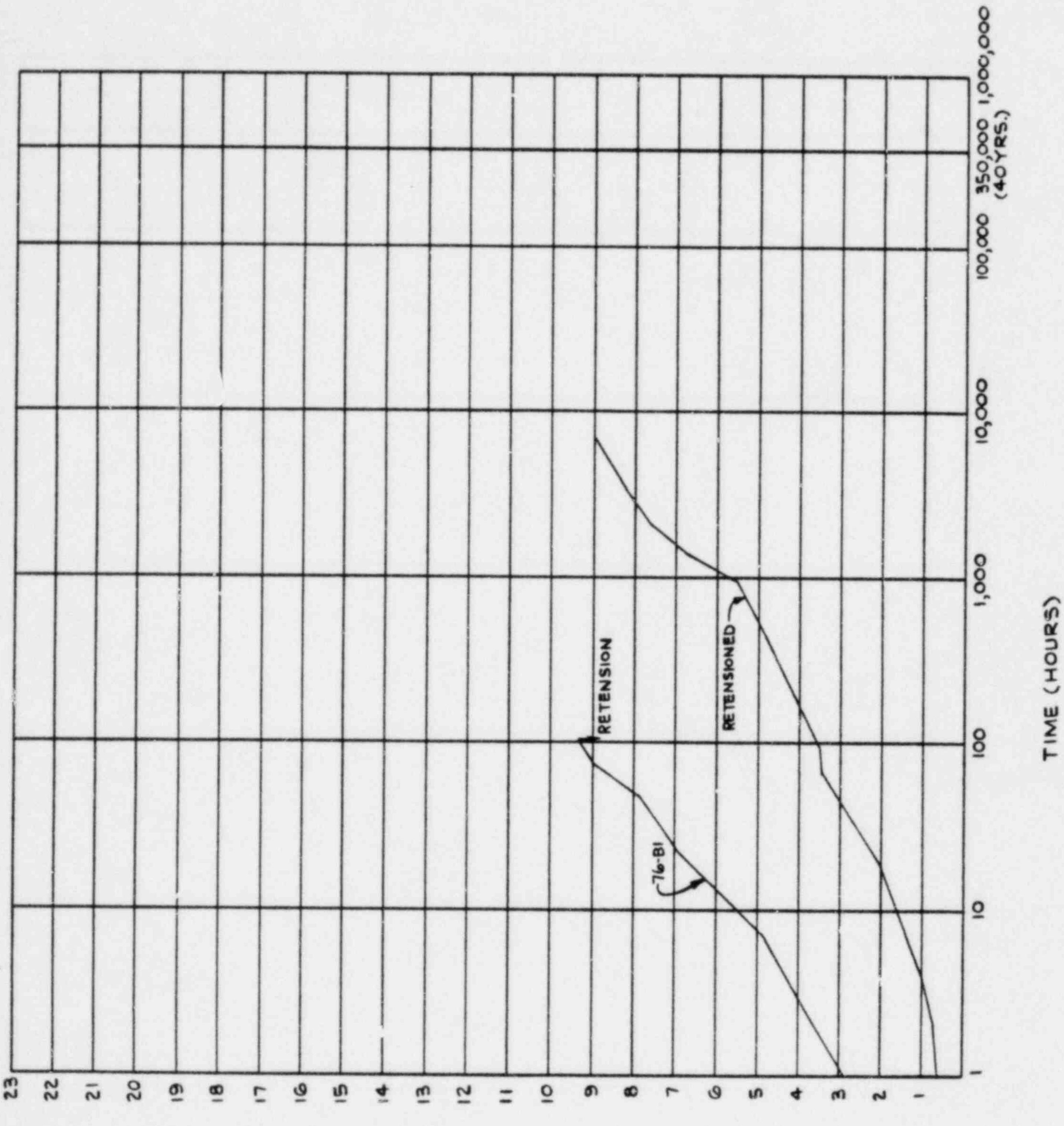


FIGURE 3-8
EFFECT OF RETENSIONING SPECIMEN #9 (TENDON 76)

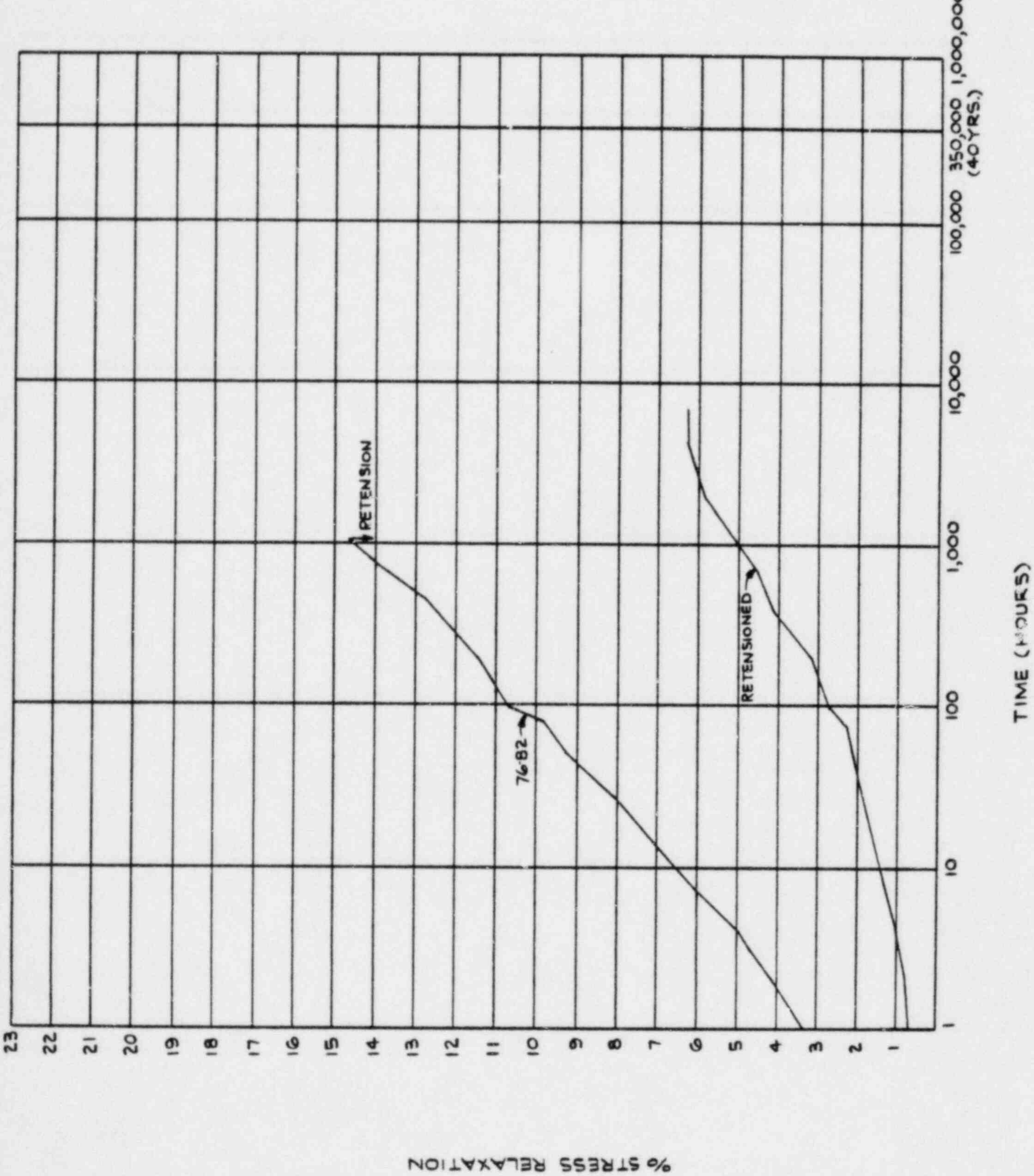


FIGURE 3-9
EFFECT OF RETENSIONING SPECIMEN #10 (TENDON 76)

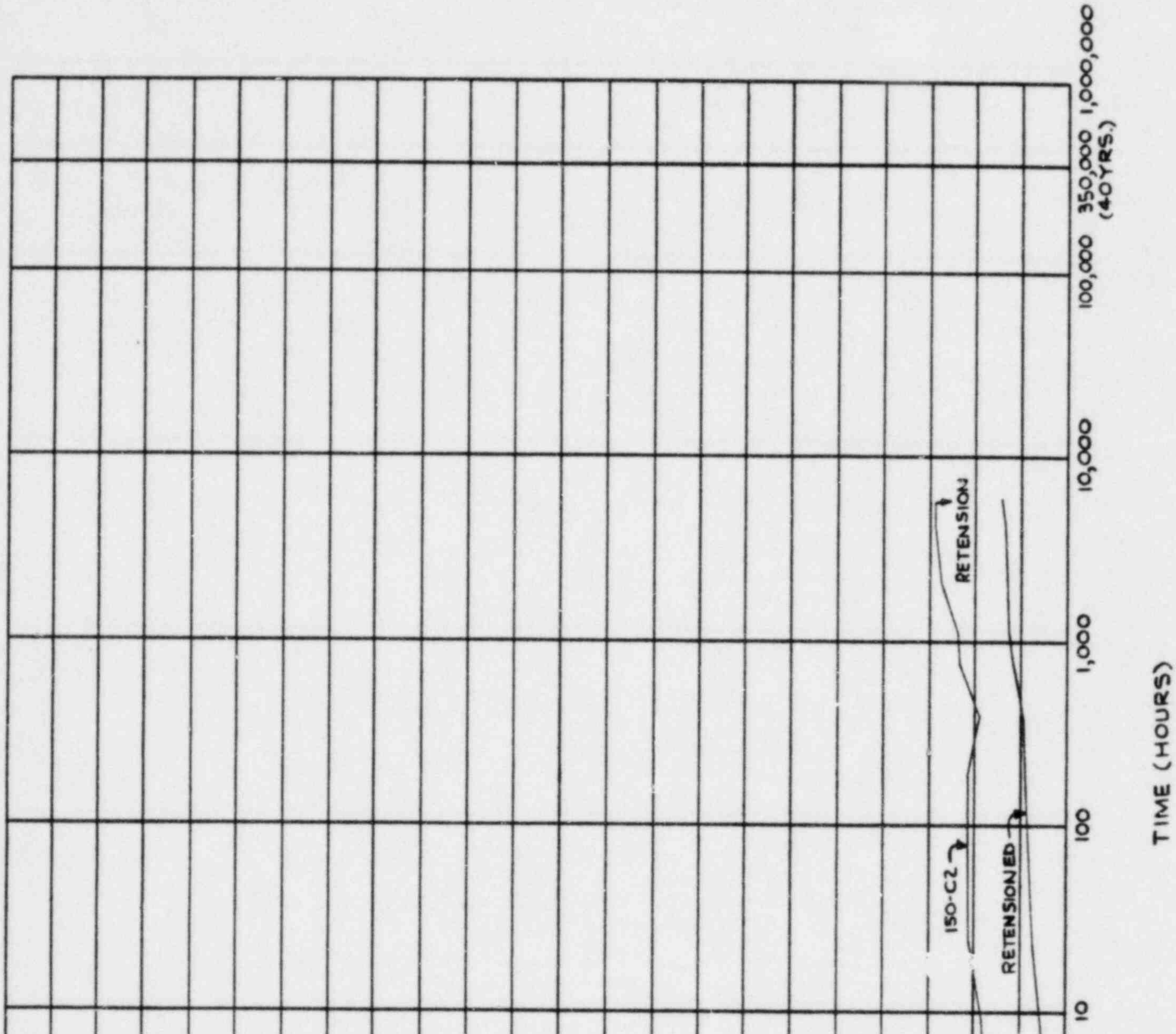


FIGURE 3-10
EFFECT OF RETENSIONING SPECIMEN #12 (TENDON 150)

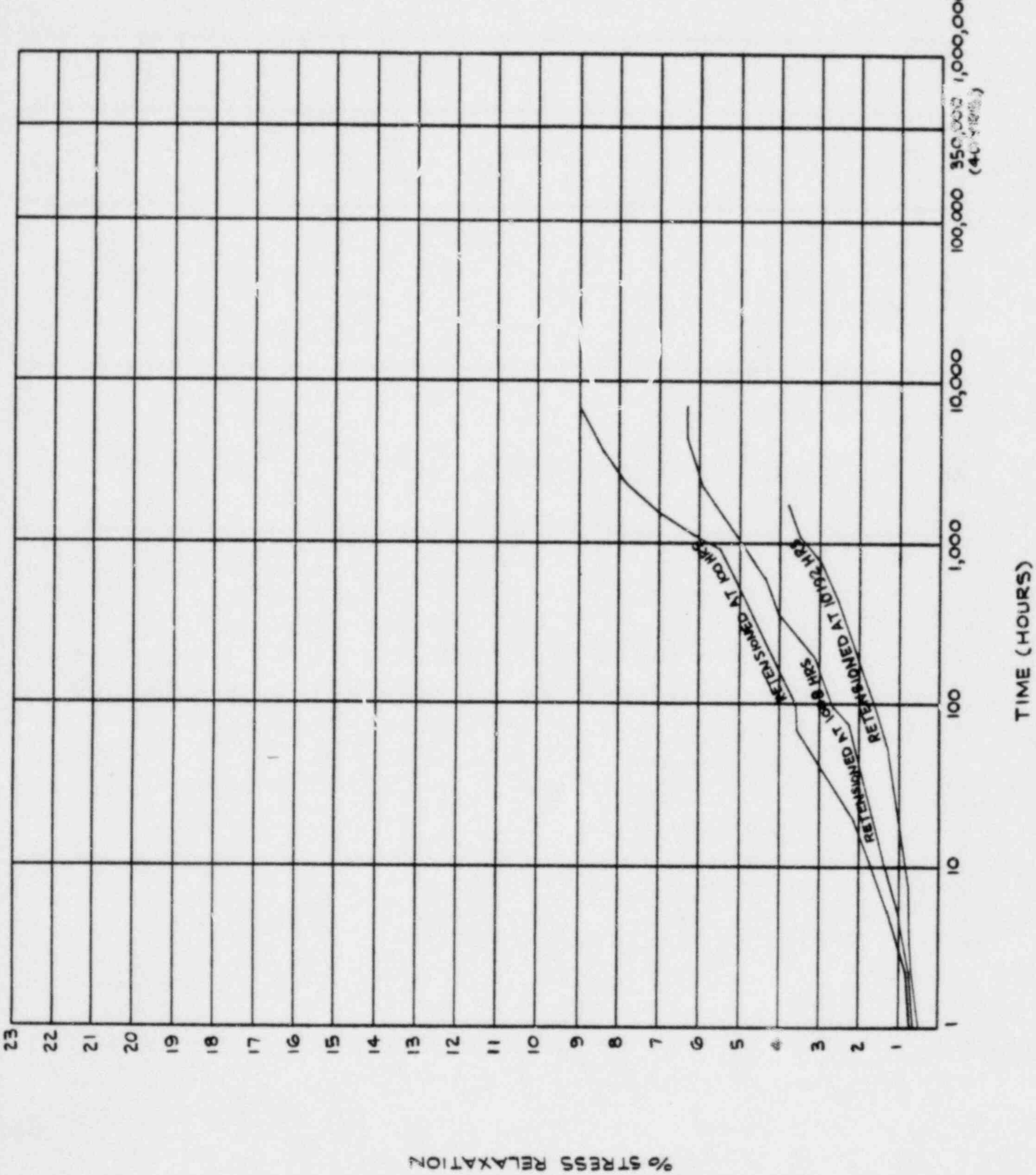


FIGURE 3-11
COMPARISON OF RETENSIONED WIRE SPECIMENS
AT 0.70 GUTS AND 104° F. FROM TENDON 76

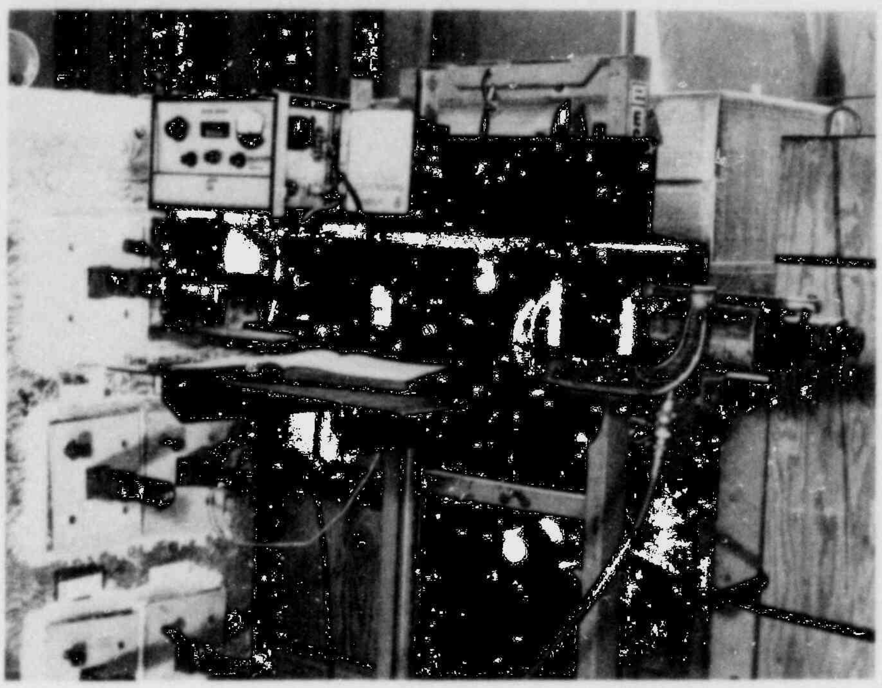


FIGURE 3–12A
EXTERNAL VIEW OF TEST CHAMBER SHOWING BEARING PLATES, CHUCKS, RAM, AND LOAD CELL

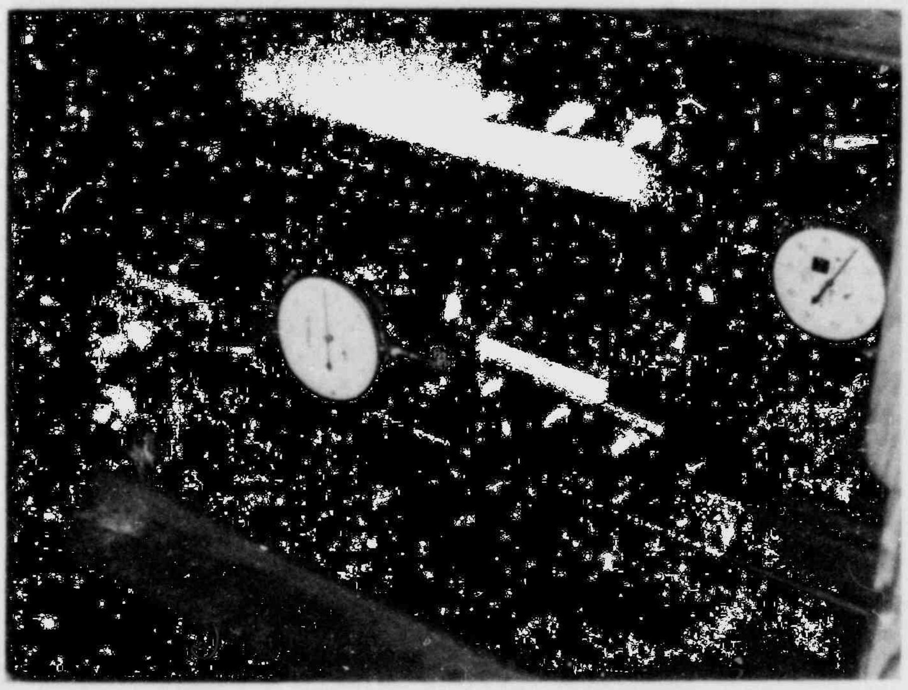


FIGURE 3–12B
INSIDE TEST CHAMBER SHOWING 5 X 3-1/2 ANGLES, DIAL GAGES AND 3/4" SUPPORT RODS (TEST WIRES NOT IN VIEW)

4.0 PREDICTING RETENSIONED TENDON FORCES

4.1 NEED FOR PREDICTIONS

The Ginna containment tendons will be surveyed in the future to determine their force levels. To properly evaluate the data collected by these surveillances, the expected force in each tendon must be known. To determine the value of this force, a prediction technique must be developed and evaluated. The procedure described in Section 2.9.3 for calculating concrete elastic shortening, creep, and shrinkage losses must be modified to obtain values for these losses which occurred subsequent to the May 1969 and June 1980 retensionings. For example, the elastic shortening which the tendons experienced during the June 1980 retensioning is based on their retensioning sequence and the incremental stress produced in the wall in retensioning from an average tendon force of 607 kips to 760 kips (see Table 1 in Appendix A). Also, the specific creep curve developed in Section 2.9.3 can be used recognizing that the superposition of concrete creep strains under incremental stress is fairly well established for elastic concrete stress levels, which exist in the containment wall. However, little information exists concerning the effects of restressing on wire stress relaxation. The Lehigh data presented in Figures 3-5 through 3-10 show graphically that the retensioned wire relaxation is significantly different from its unretensioned relaxation. Therefore, the major emphasis of this section is the prediction of stress relaxation in retensioned wire. To this end, two prediction techniques are considered: the "Factor Method" and the "Superposition Method".

The Factor Method relies on extrapolated data from the Lehigh tests for both the original and restressed wires to develop a response curve which will be used for prediction. The Superposition Method uses the unretensioned relaxation curve to predict retensioned wire relaxations and assumes that stress relaxation obeys superposition principles. Both methods are explained in the following sections and conclusions are presented concerning their applicability.

4.2 FACTOR METHOD

The Lehigh retensioning tests were designed to generate the empirical data for this approach. Three wires from one tendon (76) were retensioned at 100, 1,000 and 10,000 hours to establish a prediction curve. Figure 4-1 is a composite idealization of these three stress relaxation curves and the prediction curve generated from the empirical data. These four idealizations will be used to explain the basic development of the Factor Method of predicting retensioned stress relaxation values.

Figures 4-1a, 4-1b and 4-1c are idealized stress relaxation curves for wires retensioned at 10,000, 1000, and 100 hours. Both the original and the retensioned curves are shown with their extrapolations to some future surveillance time (ST). It is at this surveillance time that the stress relaxation information is needed. For each curve the stress relaxation values are determined at the surveillance time; these are the points A through F. Because each original curve is the plot of data from wire specimens at the same test conditions, the following equations should exist:

$$A = C = E$$

The points B, D and F are on the retensioned wire curve at the surveillance time. Each of these values is divided by A to obtain the ratio of retensioned stress relaxation to original tensioning stress relaxation for different retensioning times. These three ratios are plotted as shown in Figure 4-1d and extrapolated to the surveillance time (ST). The value of this ratio (X) at the surveillance time is determined from the extrapolated plot. X represents the factor that the original stress relaxation value at the surveillance time (ST) would be multiplied by to obtain the retensioned stress relaxation value at the surveillance time (ST).

The implementation of this procedure is dependent on the data collected in the Lehigh testing program. The duration of each retensioned data set must be sufficiently long to permit extrapolation out to as far as 30 years. At the writing of this report the Lehigh retensioning tests were not complete; therefore, this method has not been used to make any predictions in this report.

4.3 SUPERPOSITION OF RELAXATION METHOD

The following technique assumes that changes in stress relaxation due to changes in load can be superimposed. It was developed as a prediction tool for the July 1981 surveillance. It uses only the unretensioned wire relaxation curve to obtain the prediction. Figure 4-2 shows a typical stress relaxation curve plotted on a semi-log scale. It is assumed that at a time equal to t_r the tendon is retensioned. The original value of tendon force was P, but has decreased to P_o at time t_r. The new or retensioned tendon force is P_r, where P_r may not be equal to P. The tendon force must be predicted at some later time increment, Δt_s, beyond the retensioning, or at total time $t_r + \Delta t_s$. Under these conditions the new tendon force can be predicted by considering the relaxation in two parts:

1. The incremental relaxation the tendon would have experienced from tr to tr + Δt_s if not retensioned, and

2. The relaxation caused by the increase in force from P_o to P_r.

Using Figure 4-2, the relaxation at t_r is SR (t_r) and at $t_r + \Delta t_s$ is SR ($t_r + \Delta t_s$). Therefore, part 1, the incremental relaxation the tendon would have continued to experience without retensioning, is $SR\ (t_r + \Delta t_s) - SR\ (t_r)$. The second part of the relaxation is equal to $SR\ (\Delta t_s)$ at time Δt_s, measured from the origin. With these relaxation values, the tendon force loss due to tendon relaxation can be calculated as follows:

Loss 1: $P \times \left[SR\ (t_r + \Delta t_s) - SR\ (t_r) \right] /100$

Loss 2: $\left[P_r - P_o \right] \times SR\ (\Delta t_s)/100$

Thus, the total force loss is:

$$\Delta P = \text{Loss 1} + \text{Loss 2}$$

$$\Delta P = P \times \left[SR\ (t_r + \Delta t_s) - SR\ (t_r) \right] /100 + \left[P_r - P_o \right] \times SR\ (\Delta t_s)/100$$

The stress relaxation percentage based on the retensioned force value is:

$$SR_R\ (t_r + \Delta t_s) = \frac{\Delta P}{P_r} \times 100$$

If other losses are being considered, this stress relaxation force loss would be added to determine the total force loss for the system.

For the Lehigh test results, only steel stress relaxation is being considered; therefore, some simplification can be made to the above procedure. The original tensioning force and the retensioned force are identical; thus,

$$P_r = P.$$

Because only stress relaxation is present, the force just before retensioning, P_o, is

$$P_o = \frac{\left[100 - SR\ (t_r) \right]}{100} \times P$$

The two components of the stress relaxation loss are:

Loss 1: $P \times [SR\ (t_r + \Delta t_s) - SR\ (t_r)]/100$

Loss 2: $\left[P - P \times \frac{100 - SR\ (t_r)}{100}\right] \times SR\ (\Delta t_s)/100$

with the total loss equal to:

$$\Delta P = P\left\{[SR\ (t_r + \Delta t_s) - SR\ (t_r)]/100 + \left[1 - \frac{100 - SR\ (t_r)}{100}\right] \times SR\ (\Delta t_s)/100\right\}$$

The percent loss, or in this case the percent retensioned stress relaxation, is:

$$SR_R\ (t_r + \Delta t_s) = \frac{\Delta P}{P} \times 100 = SR\ (t_r + \Delta t_s) - SR\ (t_r) + \left\{1 - [100 - SR\ (t_r)]/100\right\} \times SR\ (\Delta t_s)$$

or:

$$SR_R\ (t_r + \Delta t_s) = SR\ (t_r + \Delta t_s) - SR\ (t_r) + SR\ (t_r) \times SR\ (\Delta t_s)/100$$

and finally, the retensioned stress relaxation at time increment Δt_s after retensioning at time t_r is:

$$SR_R\ (t_r + \Delta t_s) = SR\ (t_r + \Delta t_s) + SR\ (t_r)[SR\ (\Delta t_s)/100 - 1]$$

This prediction equation was used to predict the retensioned relaxation data from the Lehigh tests. The comparisons are shown in Figures 4-3 through 4-8.

4.4 CONCLUSIONS

1. The Factor Method offers promise as an empirical approach for determining long term stress relaxation in retensioned wires and tendons. However, retensioned wire stress relaxation data extending out to 10,000 hours is required in order to implement this method.

2. The Superposition Method was used to predict the stress relaxation curves for the six (6) retensioned wires (3, 4, 8, 9, 10 and 12) from the Lehigh tests. Figures 4-3 to 4-8 show the Lehigh data and the predicted curve. It is obvious that the Superposition Method under-predicts stress relaxation after 100 hours from retensioning. In general, the prediction error increases with time. Table 4-1 contains the prediction errors at the first three (3) decades and at 5000 hours (approximate end of data). These data are plotted in Figure 4-9. If a straight line is drawn through the average errors for each wire, a linear trend to the data can be seen. This linear approximation estimates that at the July 1981 surveillance the stress relaxation was under predicted by 1.9%, which is consistent with the results shown in Section 5.0 for the 14 tendons retensioned in June 1980 and surveyed in July 1981.

3. Even with the under-prediction of retension wire stress relaxation, the Superposition Method is much more realistic than using the unretensioned curve without adjustment. This can be seen from a comparison of the results in Figures 3-5 to 3-10 with those in Figures 4-3 to 4-8.

TABLE 4-1

RETENSIONED % STRESS RELAXATION
PREDICTION BY SUPERPOSITION

ΔSR (%) = Measured SR - Predicted SR

Time (hours) After Retensioning	Wire No	3	4	8	9	10	12	Avg
10		0	0.7	0.3	0.8	0.5	0.4	0.45*
100		0	0.9	0	1.6	1.0	0.7	1.00
1000		0.8	2.0	1.1	0.9	1.9	1.1	1.30
5000		1.4	3.4	1.5**	1.7	1.9	1.2	1.78

* Absolute value average
**Extrapolated; last recorded valve at 1656

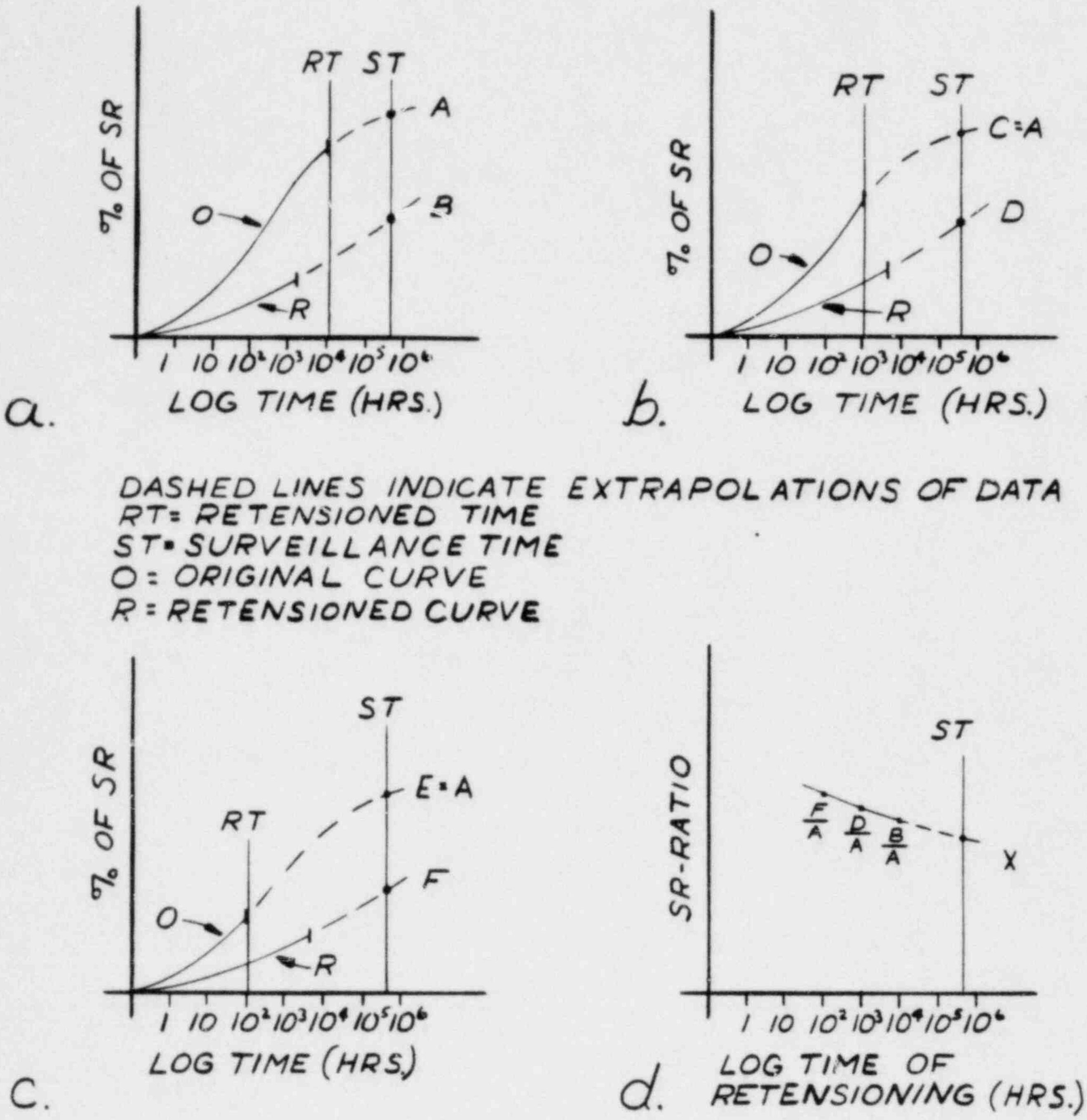


FIGURE 4-1
FACTOR METHOD

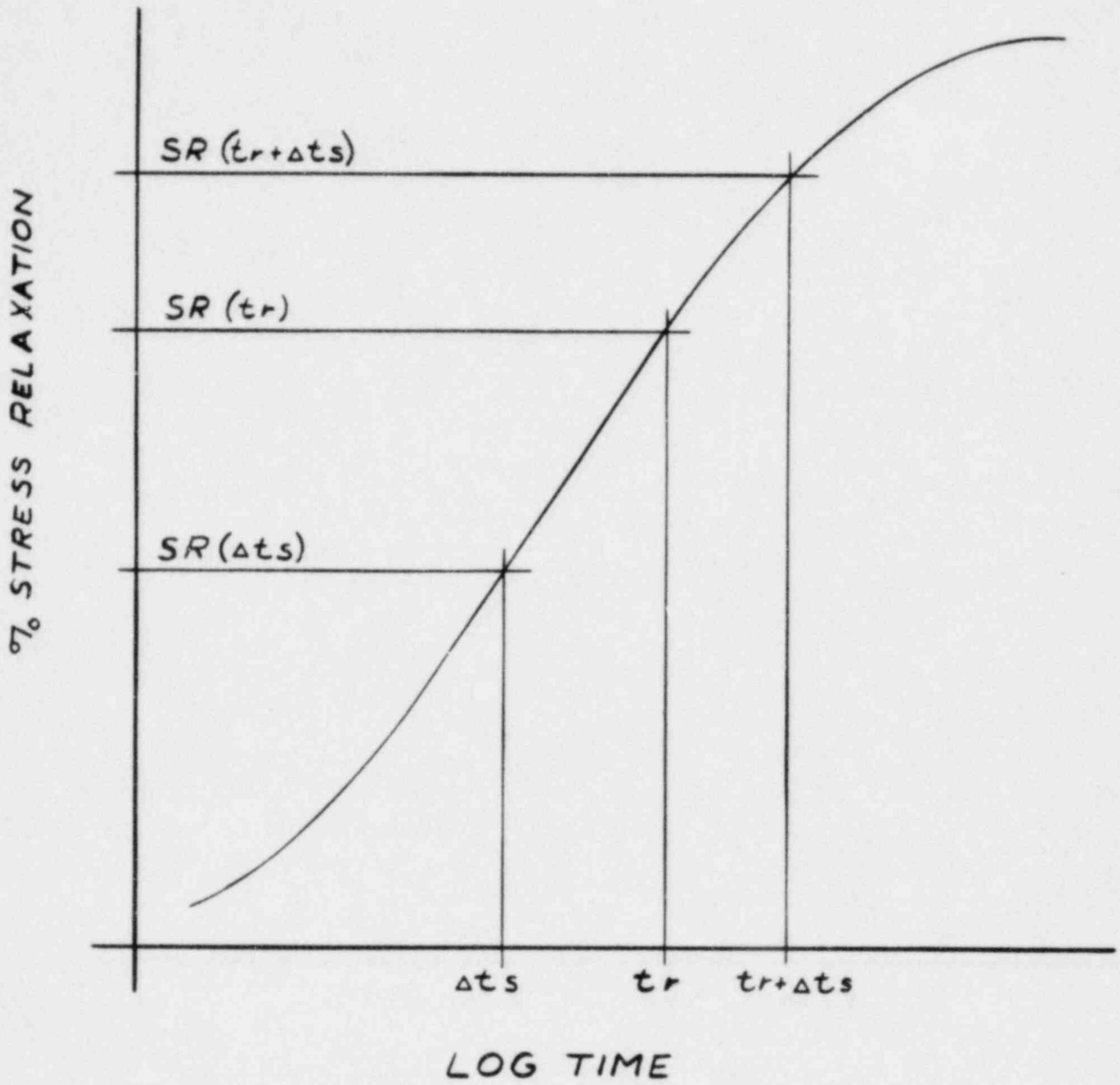


FIGURE 4-2
SUPERPOSITION METHOD

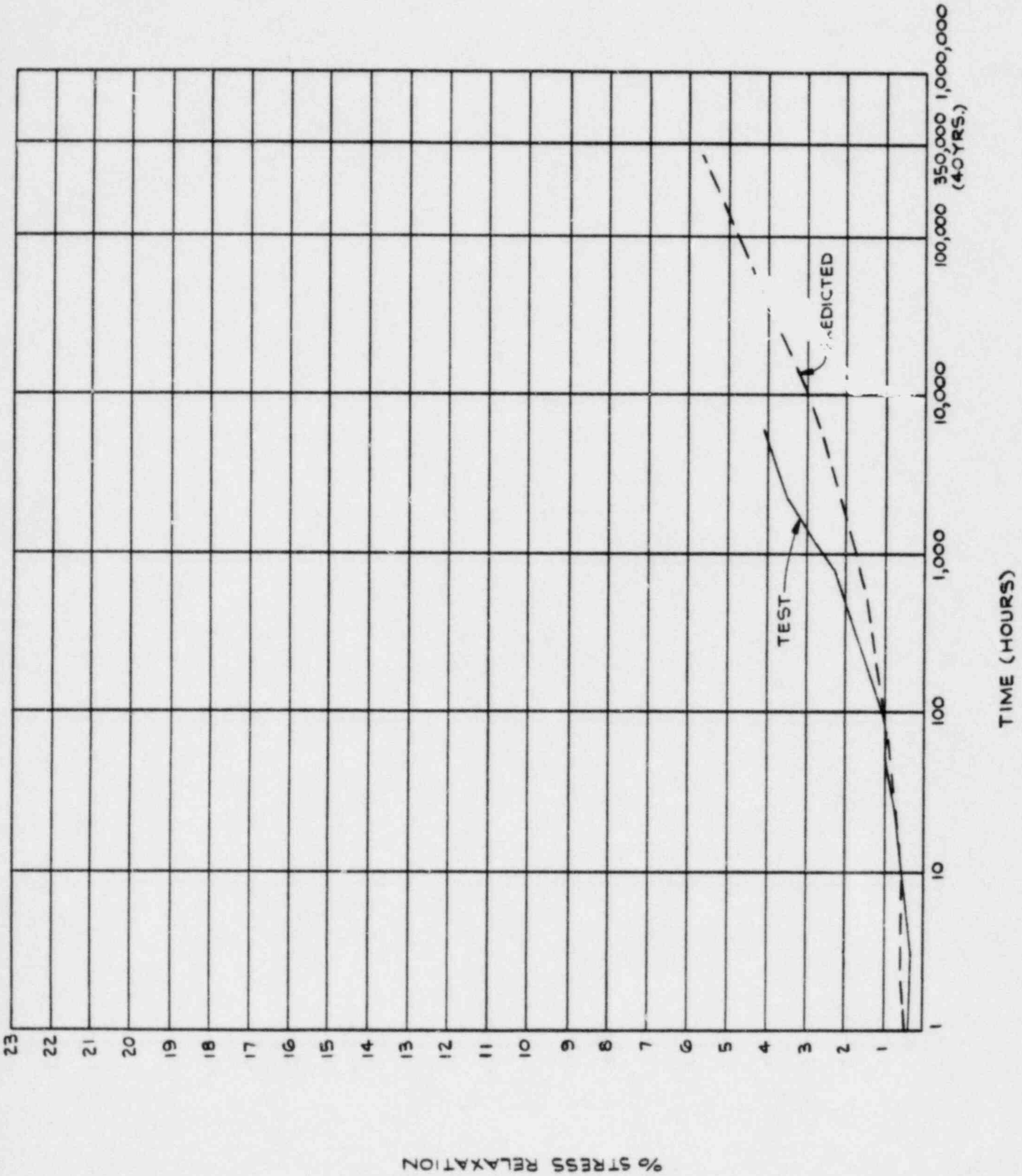


FIGURE 4-3
MEASURED VERSUS PREDICTED RETENSIONED WIRE STRESS RELAXATION,
SPECIMEN #3 (RETENSIONED AT 6000 HOURS)

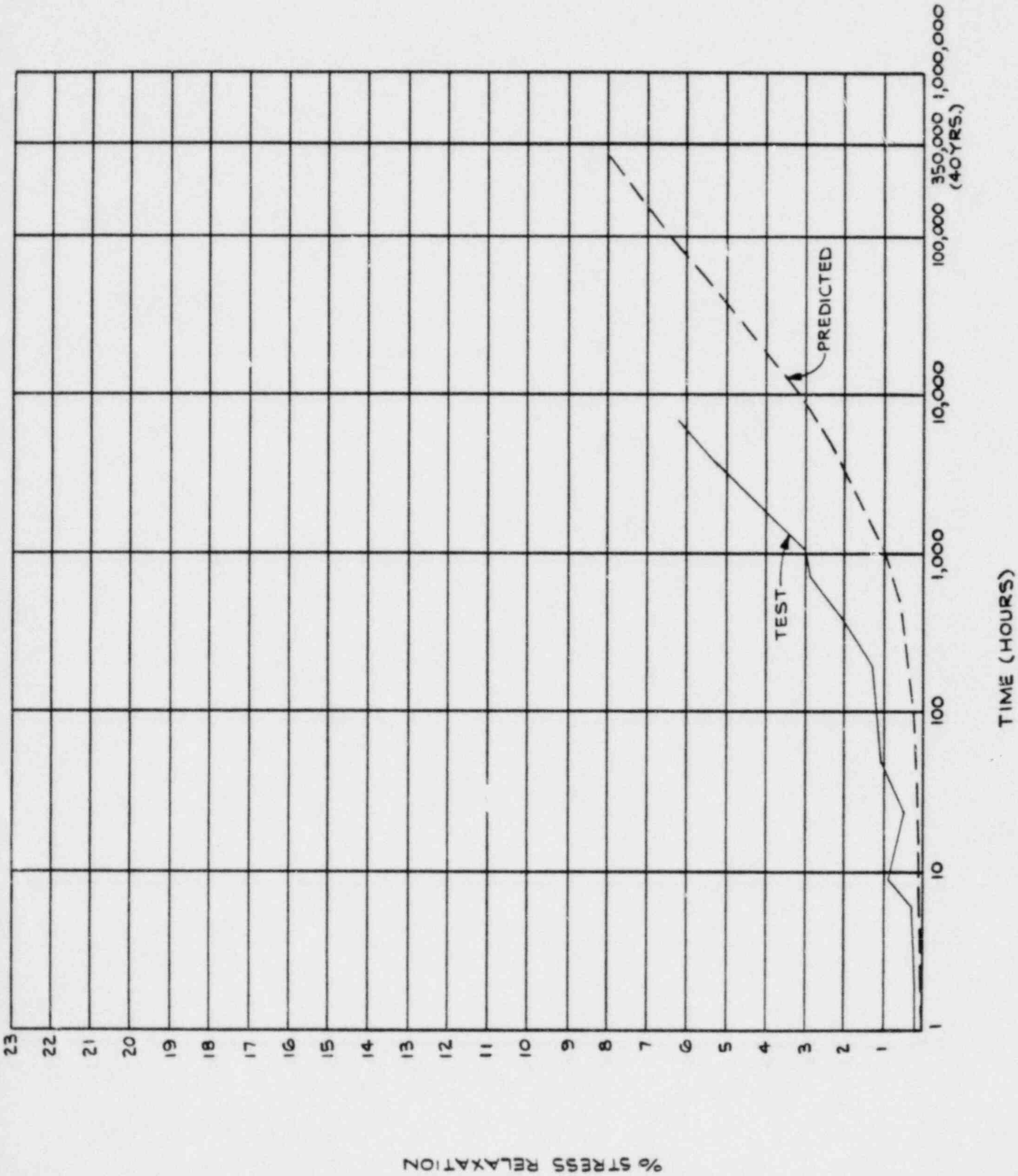


FIGURE 4–4
MEASURED VERSUS PREDICTED RETENSIONED WIRE STRESS RELAXATION,
SPECIMEN #4 (RETENSIONED AT 1000 HOURS)

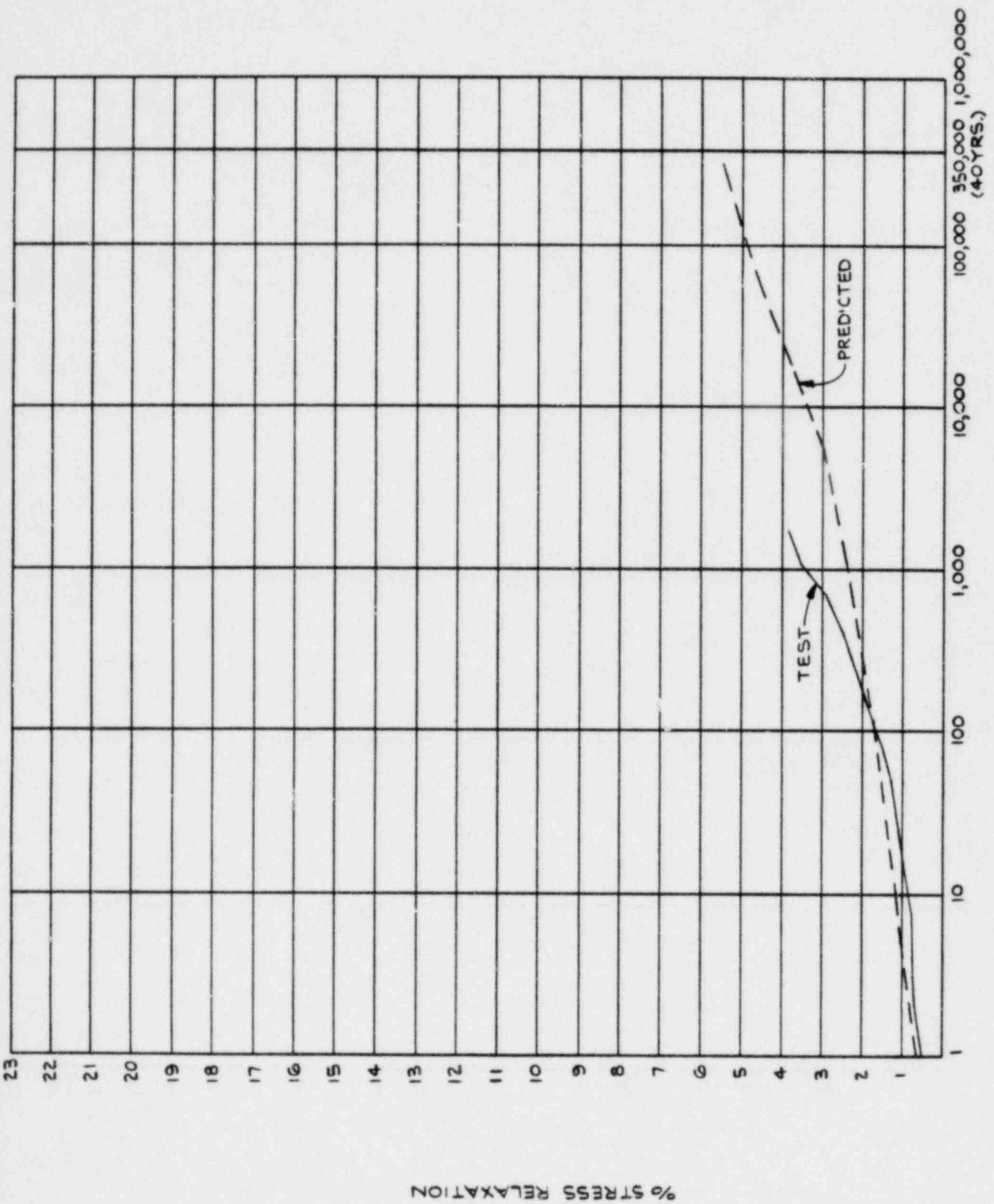


FIGURE 4-5
MEASURED VERSUS PREDICTED RETENSIONED WIRE STRESS RELAXATION,
SPECIMEN #8 (RETENSIONED AT 10,192 HOURS)

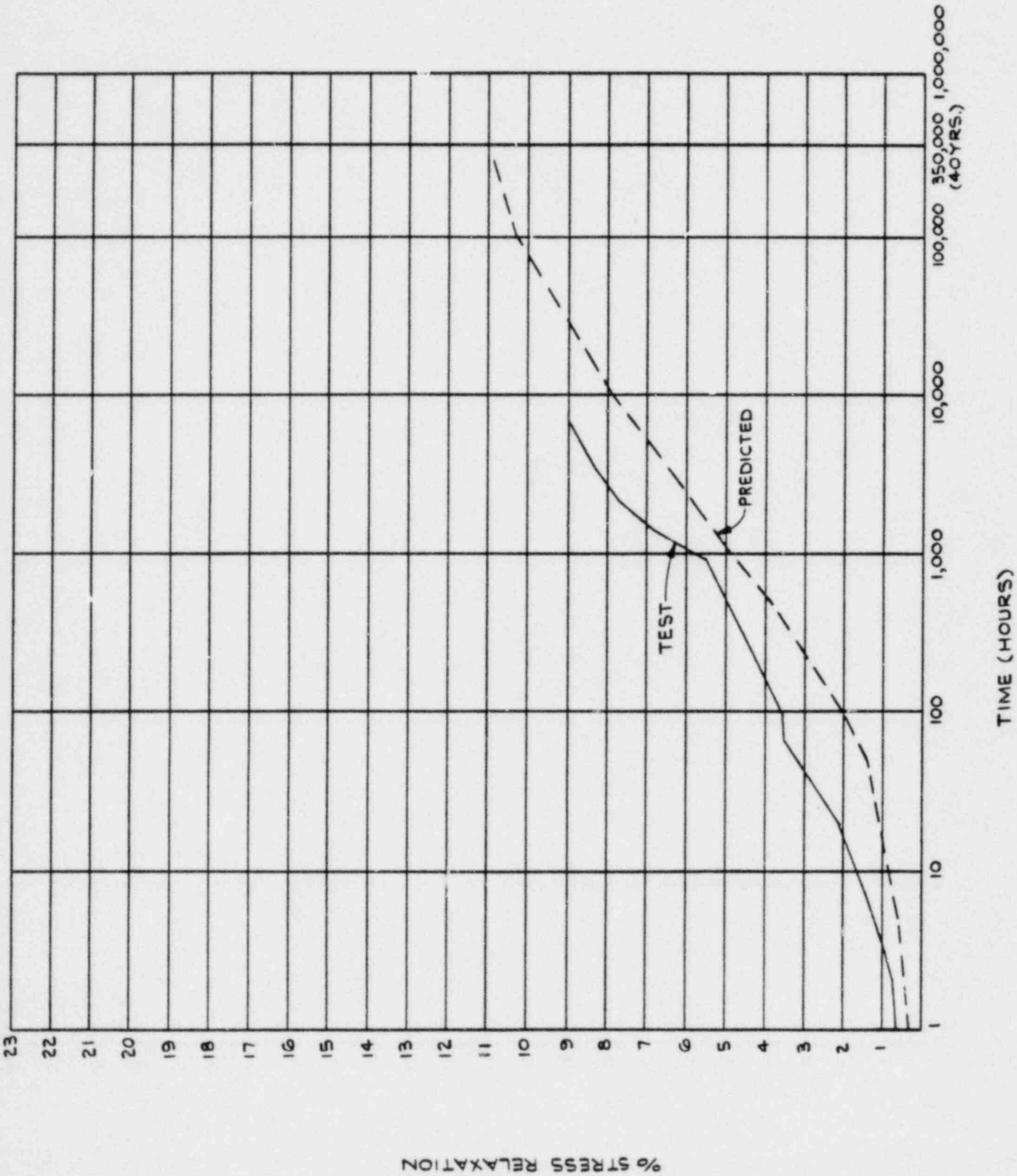


FIGURE 4-6
MEASURED VERSUS PREDICTED RETENSIONED WIRE STRESS RELAXATION,
SPECIMEN #9 (RETENSIONED AT 100 HOURS)

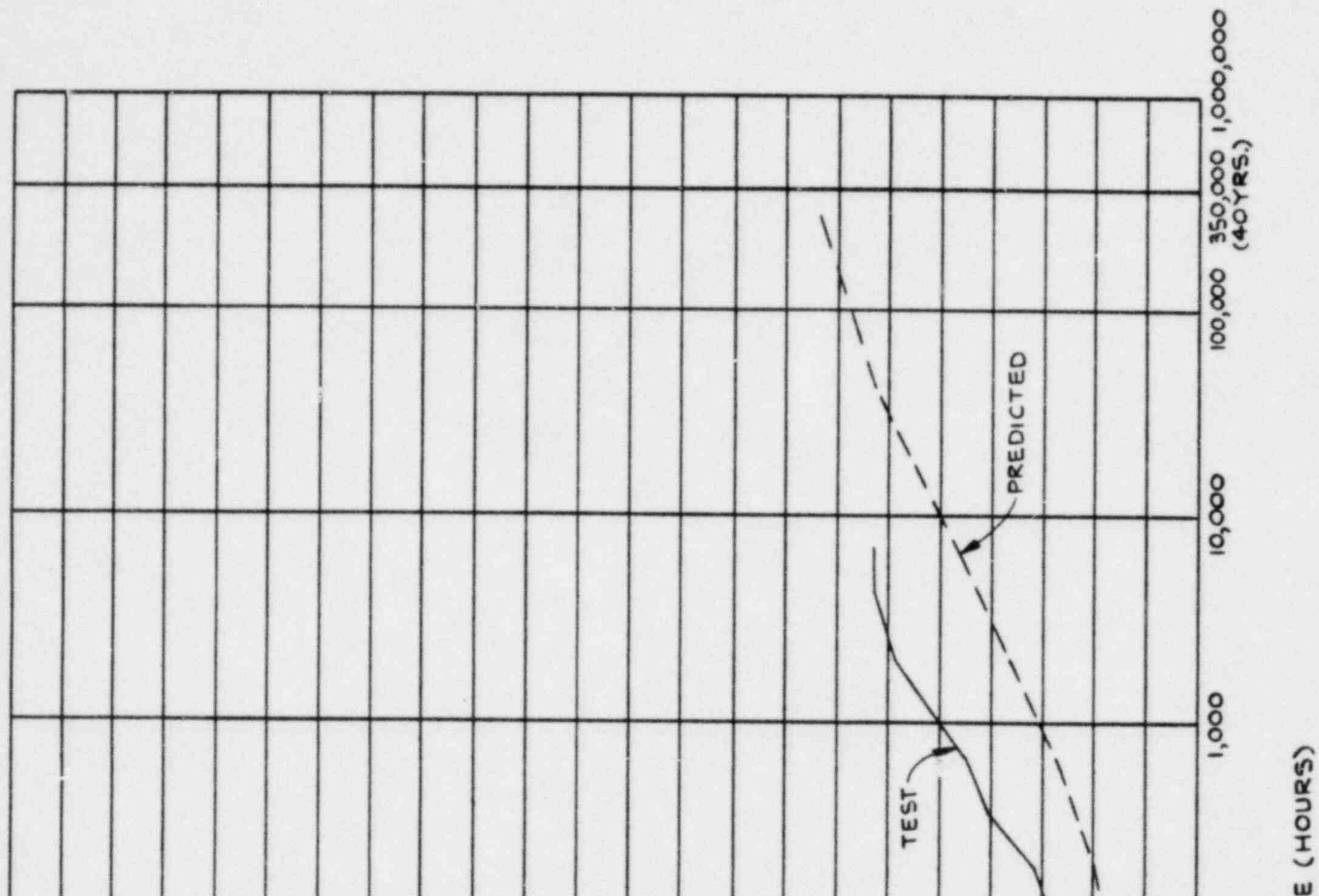


FIGURE 4-7
MEASURED VERSUS PREDICTED RETENSIONED WIRE STRESS RELAXATION, SPECIMEN #10 (RETENSIONED AT 1008 HOURS)

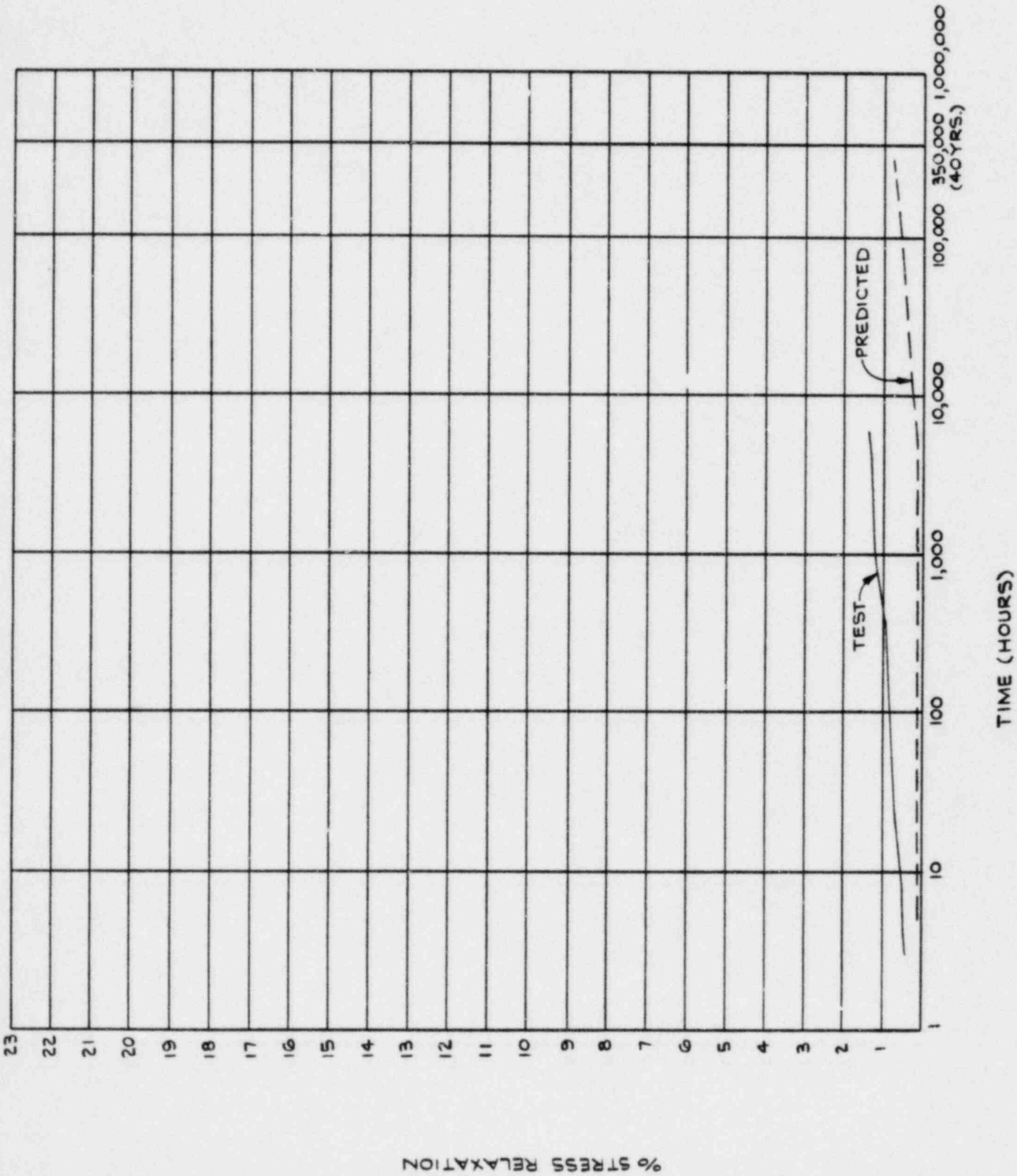


FIGURE 4-8
MEASURED VERSUS PREDICTED RETENSIONED WIRE STRESS RELAXATION, SPECIMEN #12 (RETENSIONED AT 5520 HOURS)

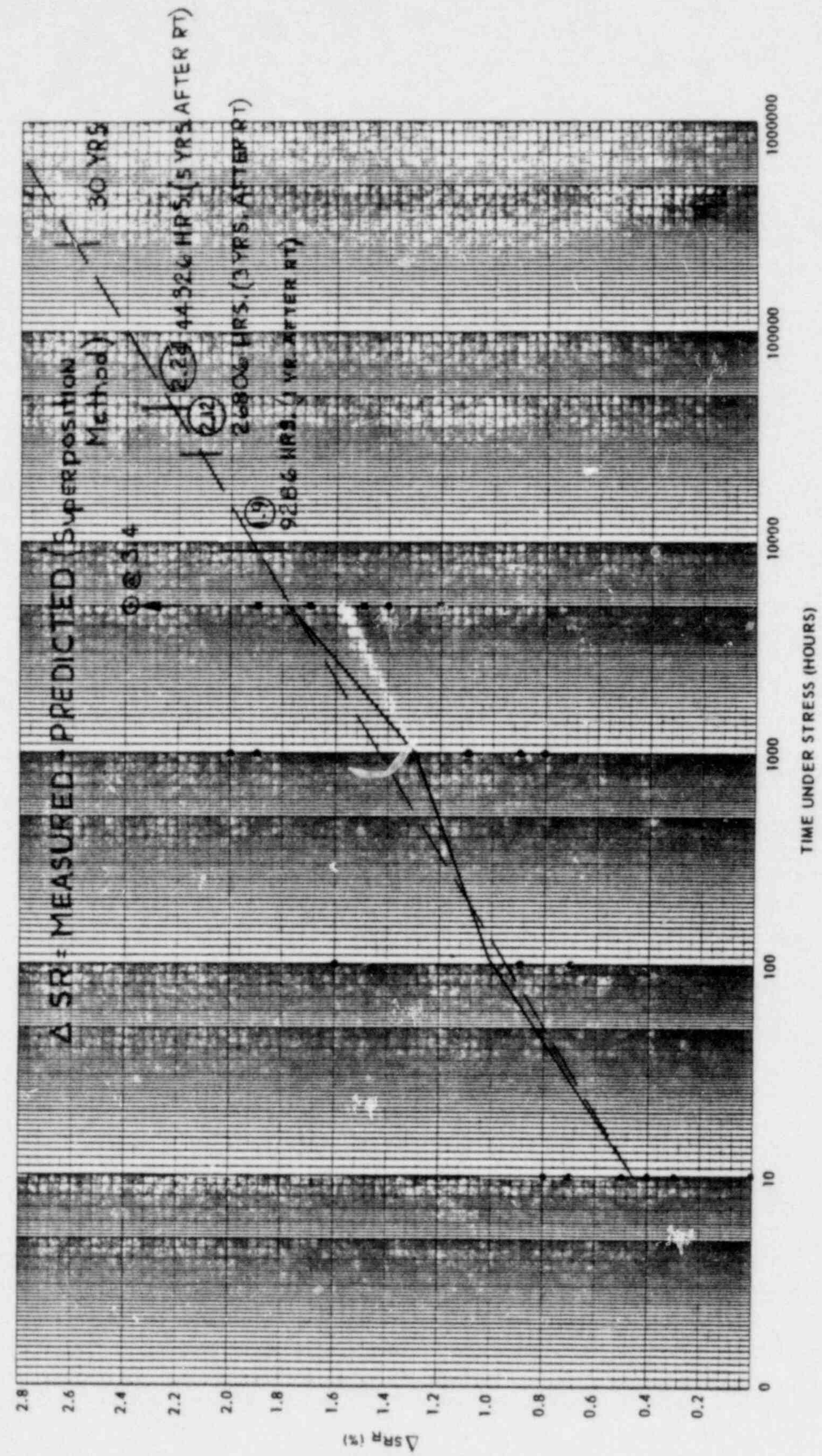


FIGURE 4-9
INCREASE OF PREDICTION ERROR WITH TIME FROM RETENSIONING

5.0 JULY 1981 TENDON SURVEILLANCE

5.1 OBJECTIVES

The July 1981 tendon surveillance program procedure is presented in detail as Appendix C. The program defines the measurement of forces for eighteen (18) tendons including the four (4) tendons with load cells. The data collection system used was designed to confirm the lift-off force data and obtain data needed to continue the investigation into the larger than predicted tendon losses.

The surveillance program was required to verify that the tendon forces are within the limits of the the Ginna Technical Specification and also to provide further information as to why tendons have experienced prestress losses in excess of their predicted values. For the surveillance program to meet these needs, objectives were established which are listed as subparagraphs below for later reference.

5.1.1 To measure lift-off forces in selected tendons and compare with the required design average tendon force of 636 kips appearing in the Ginna Technical Specification.

5.1.2 To compare measured lift-off forces with those predicted to detect abnormal force loss.

5.1.3 To compare the new strain gaged stressing rod force measuring system with the method used on previous surveillances, which used a pressure gauge and the effective ram area of the hydraulic system.

5.1.4 To test the effect of 6% overstressing, a procedure used on previous surveillances.

5.1.5 To verify the accuracy of the feeler shim method of determining lift-off by using the load cells.

5.1.6 To calibrate the loads cells for future monitoring of tendon forces.

5.2 TENDON SELECTION PROCESS

Tendons selected for surveillance were chosen to meet the overall objectives of the surveillance and specifically to:

1. Verify that tendon force losses have stabilized subsequent to the June 1980 retensioning.
2. Survey enough tendons to extend present data base.
3. Include all four tendons with load cells.
4. Include tendons retensioned at 1000 hours after initial stressing.
5. Include tendons from each tendon type category (different shapes).
6. Include two tendons selected by the USNRC.
7. Include two tendons selected at random.

To verify that the tendon force loss has stabilized, tendons 62 and 76 were selected because they experienced large losses during the first eleven (11) years. Tendon 51 was selected as an average loss tendon and tendon 155 as a minimal loss tendon. To extend the data base, tendons 17 and 84 were selected because they each have four (4) recorded data points. Load cells are present under tendons 13, 53, 93 and 133; therefore, these were selected for surveillance. Tendons 133 and 13 were used to evaluate the 6% overstress effect. To include tendons retensioned at 1000 hours, four were selected; two surveyed previously (36 and 111) and two not surveyed (33 and 116). The USNRC suggested that tendons 63 and 74 be included as tendons with larger loss of force. Tendons 21 and 125 were included as ramdomly selected tendons from different quadrants.

Table 5-1 summarizes all of the surveyed tendons and information concerning their selection.

5.3 RESULTS

The July 1981 surveillance was conducted from July 14 to July 22, 1981. USNRC and GAI personnel were present at Ginna during the surveillance, with USNRC personnel leaving on July 16, 1981. The results of this surveillance are presented below using the same order and numbering as the objectives in Section 5.1.

5.3.1 Technical Specification

The tendon force was measured in each of the 18 tendons and compared to the required design average tendon force at 636 kips. Table 5-2 contains the lift-off data collected during the surveillance. All tendons surveyed had lift-off values greater than the required 636 kips, including the four (4) tendons retensioned at 1000 hours. The weighted average of lift-off forces is 714 kips or 12% over the 636 kip requirement. The weighted average takes into account the fact that 23 tendons were not included in the June 1980 retensioning because they had been retensioned in May 1969. As a result, the forces in these tendons would be expected to be lower and not representative of the force in the remaining 137 tendons which were retensioned in June 1980. The weighted average calculation (Table 5-2) corrects for this difference in arriving at the average tendon force. Therefore, 714 kips represents the average tendon force in the containment based on the 18 tendons sampled.

5.3.2 Predicted Forces

To detect abnormal force loss, a method for predicting the retensioned tendon force losses had to be developed. The Lehigh retensioned wire tests were still in progress at the time of the surveillance; therefore, other techniques were used. Three techniques were used to predict tendon forces at the surveillance.

Two methods purposely neglected the retensioning effect on tendon force in order to obtain lower bound curves for the forces. The tendon relaxation values were obtained as if the tendons were stressed for the first time at the retensioning in June 1980. Two predictions were made: one based on the Theoretical 12% wire stress relaxation curve, and the other was based on an effective stress relaxation curve for each tendon. The determination of this effective stress relation is described in Section 2.9.3. The resulting predicted force curves are shown on Figures 5-1 through 5-18 and are labeled:

(1) 12% STEEL W/O RT - Uses 12% steel stress relaxation curve without considering retensioning.

(2) ACTUAL STEEL W/O RT - Uses effective steel stress relaxation curve without considering retensioning.

It should be mentioned that the sharp bends appearing in some of the curves are a result of the spacing selected for the time intervals and a straight line representation of the force - time curve over each interval. This procedure provides a sufficiently accurate representation of the tendon force history.

The third and more accurate prediction technique considered was a relaxation Superposition Method combined with the effective stress relaxation for each tendon. The Superposition Method is discussed in Section 4.3 and the details of the determination of the effective stress relaxation are presented in Section 2.9.3.

The effective stress relaxation for each of the 18 surveillance tendons was determined using its lift-off force measured either at the May 1969 retensioning (33, 36, 111, 116) or in June 1980 (remaining 14 tendons) immediately before retensioning. With this force an effective stress relaxation curve can be developed assuming other prestressing losses (concrete elastic shortening, creep, and shrinkage) are calculated.

The calculation procedure in Section 2.9.3 develops one point on the effective relaxation curve, which was at 1000 hours for tendons 33, 36, 111, and 116 and 97,586 hours for the remaining 14 tendons. Then, the Theoretical 12% wire curve was scaled up or down to match this data point. This means that the calculated effective tendon stress relaxation curve has the same shape as the 12% curve, but its values are scaled an amount which depends on the specific tendon under consideration.

The results of applying relaxation superposition to each effective tendon stress relaxation and predicting the retensioned tendon forces at July 1981 are presented in Table 5-2 along with the measured lift-off values and the ratio of measured to predicted for each tendon. The average value of this ratio is 0.990 with a standard deviation of 0.0413. Table 5-2 shows that for 17 out of 18 tendons, the measured forces were equal to or greater than 95% of their predicted values. The 95% value is the acceptance limit which appears in a draft ASME Code for Inservice Inspection of Concrete Containments.

Figures 5-1 through 5-18 contain the prediction curves for each tendon using this superposition method. The curve is labeled "PREDICTED WITH RT". Also shown is 95% of this prediction curve and it is labeled "95% PREDICTED WITH RT". Each figure also includes all lift-off forces for the tendon obtained at previous surveillances and at the June 1980 retensioning (labeled "RT LIFT-OFF VALUE"). These values are shown as data points. The July 1981 surveillanced lift-off value is shown and labeled as "SURVEILLANCE LIFT-OFF". The figures indicate, in the "PREDICTED

WITH RT" curves, an initial sharp drop in tendon forces which is a result of elastic shortening and first-year stress relaxation losses.

Figures 5-15 through 5-18 detail the 1000 hour retensioned tendons and include only the superposition prediction curve and 95% of it. From these figures, previous surveillance data points are generally close to the prediction curve for tendon 111 (Figure 5-17) and tendon 36 (Figure 5-18). The agreement for the other two tendons is not as good.

Based on the agreement between the measured and predicted tendon forces at the July 1981 surveillance, it is concluded that the tendons are losing force at a normal and predictable rate.

5.3.3 Force Measurement

Pressure Gauge - Ram Calibration

It has been hypothesized that the low tendon forces previously reported may be a result of the measurement system. In other words, that many of the tendon forces were actually higher than the measured values indicated. To evaluate the accuracy of the pressure gauge and effective ram area measurement system (which was used to measure tendon forces on all previous surveillances), the stressing rod was instrumented with strain gages to accurately measure the load on the stressing rod and thus the force being applied to the tendon. The application of the strain gages to the stressing rod and its calibration were performed by Brewer Engineering Laboratory. The strain gaged stressing rod then became the primary load measuring device with the pressure gauge/effective ram area as secondary.

The first step during the July 1981 surveillance was to confirm the effective ram area last used in the October 1979 lift-off tests, which was 127.60 in.^{2} Tendon 53 was chosen because it was a load cell tendon and also because it was the first on the surveillance schedule. Readings of the pressure gauge, stressing rod, and load cell were recorded from 0 to 5500 psi gauge pressure in 500 psi increments. The sequence was repeated, giving two data sets. A linear regression analysis was performed on each set and the data was plotted to verify that each set did form a straight line. The results for the pressure gauge are:

Run 1: Force (kips) = 3.049 + 0.12761 x gauge pressure (psig)
Run 2: Force (kips) = 4.23 + 0.12740 x gauge pressure (psig)

The calibration from Run 1 was arbitrarily selected selected for use in the surveillance since both calibration runs yielded practically the same force. Therefore, the following equation was used to establish the tendon force:

Force (kips) = 3.05 + 0.12761 x gauge pressure (psig)

The coefficient on the gauge pressure is the effective ram area divided by 1000. The last calibration listed its value as 127.6 in.^{2}; thus confirming the last ram area calibration and the present system. The only difference is the 3.05 kip leading constant that was not used in the past. It should be noted that this 3.05 constant only represents 0.5% of the 636 kip tendon force limit and is considered insignificant for these calculations.

The pressure gauge used to measure all pressures was calibrated by RG&E personnel, and it was certified to be reading within its specified accuracy. As a check on the pressure gauge method of determining tendon force, a comparison was made of these forces versus those determined using the strain gaged stressing rod. Both methods were used to determine the tendon force at the 2000 and 4000 psig pressure levels during the July 1981 surveillance.

Two readings were taken at each pressure level: one upon tendon loading and one upon unloading. Thus, for the 18 tendons, a total of 36 data points was available at each pressure level. The results are compared in Tables 5-3 and 5-4.

2000 psig and 4000 psig

In Table 5-3 the force differences at 2000 psig are expressed as a percentage of the stressing rod force. A statistical analysis of this data indicates that the average percent difference is very small at -0.56%. Thus, on the average, the pressure gauge determined force at 2000 psig is just as accurate as that measured by the stressing rod. The differences ranged from -7.55% to 4.32%. If the -7.55% point is discarded, the range becomes -4.33% to 4.32%. Based on the 2.45% standard deviation, σ, which appears in the table, it is generally expected that the pressure gauge would have determined tendon forces which are within ±4.9% of the rod value 95% of the time and within ±7.35% of the rod value 99% of the time. Note that the 95% and 99% values correspond to 2σ and 3σ, respectively.

Referring to Table 5-4 for the results at the 4000 psig pressure level, the conclusions are similar to those for the 2000 psig level. The average percent difference between the pressure gauge determined force and the force measured by the stressing rod is again small at -0.16%; the range is -4.66% to 3.70%, or -3.59% to 3.70% discarding the -4.66% value. Also, 95% of the time it is generally expected that the gauge force to be within ±3.5% of the rod and 99% of the time the value would be within ±5.25%.

Lift-Off

To determine if the hydraulic system (including pump, ram, fluid lines, and pressure gauge) becomes unstable when lift-off occurs, pressure gauge determined forces at lift-off were compared with the forces measured by the strain gaged stressing rod. Table 5-5 presents this comparison along with the force difference expressed as a percentage of the (more accurate) rod force. A statistical analysis of this data indicates that the average percent difference is only 0.15%. Thus, on the average, the pressure gauge determined force is just as accurate as that measured by the strain gaged stressing rod, and the standard deviation is 1.07%. The range on the data was ±2.5%, meaning that the pressure gauge determined force was always within 2.5% of the rod value. Based on the 1.07% standard deviation, it is generally expected that a pressure gauge determined force at lift-off would be within ±2.14% of that determined by the instrumented stressing rod for 95% of the tendons tested and ±3.21% for 99% of the tendons tested.

Conclusions Regarding Force Measurement Accuracy

The results of the above comparisons apply to an accurately calibrated pressure gauge - ram system and strain gaged stressing rod. Since the strain gaged stressing rod provides a more direct measurement of force, it is believed to be inherently more accurate. Based on the results above, the following conclusions can be made:

1. For the full range of pressure levels above 2000 psig, including lift-off, a pressure gauge determined force is as likely to represent an over-measurement of tendon force as it is an under-measurement, within limits. However, the average of all the tendon forces will be very accurate.

2. The accuracy of the pressure gauge determined force, as a function of pressure level, is noted below:

Confidence Level	2000 psig	4000 psig	Lift-off
95% (2σ)	±4.9%	±3.5%	±2.14%
99% (3σ)	±7.4%	±5.3%	±3.12%

3. The accuracy of the tendon force determined by the pressure gauge increases as the gauge pressure increases and is most accurate at lift-off pressures. At lift-off, practically all of the tendons tested (99%) would have pressure gauge determined force accuracies within ±3%. Note that this hold true only if the point of lift-off has been accurately determined (Section 5.3.5).

5.3.4 6% Overstressing

The Ginna FSAR (p. 5.6.2-5) states in its surveillance procedures: "Before re-seating the tendon, the hydraulic jack is used to lift the termination (tendon head) sufficiently to apply an additional stress in the wires equal to that applied during pressurization of the shell (6%), to verify its ability to withstand additional stresses applied during accident conditions." It has been postulated that this 6% overstressing performed on past surveillances may have caused larger than predicted losses in the tendon force. To investigate this hypothesis, two of the load cell tendons (13,133) were selected to be overstressed by 6%. These load cells were reconnected to the data logger and their loads recorded at one (1) hour intervals. The data for both load cells show a constant value at the same value as recorded for lift-off. Thus, the 6% overstressing did not affect the tendon fcrce.

5.3.5 Lift-Off

The exact point of lift-off in previous surveillances had been determined using two different techniques: the acoustical method and the feeler shim method. Surveillances at Ginna up to the October 1979 tests incorporated only the acoustical method; whereas, the October 1979 and June 1980 tests used the feeler shim method. It has been hypothesized that the variability of procedure may have caused lift-off forces to be recorded in error.

The acoustical method called for an operator to tap the shim stack with a hammer until the sound changed. When the sound changed, all compression had been removed from the shim stack, or in other words, lift-off had occurred. The accuracy depends heavily upon the experience and ear of the operator.

During the October 1979 lift-off tests, the feeler shim method was introduced as a more accurate method of determining lift-off. The method requires that the tendon head be lifted off the shim stack until two thin (1/32 inch) feeler shims can be inserted into the skim stack on opposite sides. The tendon head is then set back down on the shims (usually a 1000 psi reduction in the ram pressure gauge reading). Pressure is then increased until both feeler shims can be removed. If there is a large difference in pressure readings between the removal of each shim, the procedure is repeated. This method does not require an experienced operator for accurate and repeatable results. To compare both methods, the October 1979 tests used both to determine lift-off. There was no measurable difference in the two lift-off values when an experienced operator was performing the acoustical procedure.

The July 1981 surveillance procedures call for only the feeler shim method for determining lift-off values. Four of the surveyed tendons are setting on load cells which record the load between the tendon and its bearing plate. As the tendon is lifted off the load cell, the load cell reading decreases to zero.

During the lift-off of each load cell tendon, the load cell was monitored. The zero load cell reading was recorded as a lift-off value along with the values recorded for feeler shim removal. There was excellent agreement between load cell and feeler shim removal methods. This load cell data confirms the accuracy of the feeler shim method.

5.3.6 Load Cell Calibration

To continue the monitoring system using the load cells required that their calibration be confirmed during the surveillance. In fact, two load cells (93 and 133) were re-installed just prior to the surveillance and needed to be calibrated subsequent to being repaired. The load cell calibration procedure is described in Appendix D. The procedures outlined assume that the strain gaged stressing rod is used with the Vishay bridge balance unit.

The procedures were followed during the surveillance for all four load cells. Table 5-6 presents this data as of July 22, 1981 and shows all load cells were accurate and functioning at the conclusion of the surveillance.

5.4 CONCLUSIONS

1. Each of the 18 surveillance tendons in July 1981 had a lift-off force which exceeded the 636 kip minimum requirement contained in the Ginna Technical Specification. The weighted average lift-off force of all 18 tendons is 714 kips, which is 12% over the minimum required force. The weighted average

takes into account the 137 tendons retensioned in June 1980 and the 23 tendons retensioned in May 1969 in arriving at the average force of all 160 tendons in the containment. Therefore, the 714 kips value represents the average tendon force in the containment based on the 11% sample (18/160).

2. The measured tendon forces were within 5% of their predicted values determined using the superposition method described in Section 4.3. This indicated no abnormal loss of force in the tendons since the June 1980 retensioning, or the May 1969 retensioning of tendons 33, 36, 111, and 116.

3. For the 14 tendons in the July 1981 surveillance which were retensioned in June 1980, all of their predicted 30 year forces are above the 636 kip design limit.

4. The tests showed that a calibrated pressure gauge-ram system (and use of feeler shims to determine lift off) is capable of measuring the tendon force at lift-off within ± 3% accuracy. At lower pressure levels, the accuracy of this system decreases somewhat; however, 95% of the tendon forces can still be measured to within ±5% accuracy.

5. Temporarily stressing a tendon 6% over its lift-off force does not accelerate its normal rate of force loss with time.

6. The load cell data confirmed previous zero points and overall accuracy of the load cells. This data also confirmed the accuracy of the feeler shim method of determining lift-off.

TABLE 5-1

TENDON SELECTION FOR JULY 1981 SURVEILLANCE

Tendon Number	Tendon Type	Comments
13	A	Load cell
17	C	Maximum recorded data
21	A	Random from 0 to 40
33	GS	Retensioned at 1000 hours
36	HT	Retensioned at 1000 hours
51	A	Average 11 year loss
53	A	Load cell
62	A	Large 11 year loss
63	A	USNRC specified
74	C	USNRC specified
76	B	Large 11 year loss
84	A	Maximum recorded data
93	A	Load cell
111	A2	Retensioned at 1000 hours
116	FR	Retensioned at 1000 hours
125	B1	Random from 120 to 160
133	A	Load cell
155	A	Small 11 year loss

TABLE 5-2

1981 SURVEILLANCE FORCES COMPARED WITH PREDICTIONS

TENDON NO.	SEQUENCE OF LIFT-OFF	LAST(1) LOCK-OFF (kips)	PREDICTED(2) LIFT-OFF (kips)	MEASURED LIFT-OFF (kips)		RATIO MEAS./PRED.
13	1	761	737	730		0.991
155	2	754	745	738		0.991
17	3	776	760	727		0.957
21	4	765	749	725		0.968
51	5	765	748	710		0.949
53	6	761	742	734		0.989
62	7	773	754	716		0.950
63	8	769	740	722	Ave:	0.976
74	9	749	680	731	722	1.075
76	10	754	729	713		0.978
84	11	753	732	714		0.975
93	12	761	740	713		0.964
125	13	768	755	705		0.934
133	14	757	734	734		1.000
33*	15	770	655	679		1.037
36*	16	763	667	657	Ave:	0.985
111*	17	744	637	646	668	1.014
116*	18	757	634	690		1.088
AVERAGE				714(3)		0.990

NOTES:

(1) In June 1980 except for tendons marked * which were retensioned in May 1969 at 1000 hours. Note: There were 23 tendons which were retensioned in May 1969 out of 160 total tendons.

(2) Predicted by applying the superposition method to the effective stress relaxation of each tendon.

(3) Weighted average (WA) considering the tendons retensioned in May 1969 at 1000 hours.

$$WA = \frac{(722 \text{ kips})(137) + (668 \text{ kips})(23)}{160} = 714 \text{ kips}$$

TABLE 5-3

PRESSURE GAUGE VS STRESSING ROD READING
AT 2000 PSI

GAUGE PRESSURE PSI (1)	LOAD* BY PRESSURE GAUGE kips (2)	LOAD** BY STRESSING ROD kips (3)	DIFFERENCE (2)-(3) kips (4)	% DIFFERENCE (4)/(3) (5)
2000	258.3	250.6	7.7	3.07
2000	258.3	262.0	-3.7	-1.41
2000	258.3	256.2	2.1	0.82
2000	258.3	259.4	-1.1	-0.42
2000	258.3	266.0	-7.7	-2.89
2000	258.3	257.8	0.5	0.19
2000	258.3	258.6	-0.3	-0.12
2000	258.3	256.8	1.5	0.58
2000	258.3	265.4	-7.1	-2.68
2000	258.3	252.2	6.1	2.42
2000	258.3	260.0	-1.7	-0.65
2000	258.3	261.0	-2.7	-1.03
2000	258.3	254.6	3.7	1.45
2000	258.3	264.6	-6.3	-2.38
2000	258.3	269.0	-10.7	-3.98
2000	258.3	279.4	-21.1	-7.55
2000	258.3	253.8	4.5	1.77
2000	258.3	258.2	0.1	0.04
2000	258.3	264.0	-5.7	-2.16
2000	258.3	257.8	0.5	0.19
2000	258.3	260.4	-2.1	-0.81
2000	258.3	267.4	-9.1	-3.40
2000	258.3	253.0	5.3	2.09
2000	258.3	255.4	2.9	1.14
2000	258.3	247.6	10.7	4.32
2000	258.3	258.4	-0.1	-0.04
2000	258.3	251.4	6.9	2.74
2000	258.3	261.0	-2.7	-1.03
2000	258.3	253.4	4.9	1.93
2000	258.3	261.8	-3.5	-1.34
2000	258.3	258.6	-0.3	-0.12
2000	258.3	270.0	-11.7	-4.33
2000	258.3	260.4	-2.1	-0.81
2000	258.3	269.6	-11.3	-4.19
2000	258.3	255.0	3.3	1.29
2000	258.3	265.4	-7.1	-2.68

NOTES:

* Pressure Gauge Load = 3.05 + 0.12761 x Gauge Pres. (psi)
**Stressing Rod Load = 0.20 x Stressing Rod Reading (μ in./in.)

Statistics: N = 36
Average % Diff. = -0.56
Standard Deviation = 2.45
Median = -0.42
Range = -7.55 to 4.32

TABLE 5-4

PRESSURE GAUGE VS STRESSING ROD READING
AT 4000 PSI

GAUGE PRESSURE PSI (1)	LOAD* BY PRESSURE GAUGE kips (2)	LOAD** BY STRESSING ROD kips (3)	DIFFERENCE (2)-(3) kips (4)	% DIFFERENCE (4)/(3) (5)
4000	513.5	514.4	-0.9	-0.17
4000	513.5	514.0	-0.5	-0.10
4000	513.5	498.8	14.7	2.94
4000	513.5	516.2	-2.7	-0.52
4000	513.5	510.0	3.5	0.69
4000	513.5	514.2	-0.7	-0.14
4000	513.5	517.2	-3.7	-0.72
4000	513.5	516.2	-2.7	-0.52
4000	513.5	509.8	3.7	0.73
4000	513.5	521.6	-8.1	-1.55
4000	513.5	532.6	-19.1	-3.59
4000	513.5	526.6	-13.1	-2.49
4000	513.5	511.0	2.5	0.49
4000	513.5	520.6	-7.1	-1.36
4000	513.5	506.2	7.3	1.44
4000	513.5	521.8	-8.3	-1.59
4000	513.5	528.0	-14.5	-2.75
4000	513.5	538.6	-25.1	-4.66
4000	513.5	505.4	8.1	1.60
4000	513.5	518.0	-4.5	0.87
4000	513.5	512.0	1.5	0.29
4000	513.5	515.8	-2.3	-0.45
4000	513.5	514.4	-0.9	-0.17
4000	513.5	524.8	-11.3	-2.15
4000	513.5	508.4	5.1	1.00
4000	513.5	512.2	1.3	0.25
4000	513.5	510.6	2.9	0.57
4000	513.5	521.2	-7.7	-1.48
4000	513.5	512.6	0.9	0.18
4000	513.5	518.8	-5.3	-1.02
4000	513.5	499.0	14.5	2.91
4000	513.5	511.2	2.3	0.45
4000	513.5	495.2	18.3	3.70
4000	513.5	512.4	1.1	0.21
4000	513.5	503.6	9.9	1.97
4000	513.5	517.4	-3.9	-0.75

NOTES:

* Pressure Gauge Load = 3.05 + 0.12761 x Gauge Pres. (psi)

**Stressing Rod Load = 0.20 x Stressing Rod Reading (μ in./in.)

Statistics: N = 36
Average % Diff. = -0.16
Standard Deviation = 1.75
Median = -0.10
Range = -4.66 to 3.70

TABLE 5-5

PRESSURE GAUGE VS STRESSING ROD
AT LIFT-OFF

GAUGE PRESSURE PSI (1)	LOAD* BY PRESSURE GAUGE kips (2)	LOAD** BY STRESSING ROD kips (3)	DIFFERENCE (2)-(3) kips (4)	% DIFFERENCE (4)/(3) (5)
5675	727.2	730.4	-3.2	-0.44
5650	724.0	728.4	-4.4	-0.60
5850	749.6	731.2	18.4	2.52
5750	736.8	743.8	-7.0	-0.94
5875	752.8	745.0	7.8	1.05
5700	730.4	726.0	4.4	0.61
5725	733.6	727.2	6.4	0.88
5650	724.0	724.0	0	0
5675	727.2	725.0	2.2	0.30
5525	708.1	708.4	-0.3	-0.04
5550	711.3	709.2	2.1	0.30
5525	708.1	709.2	-1.1	-0.16
5700	730.4	734.2	-3.8	-0.52
5550	711.3	714.8	-3.5	-0.49
5575	714.5	716.0	-1.5	-0.21
5600	717.7	722.4	-4.7	-0.65
5475	701.7	716.8	-15.1	-2.11
5575	714.5	729.8	-15.3	-2.10
5525	708.1	726.6	-18.5	-2.55
5600	717.1	735.8	-18.7	-2.54
5575	714.5	712.6	1.9	0.27
5575	714.5	713.0	1.5	0.21
5600	717.7	714.0	3.7	0.52
5525	708.1	714.0	-5.9	-0.83
5575	714.5	712.8	1.7	0.24
5500	704.9	700.0	4.9	0.70
5575	714.5	707.6	6.9	0.98
5500	704.9	703.2	1.7	0.24
5575	714.5	709.8	4.7	0.66
5750	736.8	733.6	3.2	0.44
5775	740.0	733.8	6.2	0.84
5725	733.6	733.0	0.6	0.08
5775	740.0	733.8	6.2	0.84
5325	682.6	678.4	4.2	0.62
5350	685.8	680.0	5.8	0.85
5175	663.4	655.8	7.6	1.16
5200	666.6	659.0	7.6	1.15

TABLE 5-5 (Cont'd.)

NOTES:

* Pressure Gauge Force = 3.05 + 0.12761 x Gauge Pres. (psi)
** Stressing Rod Force = 0.20 x Stressing Rod Reading (μ in./in.)

Statistics: N = 42
Average % Diff. = 0.15
Standard Deviation S = 1.07
Median = +0.27
Range = -2.55 to +2.52

TABLE 5-6

LOAD CELL INFORMATION AS OF JULY 22, 1981

Load Cell No.	13	53	93	133
Serial No.	26917	26916	26915	26918
Voltage @ Box				
White - Blue	15.134	15.584	14.950	14.886
White - Green	14.142	14.554	13.922	13.881
Needed	15.129	15.584	14.951	14.129*
Voltage @ Recorder	15.259	15.645	15.086	15.089
Recorder				
Reading	36.4	36.7	35.3	36.7
Load (kips)	728	734	706	734
Actual Load (kips)	730	734	713	734
Difference (kips)				
Reading - Actual	-2	0	-7	0
% Difference				
Diff/Actual	-0.3	0	-1.0	0

*This value was calculated according to the described procedures, but did not produce the correct load value at the recorder; therefore, the voltage was adjusted to obtain the correct load value determined by the stressing rod at lift-off.

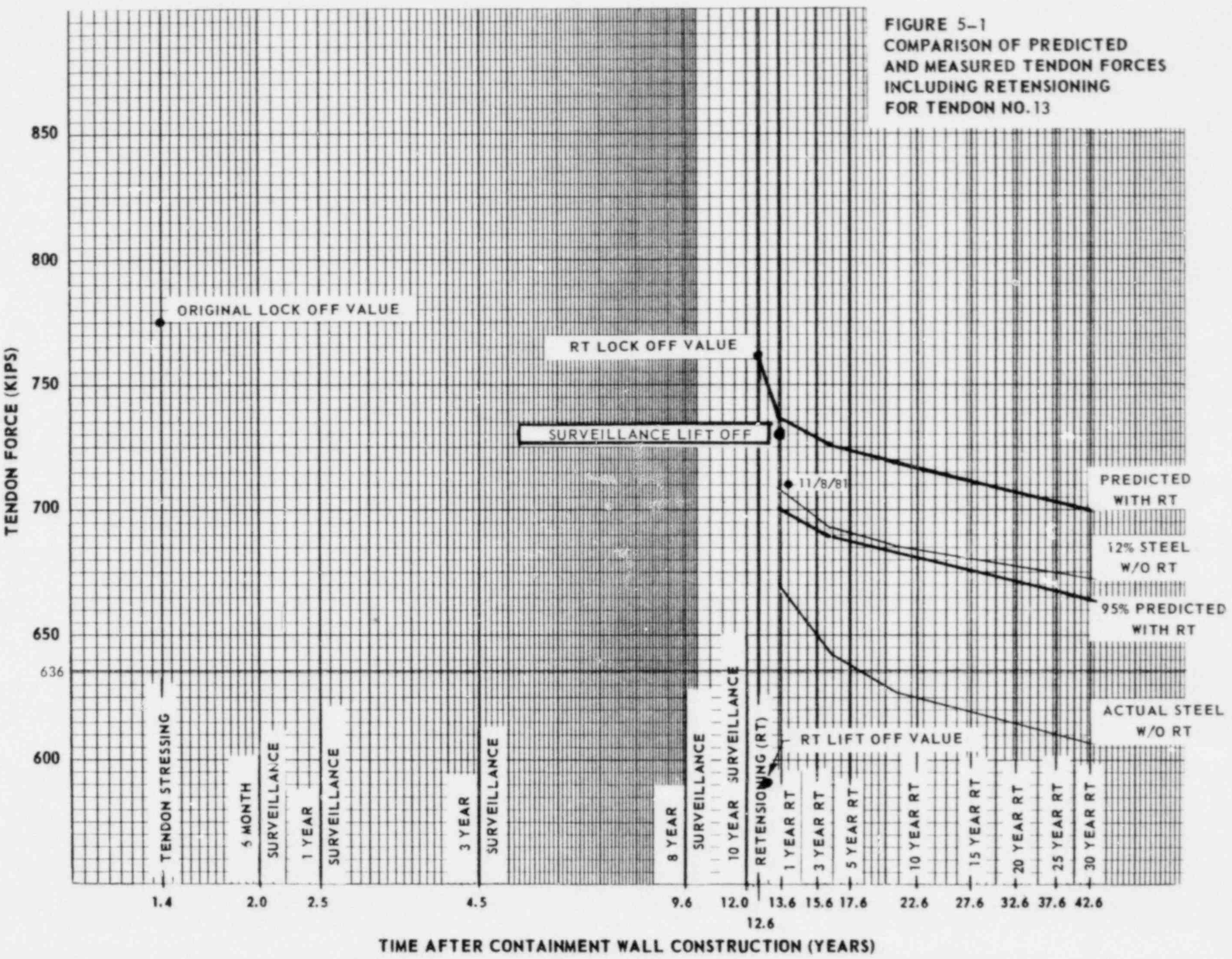


FIGURE 5-1
COMPARISON OF PREDICTED
AND MEASURED TENDON FORCES
INCLUDING RETENSIONING
FOR TENDON NO. 13
TENDON FORCE (KIPS)
850
800
750
700
650
636
600
ORIGINAL LOCK OFF VALUE
RT LOCK OFF VALUE
SURVEILLANCE LIFT OFF
11/8/81
PREDICTED
WITH RT
12% STEEL
W/O RT
95% PREDICTED
WITH RT
ACTUAL STEEL
W/O RT
RT LIFT OFF VALUE
TENDON STRESSING
6 MONTH
SURVEILLANCE
1 YEAR
SURVEILLANCE
3 YEAR
SURVEILLANCE
8 YEAR
SURVEILLANCE
10 YEAR
SURVEILLANCE
RETENSIONING (RT)
1 YEAR RT
3 YEAR RT
5 YEAR RT
10 YEAR RT
15 YEAR RT
20 YEAR RT
25 YEAR RT
30 YEAR RT
1.4
2.0
2.5
4.5
9.6
12.0
12.6
13.6
15.6
17.6
22.6
27.6
32.6
37.6
42.6
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)

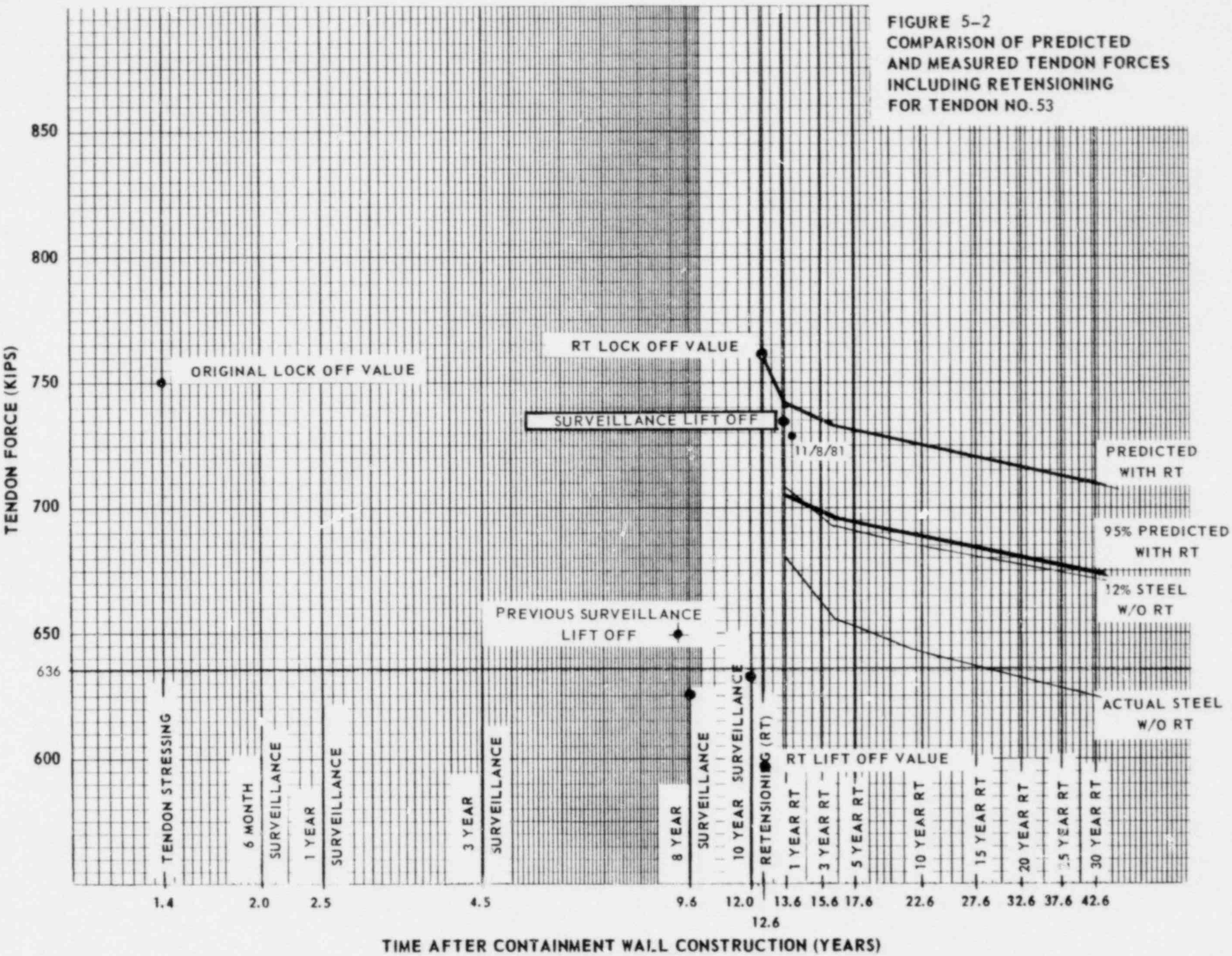


FIGURE 5-2
COMPARISON OF PREDICTED
AND MEASURED TENDON FORCES
INCLUDING RETENSIONING
FOR TENDON NO. 53

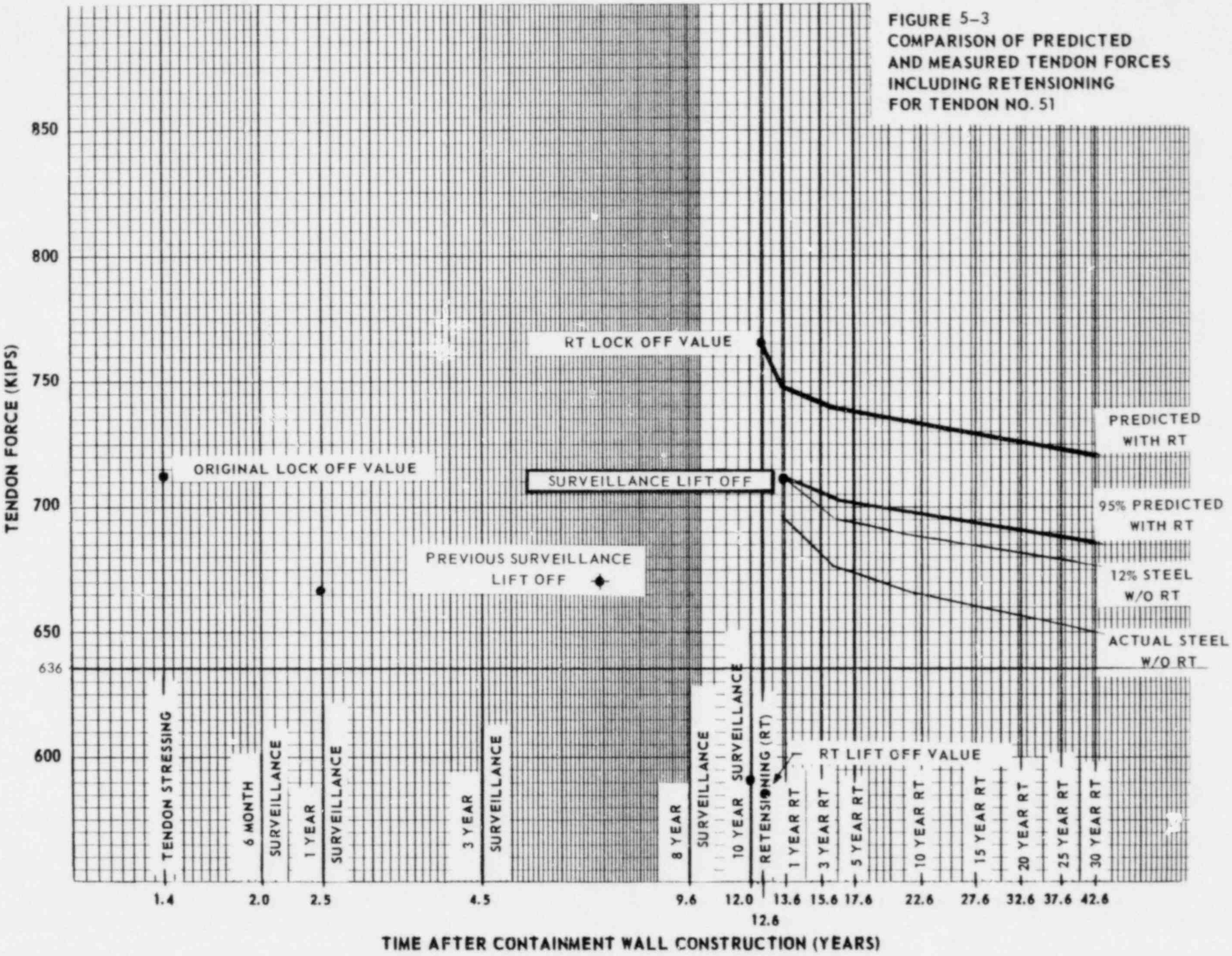


FIGURE 5-3
COMPARISON OF PREDICTED
AND MEASURED TENDON FORCES
INCLUDING RETENSIONING
FOR TENDON NO. 51
TENDON FORCE (KIPS)
850
800
750
700
650
636
600
RT LOCK OFF VALUE
PREDICTED
WITH RT
ORIGINAL LOCK OFF VALUE
SURVEILLANCE LIFT OFF
95% PREDICTED
WITH RT
PREVIOUS SURVEILLANCE
LIFT OFF
12% STEEL
W/O RT
ACTUAL STEEL
W/O RT
TENDON STRESSING
6 MONTH
SURVEILLANCE
1 YEAR
SURVEILLANCE
3 YEAR
SURVEILLANCE
8 YEAR
SURVEILLANCE
10 YEAR
SURVEILLANCE
RETENSIONING (RT)
RT LIFT OFF VALUE
1 YEAR RT
3 YEAR RT
5 YEAR RT
10 YEAR RT
15 YEAR RT
20 YEAR RT
25 YEAR RT
30 YEAR RT
1.4
2.0
2.5
4.5
9.6
12.0
12.6
13.6
15.6
17.6
22.6
27.6
32.6
37.6
42.6
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)

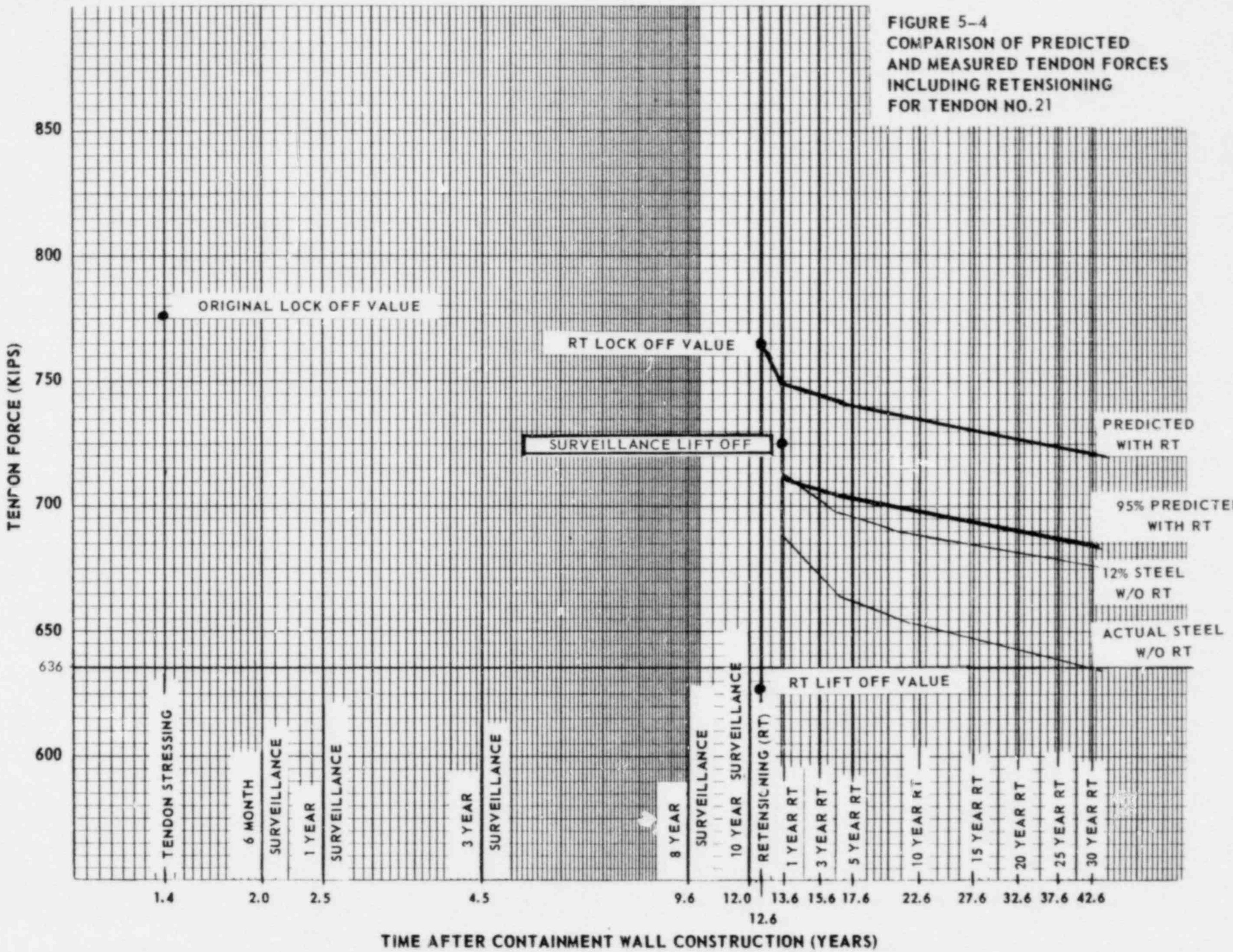


FIGURE 5-4
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES INCLUDING RETENSIONING FOR TENDON NO.21

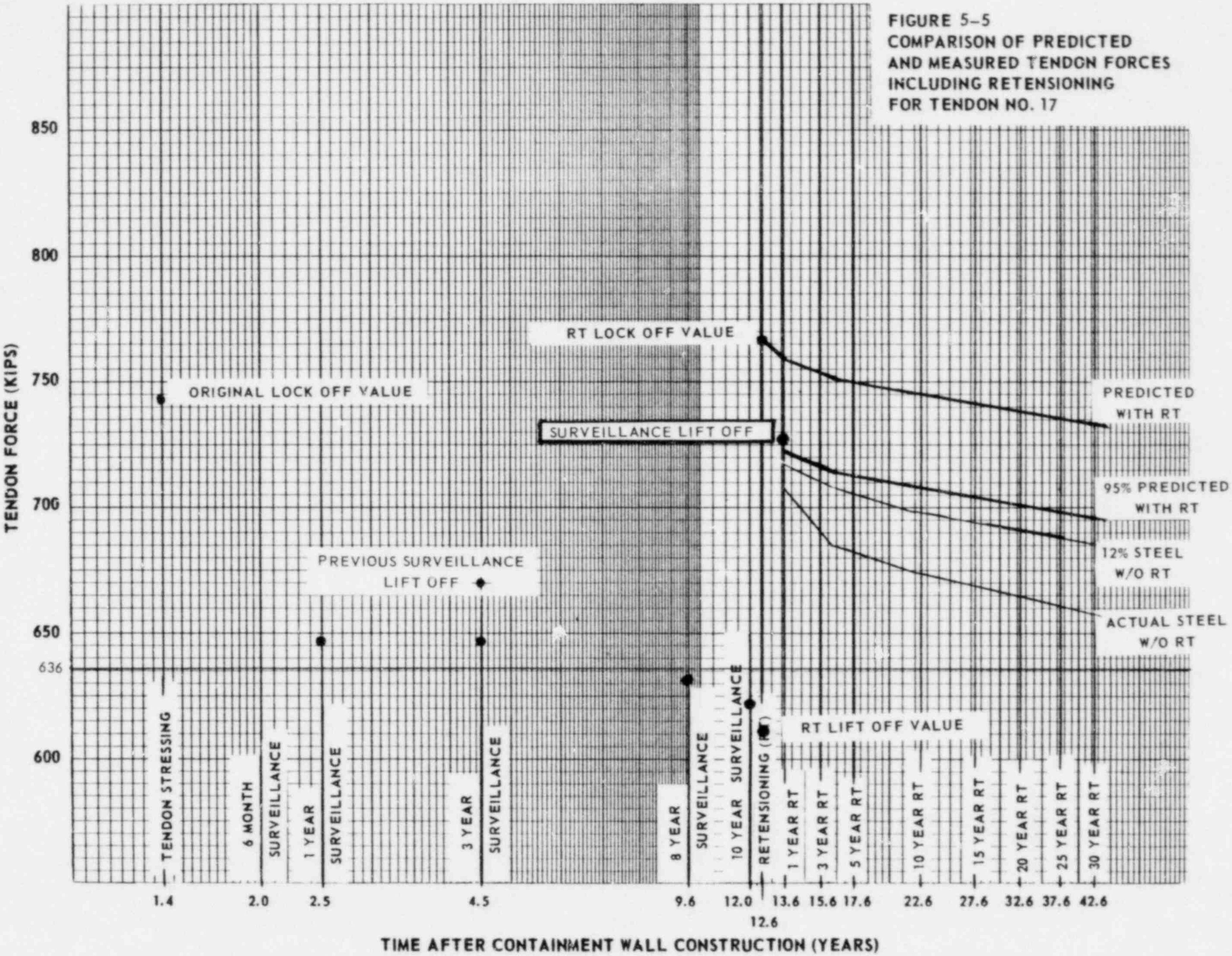


FIGURE 5-5
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES INCLUDING RETENSIONING FOR TENDON NO. 17

FIGURE 5-6
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES INCLUDING RETENSIONING FOR TENDON NO. 62

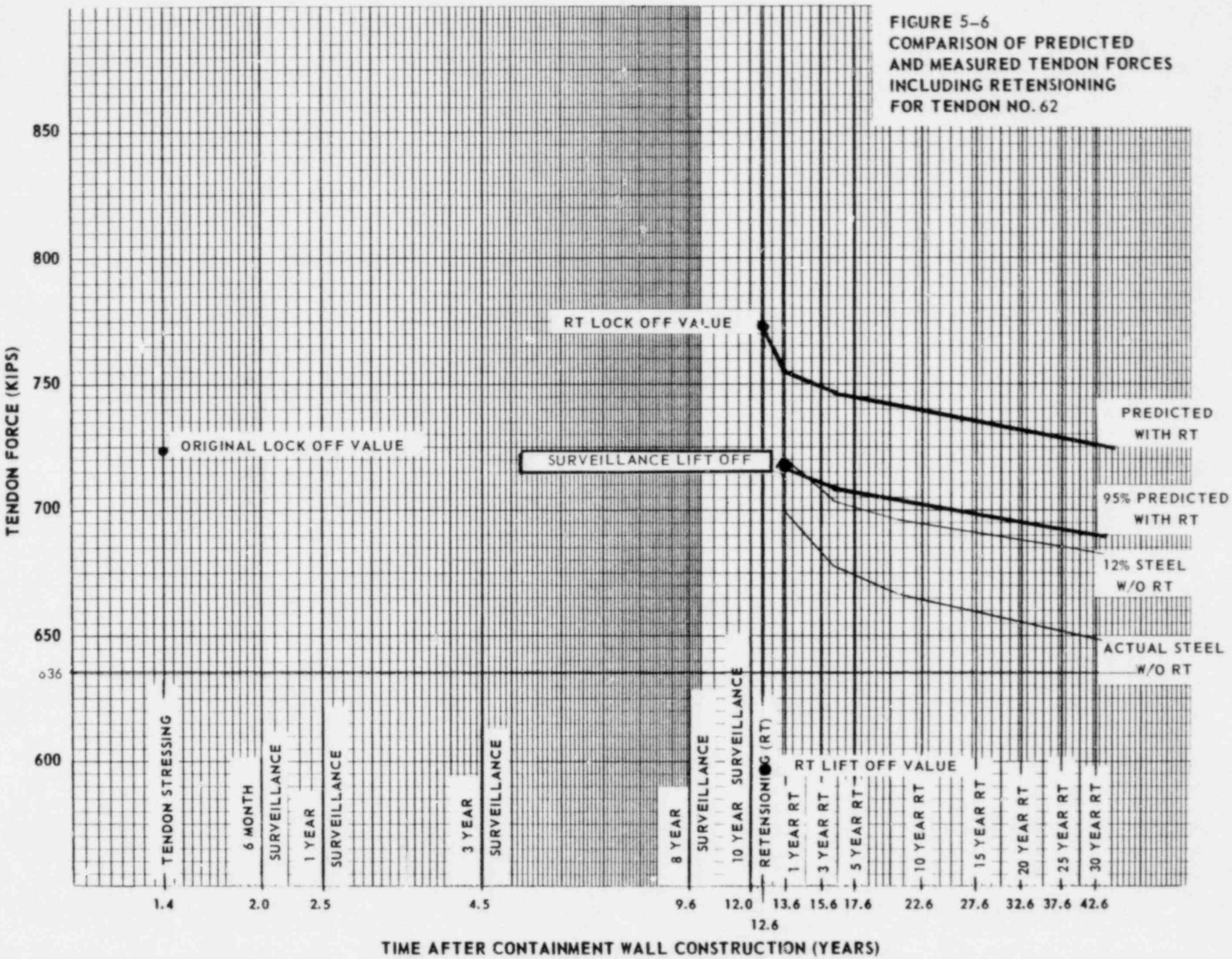
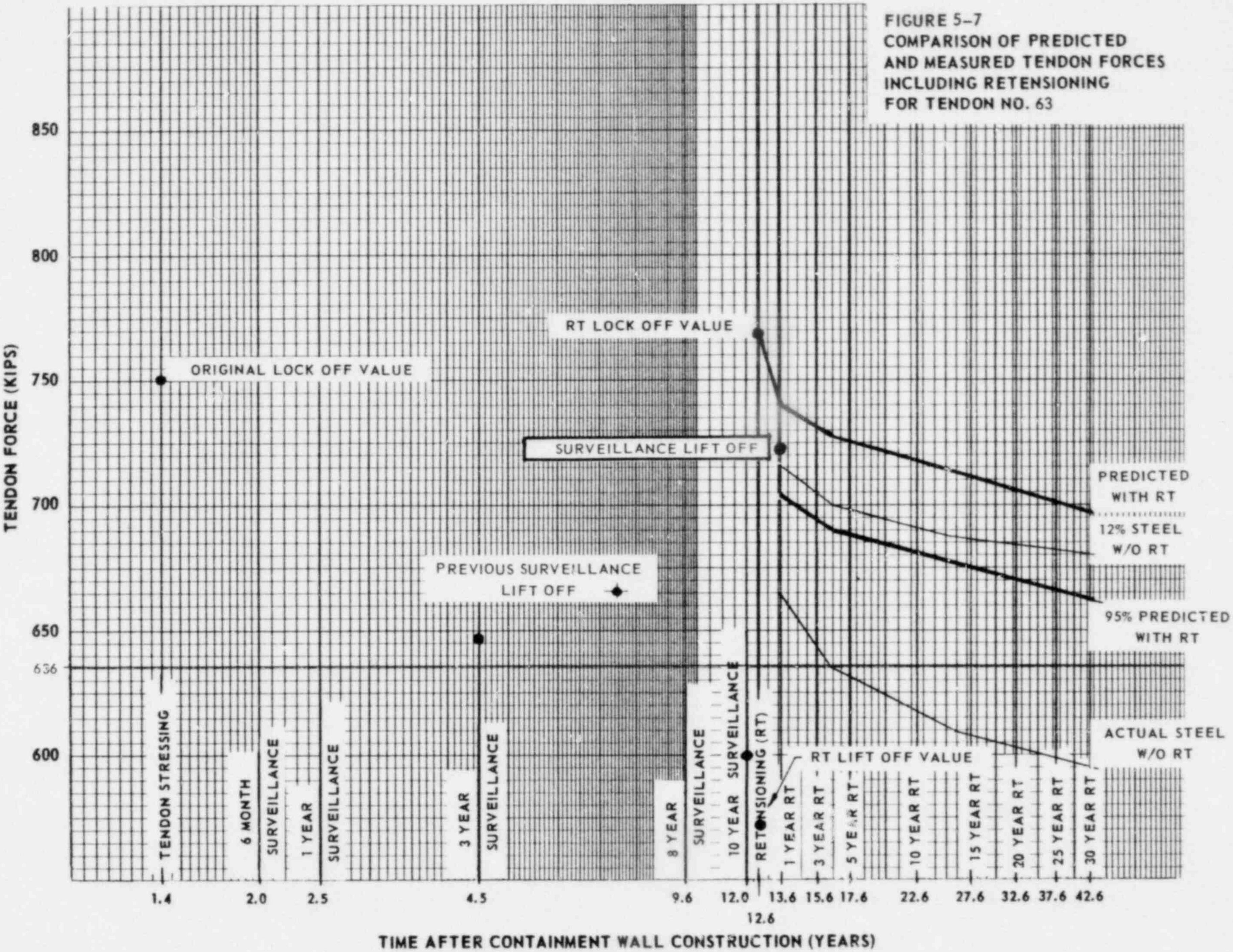


FIGURE 5-7
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES INCLUDING RETENSIONING FOR TENDON NO. 63



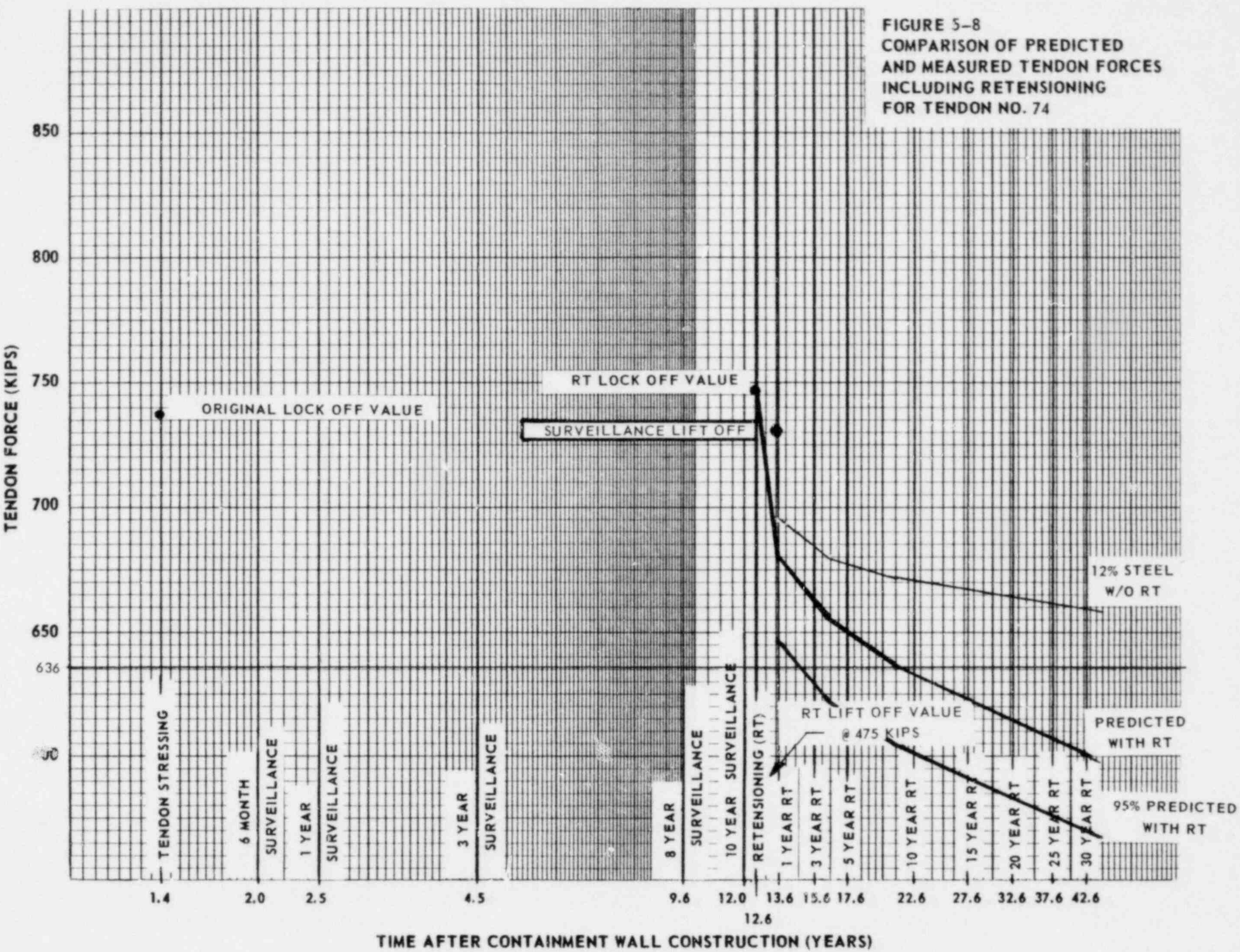


FIGURE 5-8
COMPARISON OF PREDICTED
AND MEASURED TENDON FORCES
INCLUDING RETENSIONING
FOR TENDON NO. 74
TENDON FORCE (KIPS)
850
800
750
700
650
636
ORIGINAL LOCK OFF VALUE
RT LOCK OFF VALUE
SURVEILLANCE LIFT OFF
12% STEEL
W/O RT
PREDICTED
WITH RT
95% PREDICTED
WITH RT
RT LIFT OFF VALUE
@ 475 KIPS
TENDON STRESSING
6 MONTH
SURVEILLANCE
1 YEAR
SURVEILLANCE
3 YEAR
SURVEILLANCE
8 YEAR
SURVEILLANCE
10 YEAR
SURVEILLANCE
RETENSIONING (RT)
1 YEAR RT
3 YEAR RT
5 YEAR RT
10 YEAR RT
15 YEAR RT
20 YEAR RT
25 YEAR RT
30 YEAR RT
1.4
2.0
2.5
4.5
9.6
12.0
12.6
13.6
15.6
17.6
22.6
27.6
32.6
37.6
42.6
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)

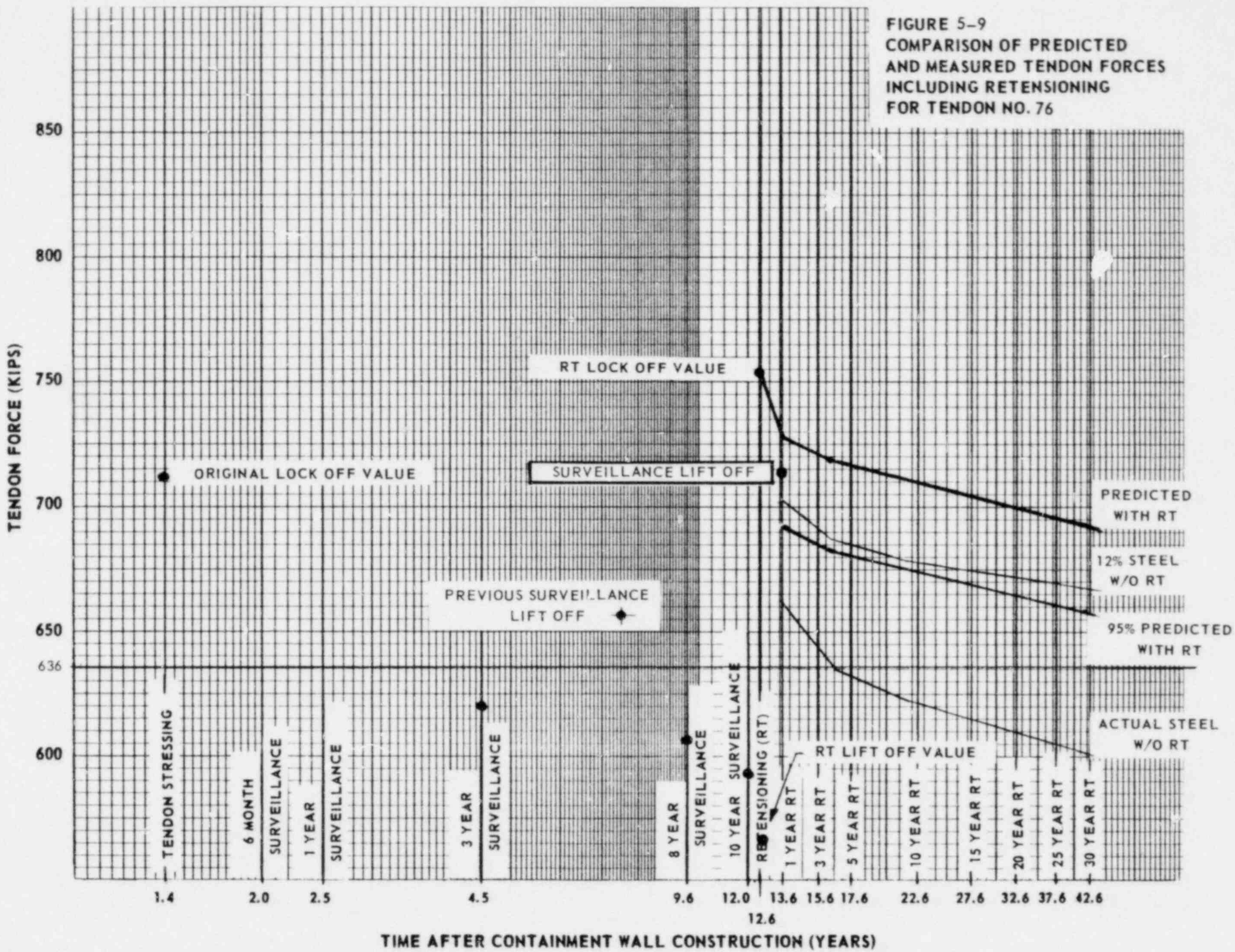


FIGURE 5-9
COMPARISON OF PREDICTED
AND MEASURED TENDON FORCES
INCLUDING RETENSIONING
FOR TENDON NO. 76
TENDON FORCE (KIPS)
850
800
750
700
650
636
600
RT LOCK OFF VALUE
ORIGINAL LOCK OFF VALUE
SURVEILLANCE LIFT OFF
PREDICTED
WITH RT
12% STEEL
W/O RT
95% PREDICTED
WITH RT
ACTUAL STEEL
W/O RT
PREVIOUS SURVEILLANCE
LIFT OFF
RT LIFT OFF VALUE
TENDON STRESSING
6 MONTH
SURVEILLANCE
1 YEAR
SURVEILLANCE
3 YEAR
SURVEILLANCE
8 YEAR
SURVEILLANCE
10 YEAR
SURVEILLANCE
RETENSIONING (RT)
1 YEAR RT
3 YEAR RT
5 YEAR RT
10 YEAR RT
15 YEAR RT
20 YEAR RT
25 YEAR RT
30 YEAR RT
1.4
2.0
2.5
4.5
9.6
12.0
12.6
13.6
15.6
17.6
22.6
27.6
32.6
37.6
42.6
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)

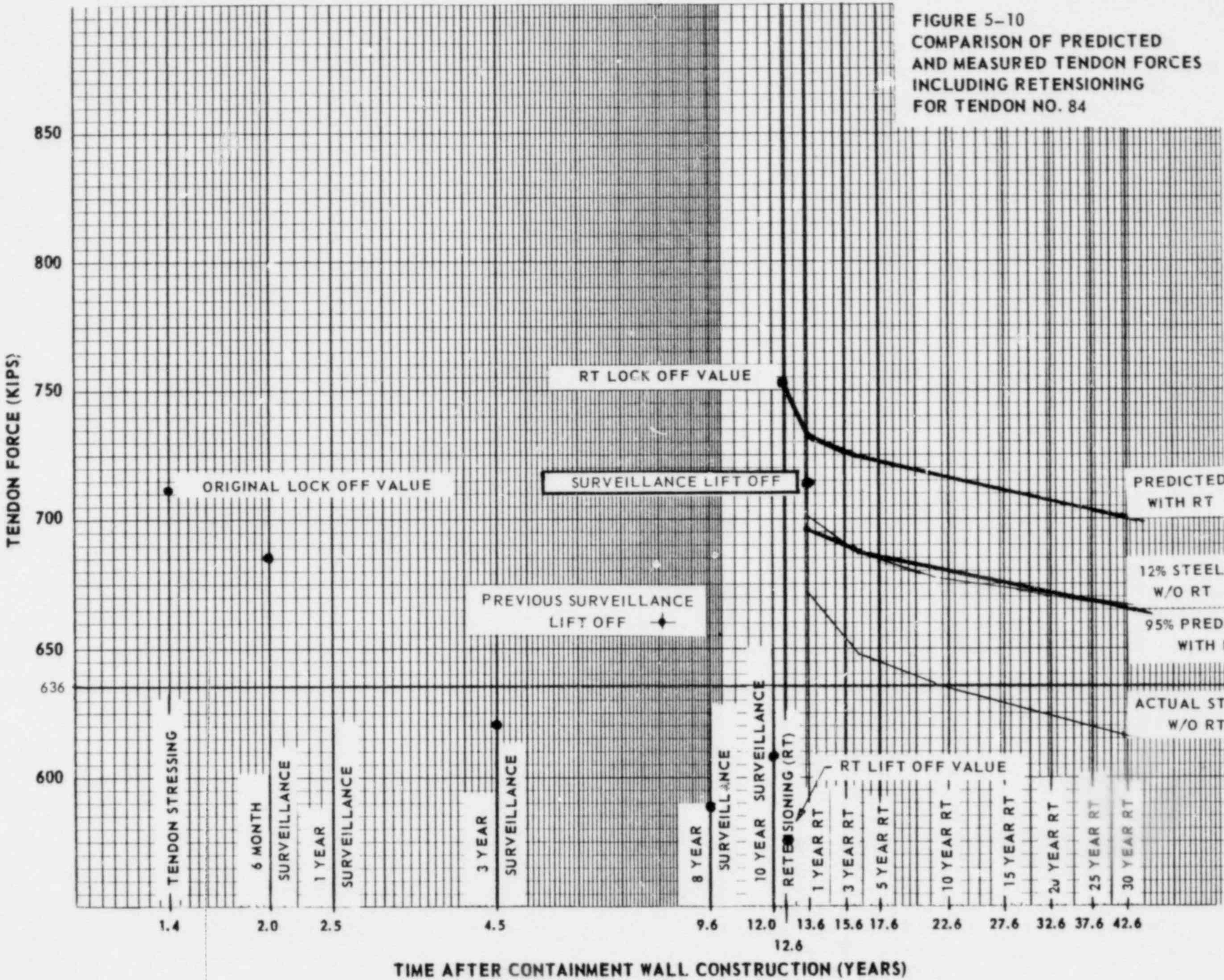


FIGURE 5-10
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES INCLUDING RETENSIONING FOR TENDON NO. 84

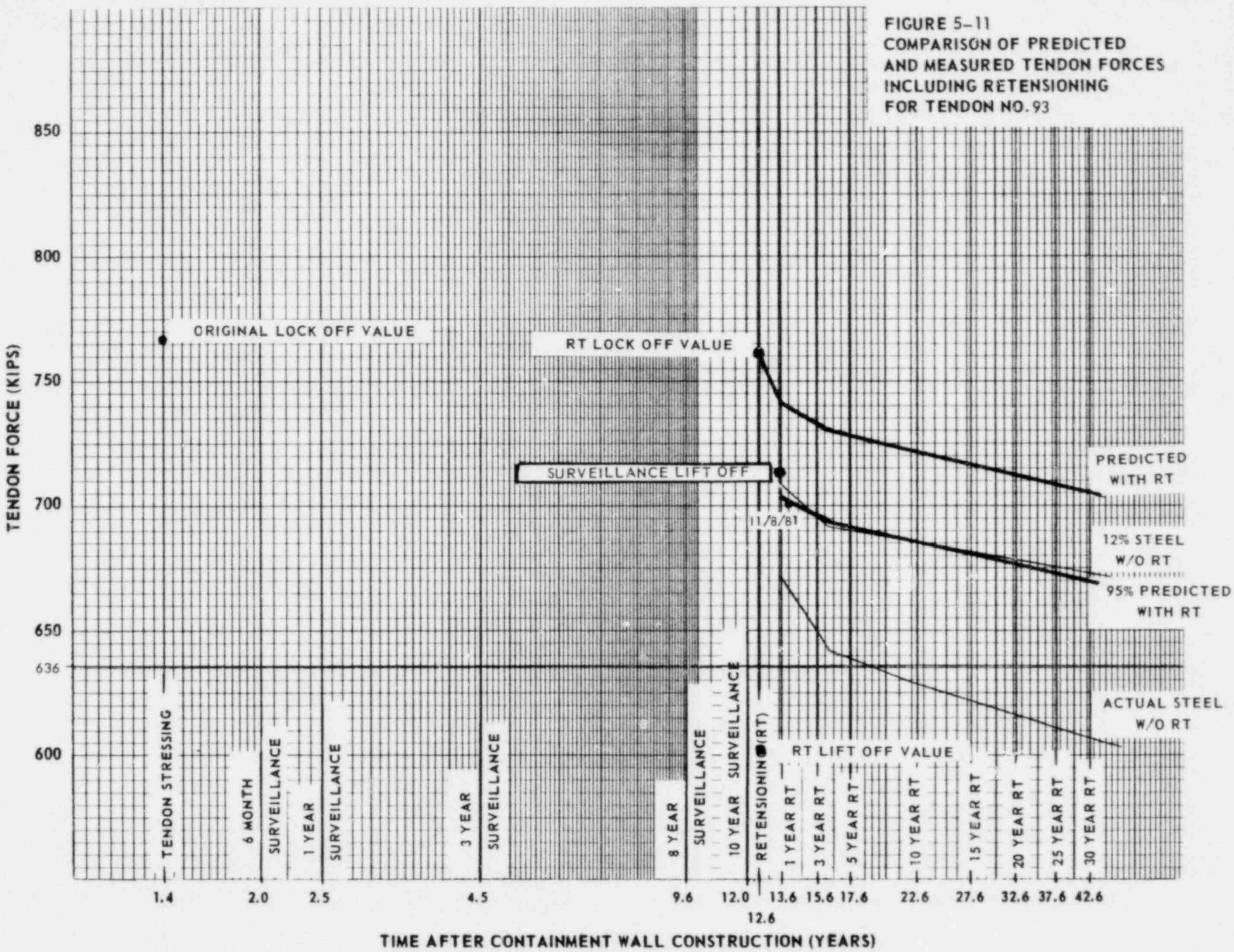
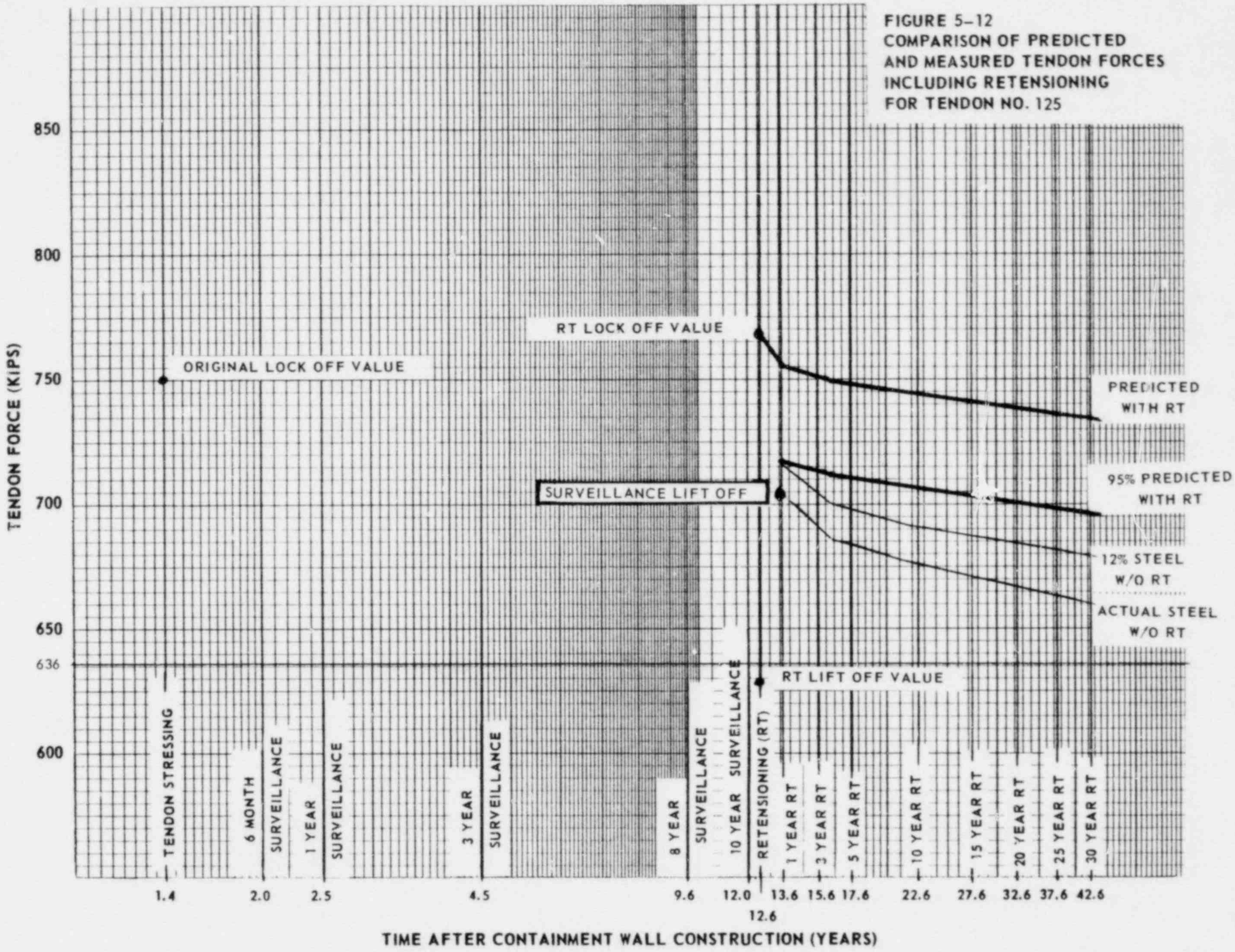


FIGURE 5-11
COMPARISON OF PREDICTED
AND MEASURED TENDON FORCES
INCLUDING RETENSIONING
FOR TENDON NO. 93
TENDON FORCE (KIPS)
850
800
750
700
650
636
600
ORIGINAL LOCK OFF VALUE
RT LOCK OFF VALUE
SURVEILLANCE LIFT OFF
11/8/81
PREDICTED
WITH RT
12% STEEL
W/O RT
95% PREDICTED
WITH RT
ACTUAL STEEL
W/O RT
RT LIFT OFF VALUE
TENDON STRESSING
6 MONTH
SURVEILLANCE
1 YEAR
SURVEILLANCE
3 YEAR
SURVEILLANCE
8 YEAR
SURVEILLANCE
10 YEAR
SURVEILLANCE
RETENSIONING (RT)
1 YEAR RT
3 YEAR RT
5 YEAR RT
10 YEAR RT
15 YEAR RT
20 YEAR RT
25 YEAR RT
30 YEAR RT
1.4
2.0
2.5
4.5
9.6
12.0
12.6
13.6
15.6
17.6
22.6
27.6
32.6
37.6
42.6
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)

FIGURE 5–12
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES INCLUDING RETENSIONING FOR TENDON NO. 125



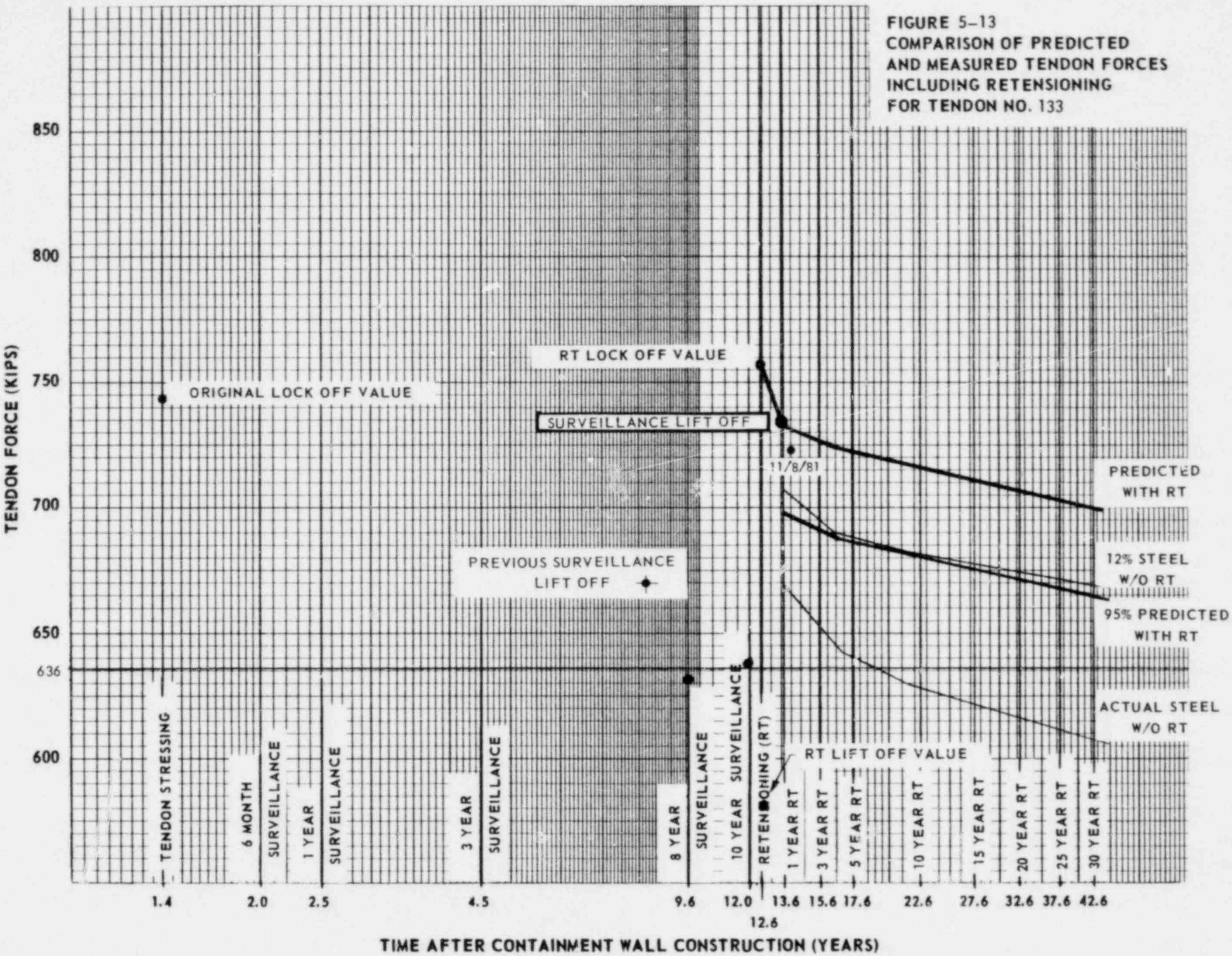


FIGURE 5-13
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES INCLUDING RETENSIONING FOR TENDON NO. 133
TENDON FORCE (KIPS)
850
800
750
700
650
636
600
RT LOCK OFF VALUE
ORIGINAL LOCK OFF VALUE
SURVEILLANCE LIFT OFF
11/8/81
PREDICTED WITH RT
12% STEEL W/O RT
95% PREDICTED WITH RT
ACTUAL STEEL W/O RT
PREVIOUS SURVEILLANCE LIFT OFF
RT LIFT OFF VALUE
TENDON STRESSING
6 MONTH SURVEILLANCE
1 YEAR SURVEILLANCE
3 YEAR SURVEILLANCE
8 YEAR SURVEILLANCE
10 YEAR SURVEILLANCE
RETENSIONING (RT)
1 YEAR RT
3 YEAR RT
5 YEAR RT
10 YEAR RT
15 YEAR RT
20 YEAR RT
25 YEAR RT
30 YEAR RT
1.4
2.0
2.5
4.5
9.6
12.0
12.6
13.6
15.6
17.6
22.6
27.6
32.6
37.6
42.6
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)

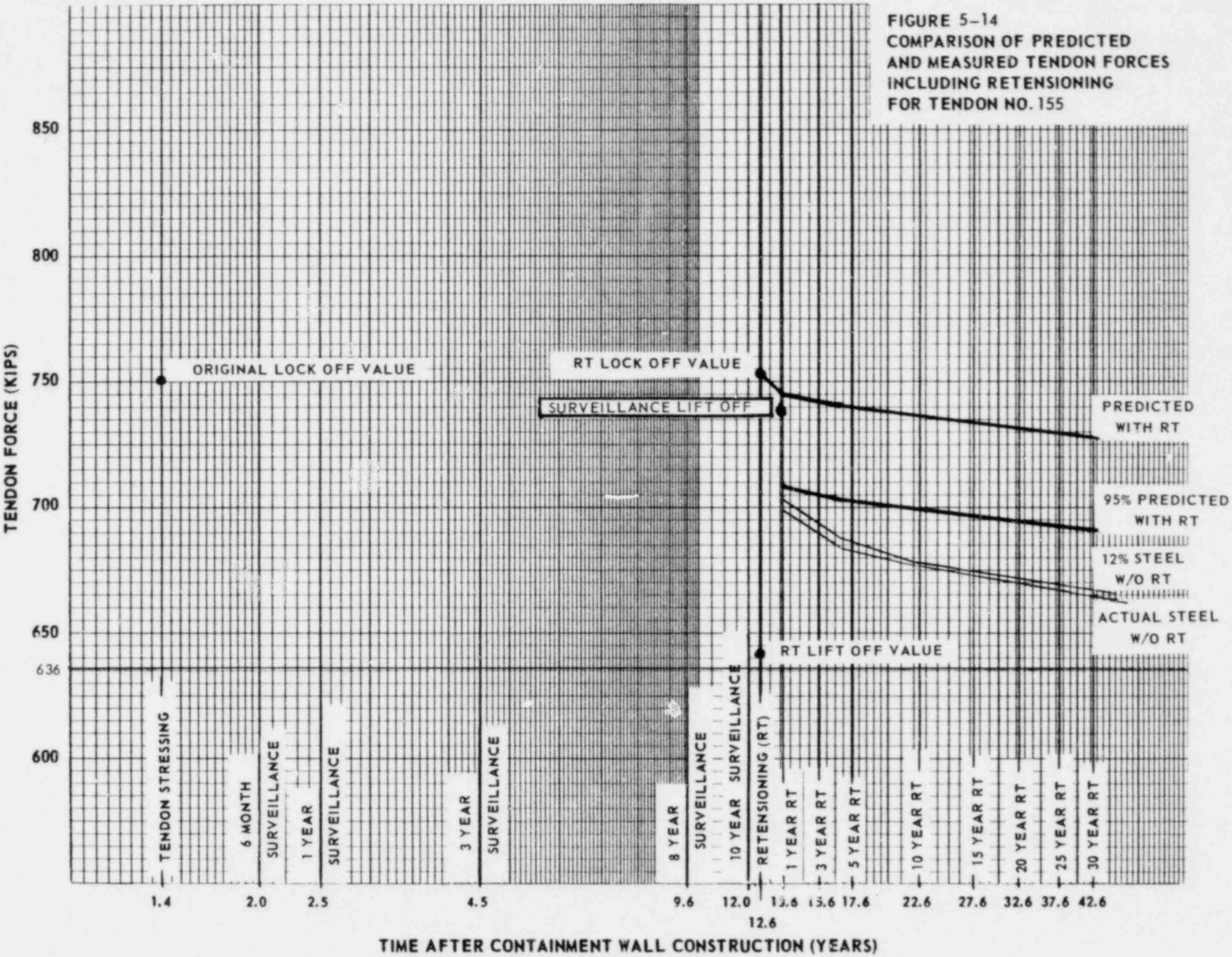
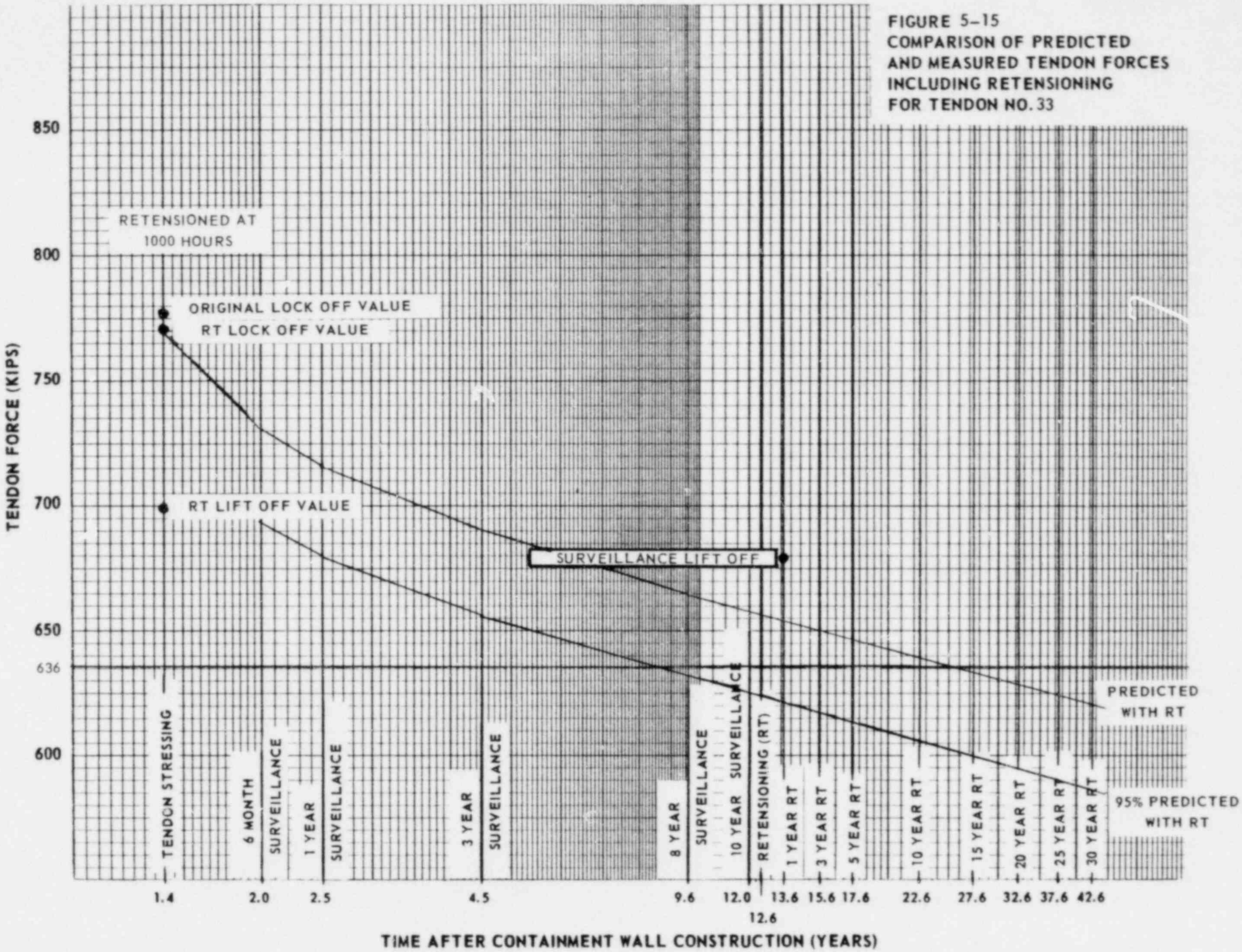


FIGURE 5-14
COMPARISON OF PREDICTED
AND MEASURED TENDON FORCES
INCLUDING RETENSIONING
FOR TENDON NO. 155
TENDON FORCE (KIPS)
850
800
750
700
650
636
600
ORIGINAL LOCK OFF VALUE
RT LOCK OFF VALUE
SURVEILLANCE LIFT OFF
PREDICTED
WITH RT
95% PREDICTED
WITH RT
12% STEEL
W/O RT
ACTUAL STEEL
W/O RT
RT LIFT OFF VALUE
TENDON STRESSING
6 MONTH
SURVEILLANCE
1 YEAR
SURVEILLANCE
3 YEAR
SURVEILLANCE
8 YEAR
SURVEILLANCE
10 YEAR
SURVEILLANCE
RETENSIONING (RT)
1 YEAR RT
3 YEAR RT
5 YEAR RT
10 YEAR RT
15 YEAR RT
20 YEAR RT
25 YEAR RT
30 YEAR RT
1.4
2.0
2.5
4.5
9.6
12.0
12.6
13.6
15.6
17.6
22.6
27.6
32.6
37.6
42.6
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)

FIGURE 5-15
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES INCLUDING RETENSIONING FOR TENDON NO. 33



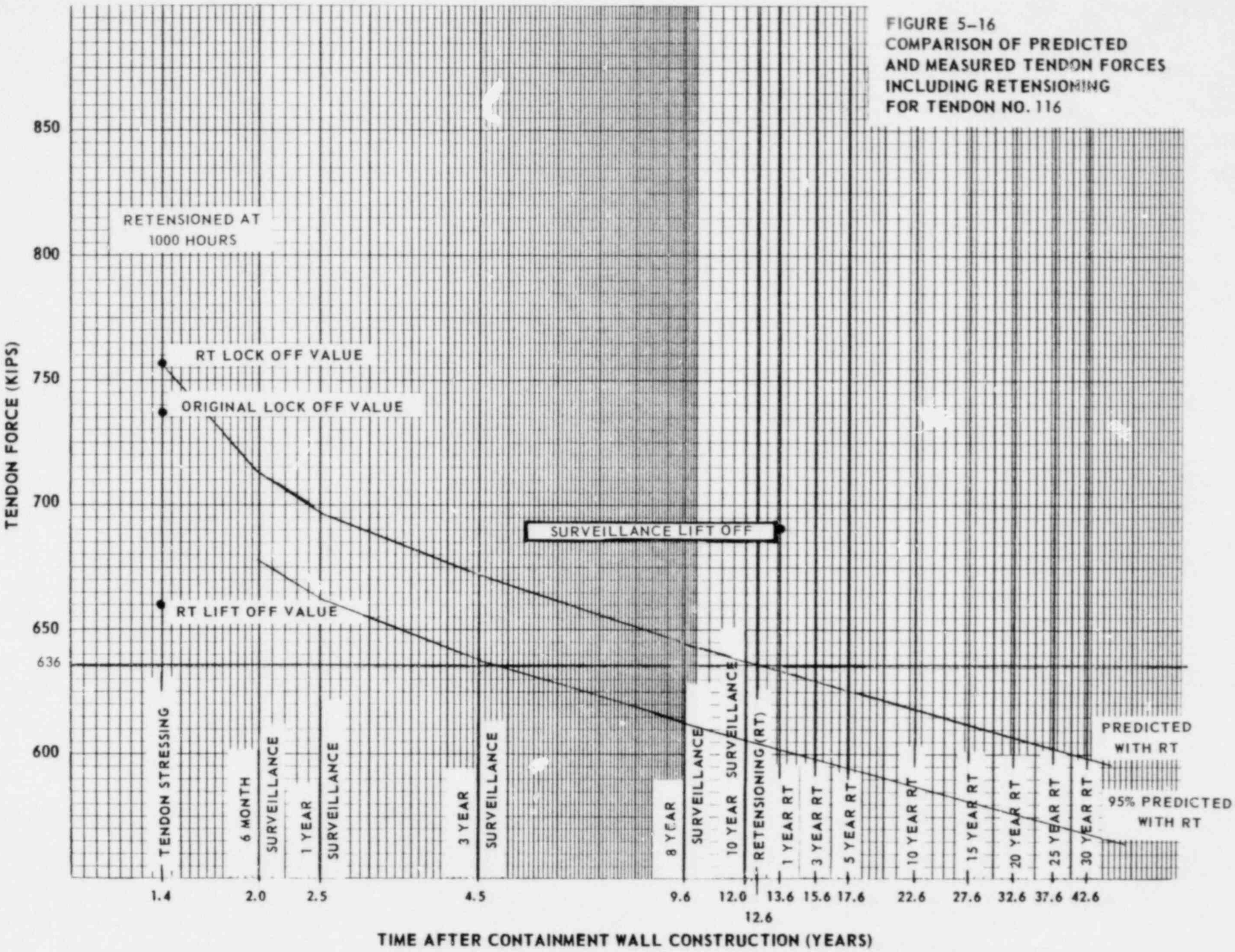


FIGURE 5-16
COMPARISON OF PREDICTED
AND MEASURED TENDON FORCES
INCLUDING RETENSIONING
FOR TENDON NO. 116
TENDON FORCE (KIPS)
850
800
750
700
650
636
600
RETENSIONED AT
1000 HOURS
RT LOCK OFF VALUE
ORIGINAL LOCK OFF VALUE
RT LIFT OFF VALUE
SURVEILLANCE LIFT OFF
PREDICTED
WITH RT
95% PREDICTED
WITH RT
TENDON STRESSING
6 MONTH
SURVEILLANCE
1 YEAR
SURVEILLANCE
3 YEAR
SURVEILLANCE
8 YEAR
SURVEILLANCE
10 YEAR
SURVEILLANCE
RETENSIONING (RT)
1 YEAR RT
3 YEAR RT
5 YEAR RT
10 YEAR RT
15 YEAR RT
20 YEAR RT
25 YEAR RT
30 YEAR RT
1.4
2.0
2.5
4.5
9.6
12.0
12.6
13.6
15.6
17.6
22.6
27.6
32.6
37.6
42.6
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)

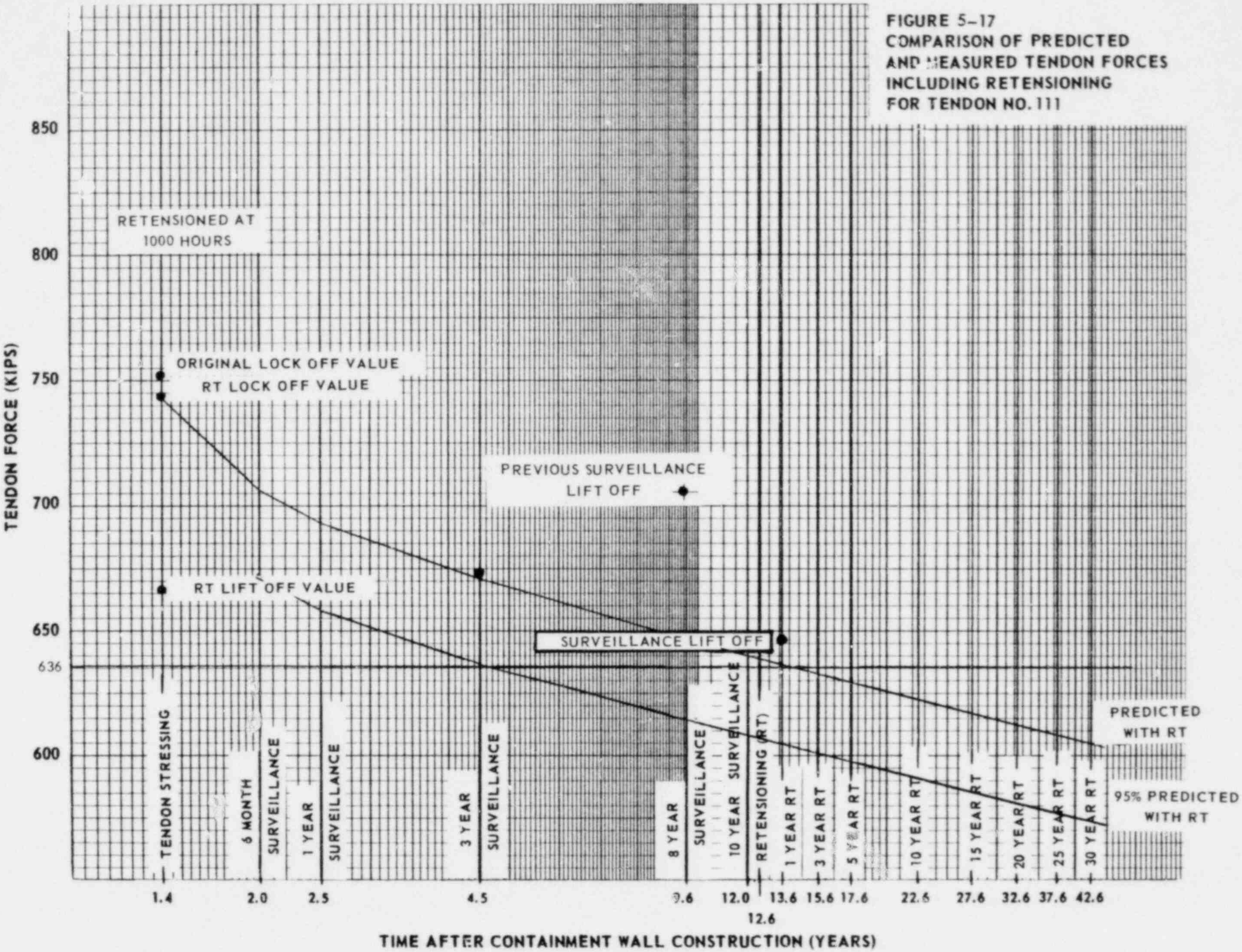


FIGURE 5-17
COMPARISON OF PREDICTED
AND MEASURED TENDON FORCES
INCLUDING RETENSIONING
FOR TENDON NO. 111
TENDON FORCE (KIPS)
850
800
750
700
650
636
600
RETENSIONED AT
1000 HOURS
ORIGINAL LOCK OFF VALUE
RT LOCK OFF VALUE
PREVIOUS SURVEILLANCE
LIFT OFF
RT LIFT OFF VALUE
SURVEILLANCE LIFT OFF
PREDICTED
WITH RT
95% PREDICTED
WITH RT
TENDON STRESSING
6 MONTH
SURVEILLANCE
1 YEAR
SURVEILLANCE
3 YEAR
SURVEILLANCE
8 YEAR
SURVEILLANCE
10 YEAR SURVEILLANCE
RETENSIONING (RT)
1 YEAR RT
3 YEAR RT
5 YEAR RT
10 YEAR RT
15 YEAR RT
20 YEAR RT
25 YEAR RT
30 YEAR RT
1.4
2.0
2.5
4.5
9.6
12.0
12.6
13.6
15.6
17.6
22.6
27.6
32.6
37.6
42.6
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)

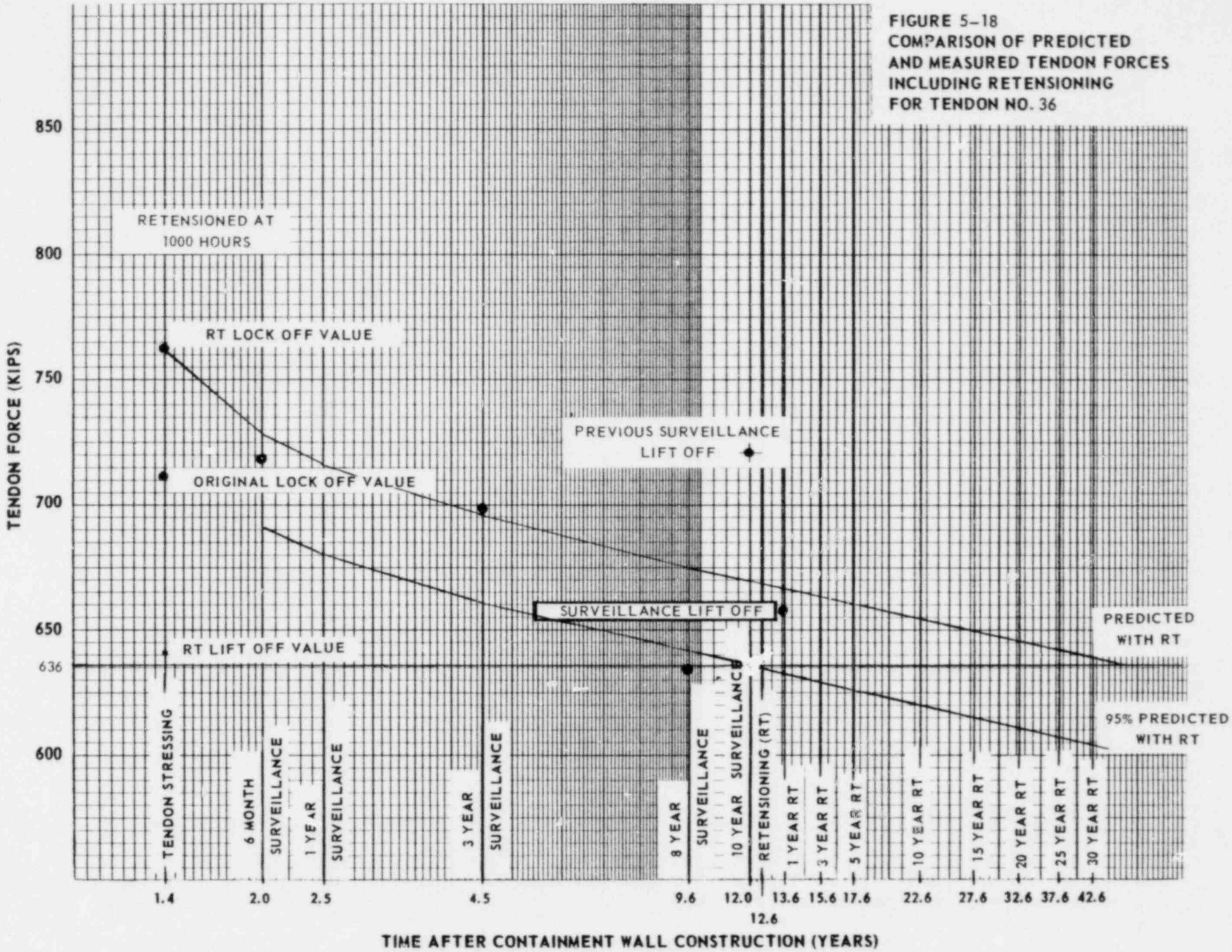


FIGURE 5-18
COMPARISON OF PREDICTED
AND MEASURED TENDON FORCES
INCLUDING RETENSIONING
FOR TENDON NO. 36
TENDON FORCE (KIPS)
850
800
750
700
650
636
600
RETENSIONED AT
1000 HOURS
RT LOCK OFF VALUE
ORIGINAL LOCK OFF VALUE
PREVIOUS SURVEILLANCE
LIFT OFF
SURVEILLANCE LIFT OFF
RT LIFT OFF VALUE
PREDICTED
WITH RT
95% PREDICTED
WITH RT
TENDON STRESSING
6 MONTH
SURVEILLANCE
1 YEAR
SURVEILLANCE
3 YEAR
SURVEILLANCE
8 YEAR
SURVEILLANCE
10 YEAR SURVEILLANCE
RETENSIONING (RT)
1 YEAR RT
3 YEAR RT
5 YEAR RT
10 YEAR RT
15 YEAR RT
20 YEAR RT
25 YEAR RT
30 YEAR RT
1.4
2.0
2.5
4.5
9.6
12.0
12.6
13.6
15.6
17.6
22.6
27.6
32.6
37.6
42.6
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)

6.0 SUMMARY OF CONCLUSIONS RELATED TO CAUSE OF TENDON FORCE LOSSES

This report describes an investigation into possible causes for the larger-than-predicted force losses which the Ginna containment tendons have exhibited over the past 12 years. Information gained from various phases of the tendon project was used to reach the final conclusions of the investigation. Three of these phases have been separated in the report as Section 3.0 - Stress Relaxation Tests; Section 4.0 - Predicting Retensioned Tendon Forces, and Section 5.0 - July 1981 Tendon Surveillance. Conclusions regarding each of these studies are contained in the individual sections.

The following conclusions relate directly to the possible causes for the larger-than-predicted force losses. Detailed conclusions appear in Section 2.0 with each item.

1. The wire supplied for the Ginna tendons was originally classified as a 12% relaxation grade of wire, meaning that when initially stressed to 70% GUTS (Guaranteed Ultimate Tensile Strength) and tested at 68° F the wire would exhibit a 12% stress relaxation after 40 years under load. The 12% relaxation grade was the grade of wire commercially available at the time of the Ginna containment design. The tests conditions of 70% GUTS and 68° F are standard conditions which were generally used by the nuclear industry as a basis for classifying relaxation grades of prestressing wire. Thus, the original Ginna containment design and the predicted tendon forces at subsequent surveillances used stress relaxation values based on a 12% relaxation grade of wire.

   Test wires removed from two of three tendons exhibited stress relaxation properties at the standard test condition (70% GUTS and 68° F) which exceeded the stress relaxation property of the 12% wire. In fact, the heat of wire from one tendon (heat #30091 in tendon 76) would be classified as a 16% relaxation grade based on its test results extrapolated to 40 years. The third tendon test wires exhibited a 40 year stress relaxation less than 6% at the standard test condition. Therefore, it is concluded that the relaxation grade of some heats of wire supplied for Ginna exceeded 12%; however, there is evidence to suggest a large variation in relaxation grades across wire heats.

Even though this variation exists at the standard condition of 0.70 GUTS and 68° F, the stress relaxation properties of test wires from all heats exceed that of the 12% wire at the temperatures believed to be applicable for the actual tendons. These temperatures are expected to be in a range of 85° F to 95° F. For these temperatures, the interpolated stress relaxation properties of the test wires at 100,000 hours range from 14% to 17.5%, which exceed the value of 10% associated with the nominal 12% wire. An increase in stress relaxation by 4 to 7.5 percentage points results in 30 to 56 kips of additional loss in tendon force. This generally accounts for the 39 kip average difference between predicted and measured tendon force in June 1980 for a 35 tendon sample, after the tendons had been stressed for approximately 100,000 hours.

A more specific comparison was made for 64 tendons which were involved in the June 1980 lift-off tests. These tendons were comprised solely of wires from the same heats as the test wires. The average value of effective stress relaxation which these tendons exhibited was 15%. This exceeds the 10% value for the nominal 12% wire. However, the 15% value was consistent with the test values for the wires, which were in the 14.0% to 17.5% range at the 85° F to 95° F temperature range believed to be generally for the tendons. Therefore, stress relaxation values in this range provide an explanation as to why the lift-off forces measured in June 1980, and in past surveillances, were generally less than those predicted using the relaxation properties of 12% relaxation grade wire. In addition it appears that for the operational tendon temperatures, 40 year stress relaxation properties in the 15% to 18.5% range, rather than the 12% value, are applicable.

2. The larger-than-predicted tendon losses cannot be explained by inaccuracies in the measurement of the tendon lift-off forces. For most of the tendons included in the lift-off tests performed in October 1979 and June 1980, their forces were measured to within a ±3% accuracy. The tendon forces are as likely to have been over-measured as they were under-measured in these tests.

3. The creep data reported in the Ginna FSAR indicates that the elastomeric pad exhibits very little creep displacement, and the corresponding tendon force loss is only 2 kips. Since this creep data was developed from only one pad test and the loading duration was relatively short, 72 hours, there is a lack of confirmation of these low creep characteristics. However, ten-year neoprene creep data is reported in Reference 4. This information was used to determine the pad creep and resulting tendon force loss of 4 kips. This value is still very small, and it is not the cause of the larger-than-predicted force losses which the tendons have exhibited in the past.

4. From the tendon thermal expansion evaluation, the tendon forces appear to be affected by seasonal temperature changes. However, this effect does not explain the

general downward trend that the measured forces exhibited relative to their predicted values. Nevertheless, to develop consistent tendon force data, all tendon surveillances should be performed in the same month of the year.

5. Based on an evaluation of rock anchor and tendon elongation data, it is concluded that the tendon losses are not related to the performance of the rock anchors.

6. Losses cannot be attributed to a failure of the rock surrounding the rock anchors. Rock creep is calculated to produce a minor force loss of 0.10 kips. Therefore, it is not the cause of the larger-than-predicted tendon force losses.

7. The stress levels in the tendons remained in the linear, elastic range. Consequently, inelastic tendon behavior did not occur and was not a factor in the tendon force losses.

8. The procedure used in past surveillances of applying a temporary 6% overstress does not accelerate the existing rate of force loss. Therefore, this practice was not a factor in the tendon losses.

9. The tendon force losses are not related to the tendon geometry (curvature).

10. From the conclusions above, the only causes which have a significant effect on the tendon forces are seasonal temperature changes and wire stress relaxation property. The effects of the other causes investigated were found to be either non-existent or negligible. Even though seasonal temperature changes do effect tendon forces, they

do not account for the general downward trend of the measured forces relative to their predicted values. Therefore, tendon wire stress relaxation is the only single cause which would explain the larger-than-predicted force loss in the tendons. The loss prediction is based on a 12% relaxation grade of wire. The tested wires exhibit relaxation properties in excess of the 12% wire, and these relaxation properties are consistent with the relaxation losses experienced by the tendons.

7.0 FUTURE SURVEILLANCES

The future tendon lift-off tests for Ginna are to be based on the intervals specified in USNRC Regulatory Guide 1.35 using July 1981 as the first inspection period. The remaining lift-off tests are to be scheduled for July 1983 and July 1985, and then every five (5) years thereafter.

8.0 REFERENCES

1. EVALUATION OF PRESTRES :D TENDON FORCES FOR ROBERT E. GINNA NUCLEAR POWER STATION; Gilbert Associates, Inc., November 1979; Revision 1 - April 1980.

2. Summary of meeting involving the USNRC, Rochester Gas and Electric Corporation, and Gilbert Associates to discuss rock anchor design at the R. E. Ginna Nuclear Power Station, USNRC memorandum from R. P. Snaider to Dennis M. Crutchfield, dated March 17, 1981.

3. ENGINEERING PROPERTIES OF ROCK, I. W. Farmer, E. and F. N. Spon Ltd., London, 1968.

4. DESIGN OF NEOPRENE BEARING PADS - E. I. DuPont and Nemours and Company, 1959.

5. REPORT ON RECOMMENDED CONCRETE CREEP AND SHRINKAGE VALUES FOR COMPUTING PRESTRESS LOSSES, by Schupack and Associates, Appendix 5J, PSAR for Three Mile Island Nuclear Power Station, Unit 2, Docket No. 50-320.

APPENDIX A

TENDON FORCE HISTORY

AND

FORCES AND ELONGATIONS FOR JUNE 1980 RETENSIONING

TABLE 1

GINNA
FORCES AND ELONGATIONS FOR RETENSIONED TENDONS

TENDON I.D. NO.	LIFT-OFF FORCE (Kips)	FINAL LOCK-OFF FORCE (Kips)	ELONGATION[d] (in)	
			MEASURED	CALCULATED
1	2	3	4	5
1	618	773	1 13/16	1 11/16
2	626	758	1 9/16	1 5/8
3	633	769	1 5/8	1 9/16
4	618	765	1 3/4	1 11/16
5	614	765	1 7/8	1 3/4
6[b]	618	769	1 13/16	1 11/16
7	626	758	1 5/8	1 5/8
8[b]	603	769	2 1/16	1 7/8
9	603	758	2	1 7/8
10	633	758	1 11/16	1 9/16
11	610	761	1 5/8	1 13/16
12	629	758	1 5/8	1 9/16
13	580	761	2 1/8	2 1/16
14	584	758	2 1/8	2 1/16
15	626	769	1 1/2	1 5/8
16	633	758	1 5/8	1 9/16
17[b]	611	776	1 13/16	1 3/4
18[b]	580	773	1 13/16	2 1/16
19	603	761	1 15/16	1 7/8
20	611	773	1 13/16	1 3/4
21	626	765	1 11/16	1 5/8
22	603	754	1 7/8	1 7/8
23	588	750	2 3/8	2
24	565	761	2 5/16	2 1/4
25	618	761	1 13/16	1 11/16
26	603	769	2 3/16	1 7/8
27	603	769	2 1/8	1 7/8
28	603	765	2	1 7/8
29	580	769	2 1/4	2 1/16
30[b]	609	761	2	1 13/16
31	596	754	2	1 15/16
32[a]				
33[a]				
34[a]				
35[a]				
36[a]				
37[a]				
38[a]				
39[a]				
40[b]	648	765	1 9/16	1 3/8
41	603	769	2 1/16	1 7/8
42	596	758	2 1/8	1 15/16
43	596	761	2 1/8	1 15/16
44	569	750	2 1/4	2 3/16
45[b]	633	765	1 11/16	1 9/16

TABLE 1 (Continued)

TENDON I.D. NO.	LIFT-OFF FORCE (Kips)	FINAL LOCK-OFF FORCE (Kips)	ELONGATION[d] (in)	
			MEASURED	CALCULATED
1	2	3	4	5
46	603	769	1 11/16	1 7/8
47	626	758	1 7/16	1 5/8
48[b]	558	746	1 13/16	2 5/16
49	569	754	1 11/16	2 3/16
50[b]	603	765	1 7/8	1 7/8
51[b]	588	765	2 1/4	2
52	584	758	2 5/16	2 1/16
53[b]	596	761	2 1/8	1 15/16
54	565	761	2 5/16	2 1/4
55	603	754	1 11/16	1 7/8
56[a]				
57	607	769	1 9/16	1 13/16
58[b]	573	754	1 3/4	2 3/16
59	580	761	2 3/16	2 1/16
60[b]	596	761	2	1 15/16
61	645	769	1 7/16	1 7/16
62	596	773	2	1 15/16
63[b]	573	769	2 3/8	2 3/16
64	573	761	2 5/16	2 3/16
65	606	768	1 13/16	1 13/16
66	595	761	1 13/16	1 15/16
67[b]	618	753	1 11/16	1 11/16
68	577	761	2 3/16	2 1/8
69	596	761	2 1/16	1 15/16
70	618	761	1 11/16	1 11/16
71	599	768	2	1 7/8
72	580	765[c]	1 7/8	2 1/16
73[a]				
74	475	746	2 1/4	2 3/16
75[b]	565	761	1 13/16	2 1/4
76[b]	565	754	2 7/16	2 1/4
77	596	761	2 1/8	1 15/16
78	580	753	2 1/8	2 1/16
79	595	746	2 1/8	1 15/16
80	595	768	2	1 15/16
81	599	768	2 1/16	1 7/8
82	591	753	2 1/8	2
83[b]	603	753[c]	2	1 7/8
84[b]	576	753	2 5/16	2 1/8
85	625	761[c]	1 11/16	1 5/8
86	603	746[c]	1 15/16	1 7/8
87	614	768	1 15/16	1 3/4
88	595	757[c]	2 1/8	1 15/16
89	618	772	1 5/8	1 11/16
90	603	757	1 15/16	1 7/8
91	603	750[c]	2 1/8	1 7/8
92	606	772	1 15/16	1 13/16

TABLE 1 (Continued)

TENDON I.D. NO.	LIFT-OFF FORCE (Kips)	FINAL LOCK-OFF FORCE (Kips)	ELONGATION[d] (in)	
			MEASURED	CALCULATED
1	2	3	4	5
93	603	761	1 7/8	1 7/8
94	618	761	1 3/4	1 11/16
95[b]	648	772	1 1/2	1 3/8
96[b]	625	761	1 3/4	1 5/8
97	625	753	1 11/16	1 5/8
98	603	746	1 7/8	1 7/8
99	610	746	1 13/16	1 3/4
100[b]	610	753[c]	1 7/8	1 3/4
101	614	746[c]	1 15/16	1 3/4
102	618	768	1 3/4	1 11/16
103	599	757	2 1/16	1 7/8
104	610	753	1 5/8	1 3/4
105	621	746[c]	1 11/16	1 5/8
106[b]	633	746	1 5/8	1 9/16
107	625	761	1 3/4	1 5/8
108	618	753	1 5/8	1 11/16
109	603	750	1 15/16	1 7/8
110[b]	633	753	1 7/16	1 9/16
111[a]				
112[a]				
113[a]				
114[a]				
115[a]				
116[a]				
117[a]				
118[a]				
119[a]				
120[a]				
121[a]				
122[a]				
123	580	757	1 7/8	2 1/16
124[b]	588	753	1 7/8	2
125	629	768	1 1/8	1 9/16
126[a]				
127	603	761	1 7/16	1 7/8
128	625	753	1 1/16	1 5/8
129	573	753	2 3/16	2 3/16
130[b]	629	746[c]	1 9/16	1 9/16
131	621	768	1 13/16	1 11/16
132[b]	610	768	1 7/8	1 3/4
133[b]	580	757	2 1/16	2 1/16
134	595	753	2	1 15/16
135	569	753	2 3/16	2 3/16
136	580	757	2 3/16	2 1/16
137	595	753	2	1 15/16
138[b]	603	753	1 7/8	1 7/8
139	640	761	1 3/8	1 7/16
140[b]	584	765	2 3/16	2 1/16

TABLE 1 (Continued)

TENDON I.D. NO.	LIFT-OFF FORCE (Kips)	FINAL LOCK-OFF FORCE (Kips)	ELONGATION[d] (in)	
			MEASURED	CALCULATED
1	2	3	4	5
141	610	753	1 3/4	1 3/4
142[b]	606	746[c]	1 15/16	1 13/16
143	618	753	1 5/8	1 11/16
144	633	761	1 9/16	1 9/16
145	640	768	1 3/8	1 7/16
146	625	753	1 5/8	1 5/8
147	648	746[c]	1 7/16	1 3/8
148	606	757	1 3/4	1 13/16
149	618	768	1 13/16	1 11/16
150[b]	641	761	1 7/16	1 7/16
151	580	761	2 5/16	2 1/16
152	614	758	1 7/8	1 3/4
153	603	761	1 15/16	1 7/8
154[b]	625	761	1 5/8	1 5/8
155	641	754	1 3/8	1 7/16
156	596	761	2 1/16	1 15/16
157	614	758	1 13/16	1 3/4
158	625	768	1 9/16	1 5/8
159[b]	645	761	1 7/16	1 7/16
160[b]	603	761	1 7/8	1 3/4
AVE.	607	760	1 7/8	1 13/16

FOOTNOTES:

(a) These tendons were retensioned at 1000 hrs. after original stressing, and they were not included in the 11 yr. retensioning.

(b) These tendons have been included in past surveillances; consequently, a tendon force history has been established.

(c) These forces reflect remeasured values due to tendon twist in the 6% overstressing process.

(d) These are the tendon elongations from lift-off (column 2) to 73.5% GUTS.

SEMI-LOGARITHMIC
2 CYCLES X 10 DIVISIONS PER INCH

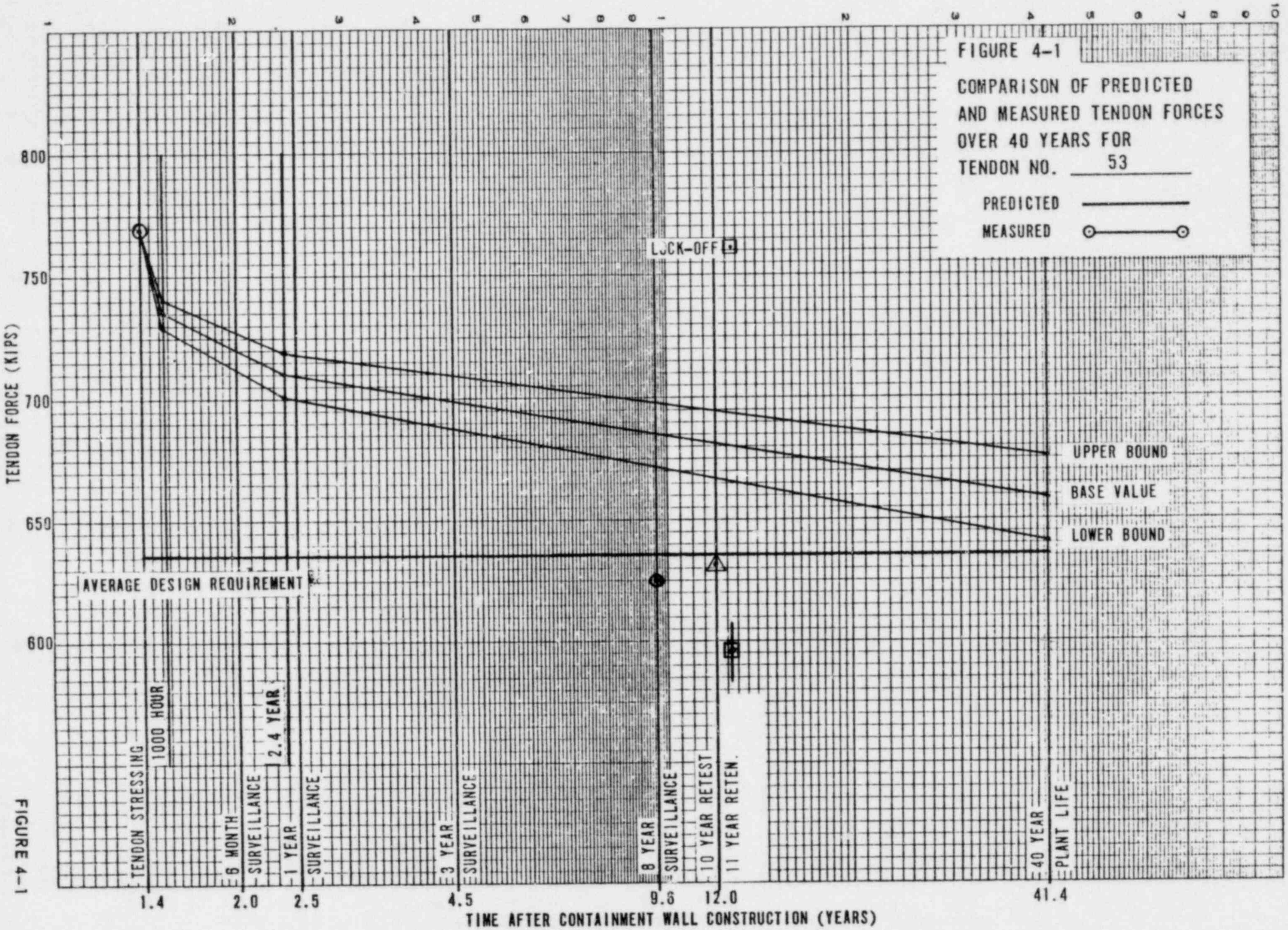


FIGURE 4-1

[redacted] NO. [redacted] 210 [redacted] GEN [redacted] PH P [redacted] EU [redacted] DICT [redacted] CO. [redacted]
SEMI-LOGARITHMIC
2 CYCLES X 10 DIVISIONS PER INCH

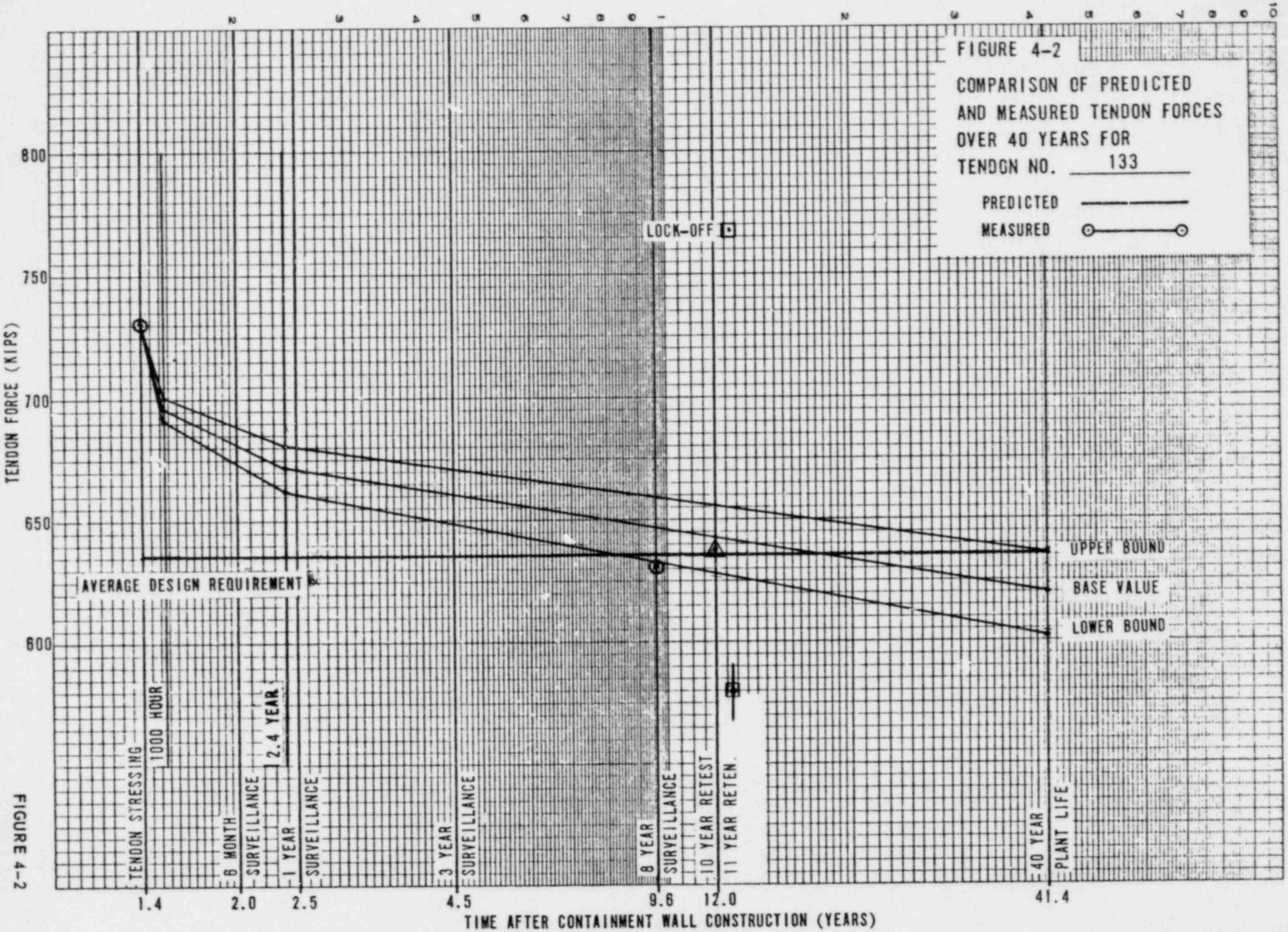
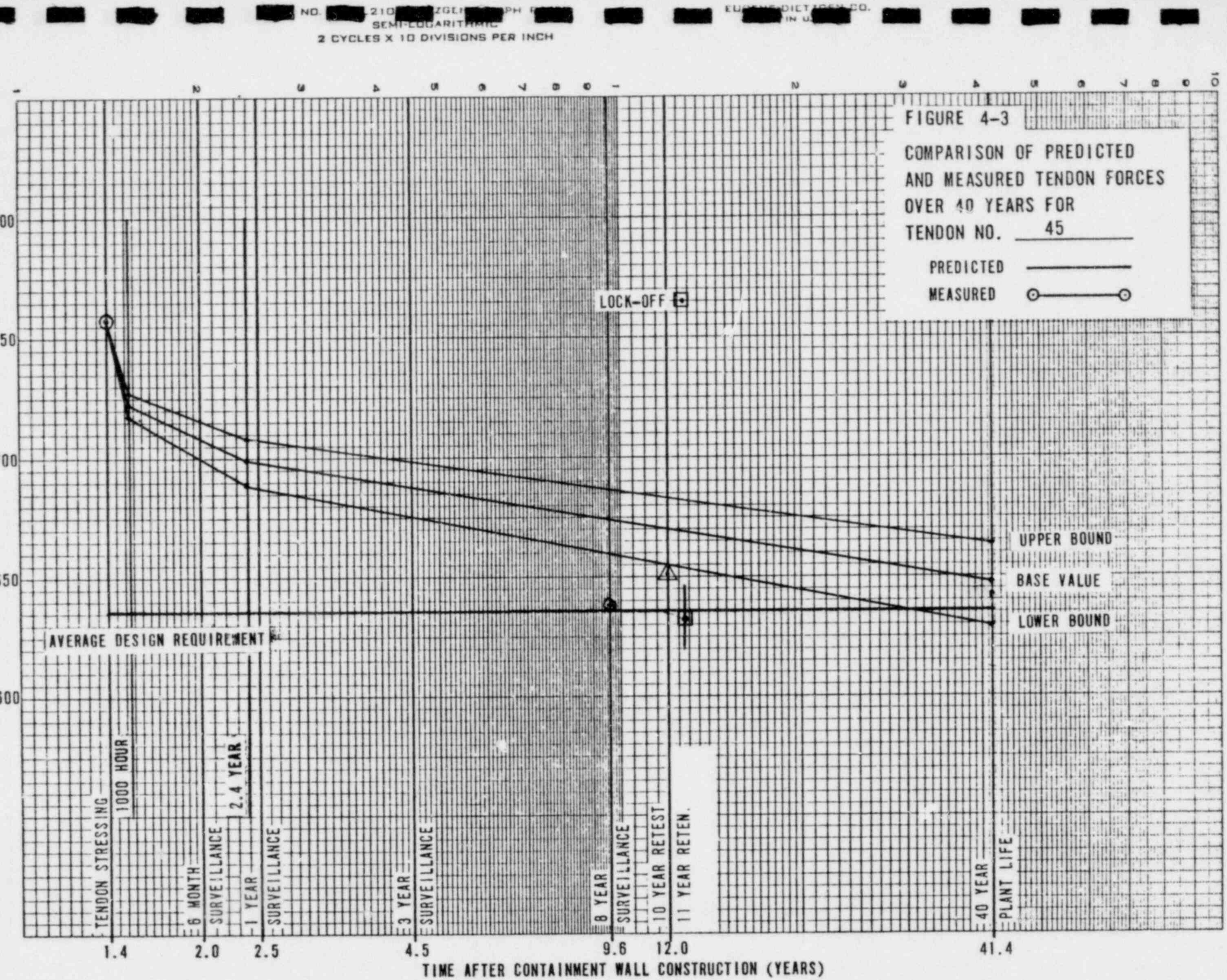


FIGURE 4-2



SEMI-LOGARITHMIC
2 CYCLES X 10 DIVISIONS PER INCH
FIGURE 4-3
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES OVER 40 YEARS FOR TENDON NO. 45
PREDICTED
MEASURED
LOCK-OFF
TENDON FORCE (KIPS)
800
750
700
650
600
UPPER BOUND
BASE VALUE
LOWER BOUND
AVERAGE DESIGN REQUIREMENT
TENDON STRESSING
1000 HOUR
6 MONTH SURVEILLANCE
2.4 YEAR
1 YEAR SURVEILLANCE
3 YEAR SURVEILLANCE
8 YEAR SURVEILLANCE
10 YEAR RETEST
11 YEAR RETEN.
40 YEAR PLANT LIFE
1.4
2.0
2.5
4.5
9.6
12.0
41.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)

FIGURE 4-3

SEMI-LOGARITHMIC
2 CYCLES X 10 DIVISIONS PER INCH

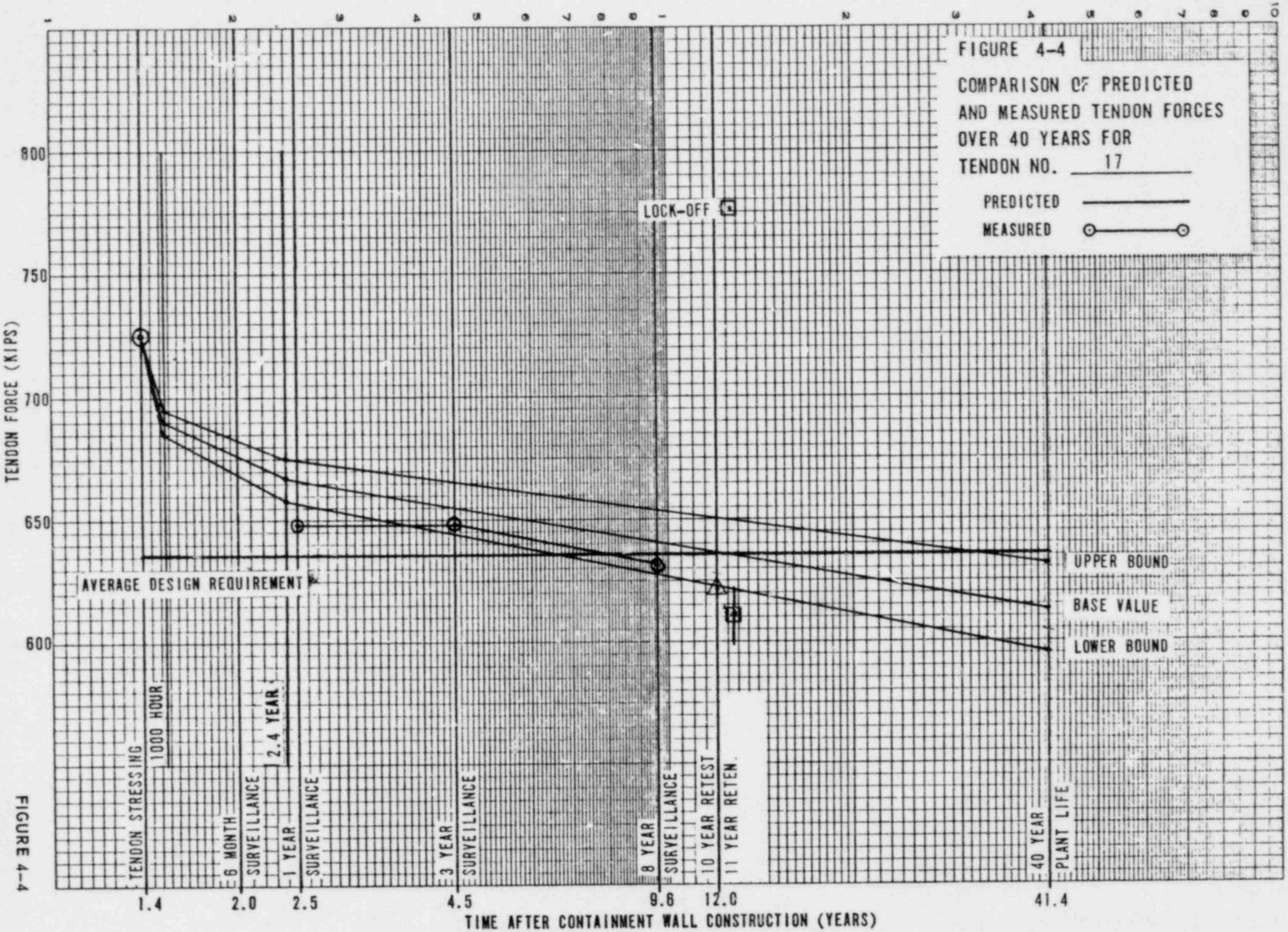


FIGURE 4-4

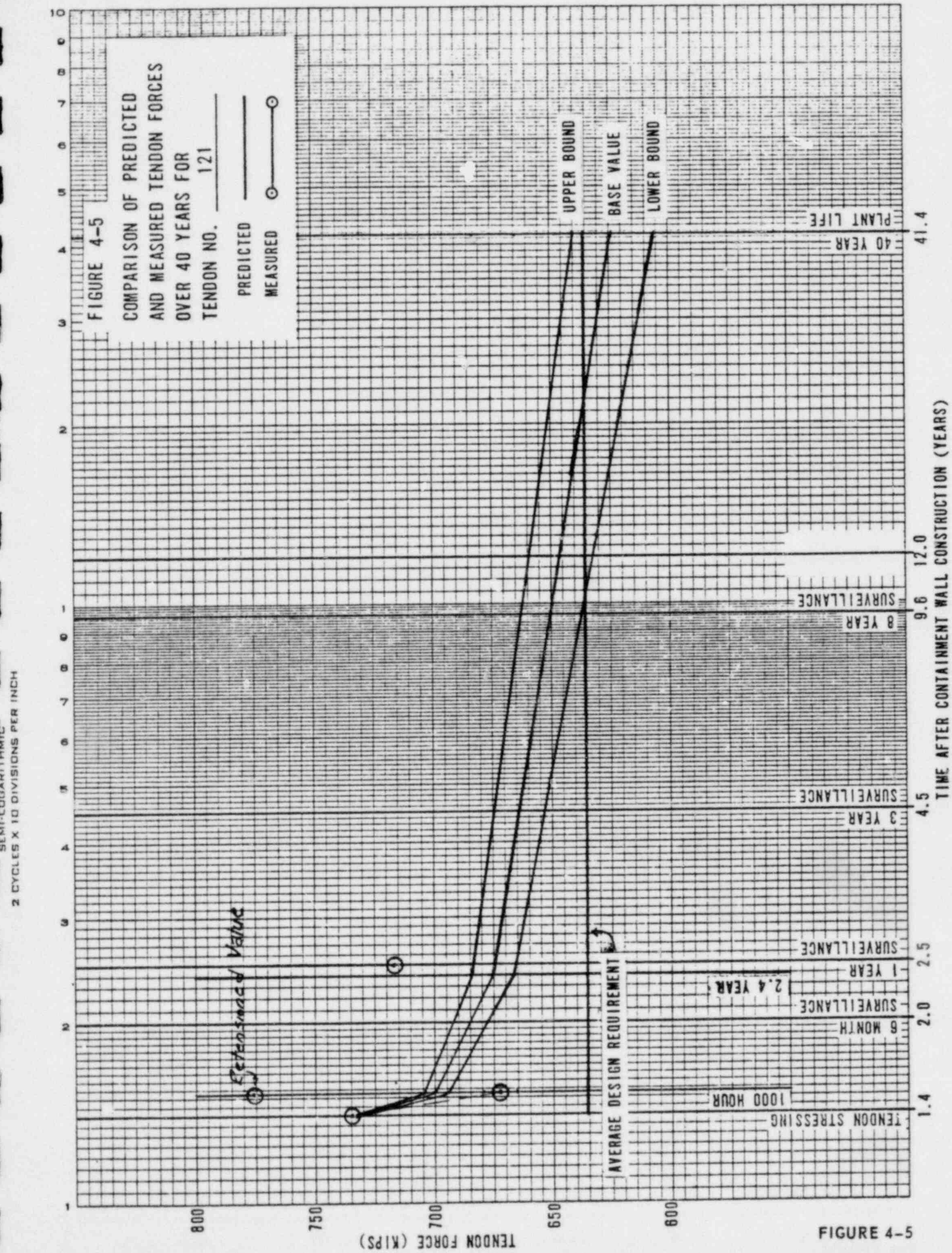


FIGURE 4-5
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES OVER 40 YEARS FOR TENDON NO. 121
PREDICTED
MEASURED
UPPER BOUND
BASE VALUE
LOWER BOUND
AVERAGE DESIGN REQUIREMENT
Extrapolated Value
TENDON STRESSING
1000 HOUR
6 MONTH
SURVEILLANCE
2.4 YEAR
1 YEAR
SURVEILLANCE
3 YEAR
SURVEILLANCE
8 YEAR
SURVEILLANCE
40 YEAR
PLANT LIFE
1.4
2.0
2.5
4.5
9.6
12.0
41.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)
800
750
700
650
600
TENDON FORCE (KIPS)
SEMI-LOGARITHMIC
2 CYCLES X 10 DIVISIONS PER INCH

FIGURE 4-5

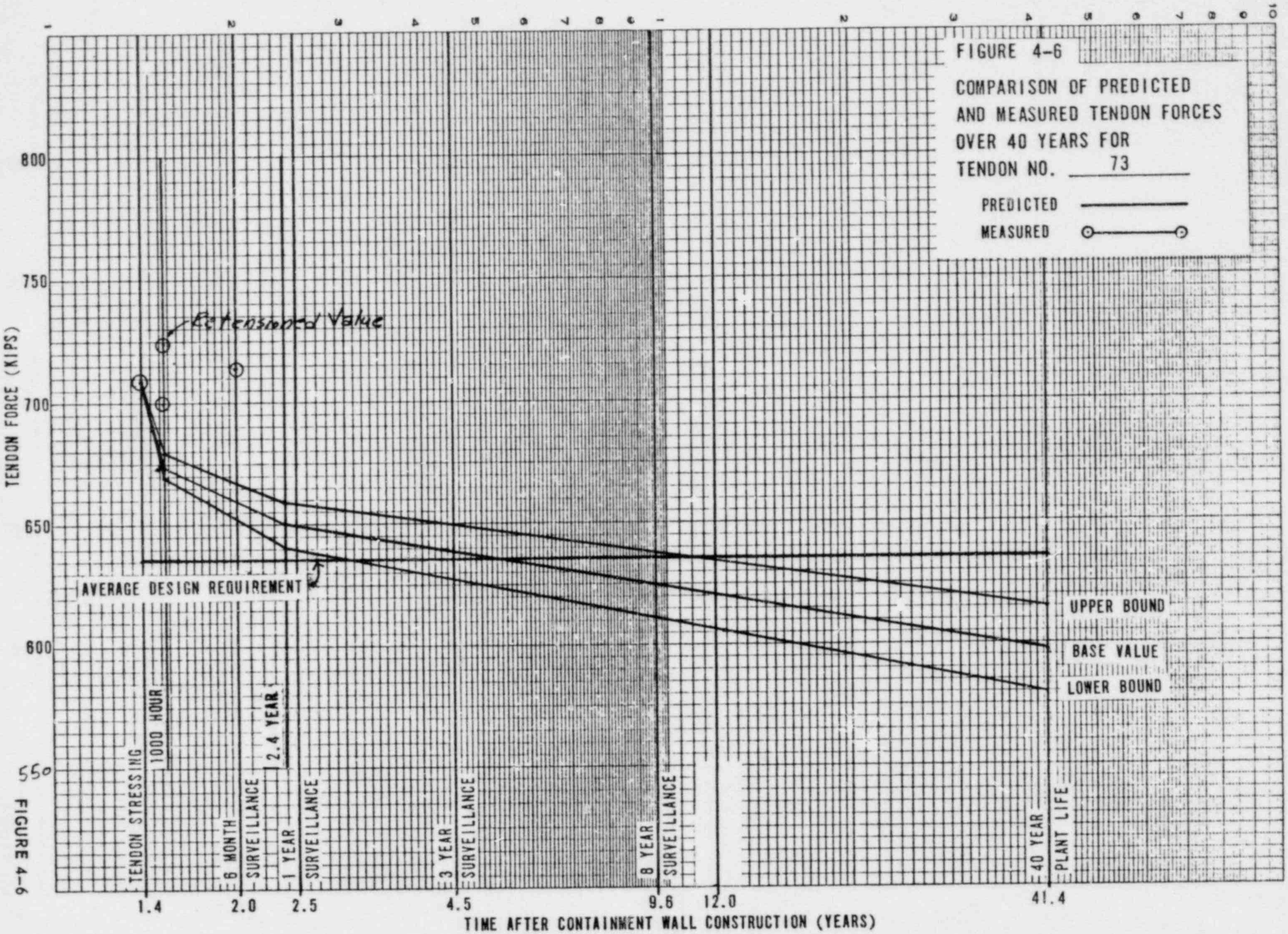


FIGURE 4-6
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES OVER 40 YEARS FOR TENDON NO. 73
PREDICTED
MEASURED
Retensioned Value
AVERAGE DESIGN REQUIREMENT
UPPER BOUND
BASE VALUE
LOWER BOUND
TENDON STRESSING
1000 HOUR
6 MONTH
SURVEILLANCE
2.4 YEAR
1 YEAR
SURVEILLANCE
3 YEAR
SURVEILLANCE
8 YEAR
SURVEILLANCE
40 YEAR
PLANT LIFE
800
750
700
650
600
550
TENDON FORCE (KIPS)
1.4
2.0
2.5
4.5
9.6
12.0
41.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)

FIGURE 4-6

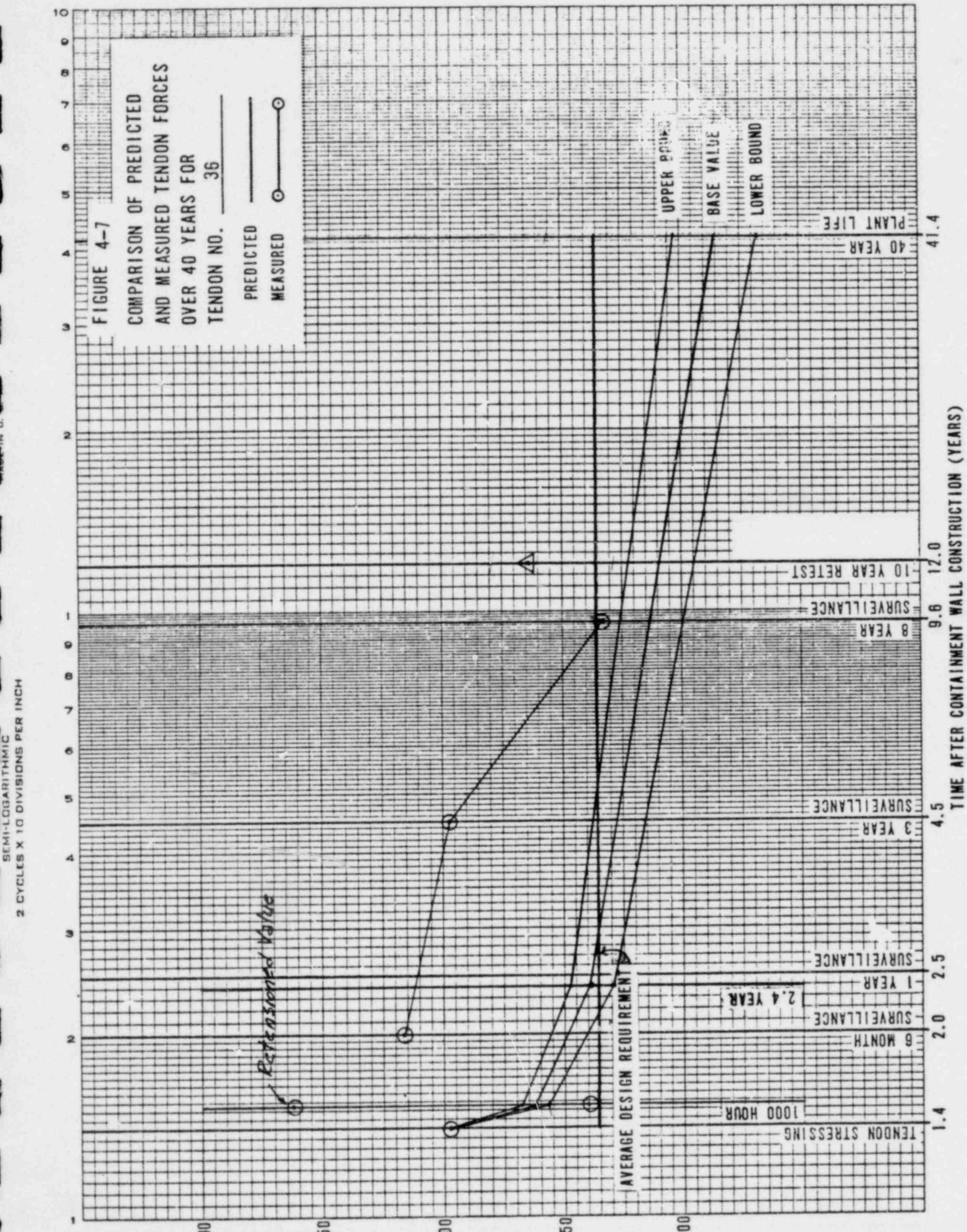


FIGURE 4-7
COMPARISON OF PREDICTED
AND MEASURED TENDON FORCES
OVER 40 YEARS FOR
TENDON NO. 36
PREDICTED
MEASURED
UPPER BOUND
BASE VALUE
LOWER BOUND
PLANT LIFE
40 YEAR
10 YEAR RETEST
SURVEILLANCE
8 YEAR
SURVEILLANCE
3 YEAR
SURVEILLANCE
1 YEAR
2.4 YEAR
SURVEILLANCE
6 MONTH
1000 HOUR
TENDON STRESSING
41.4
12.0
9.6
4.5
2.5
2.0
1.4
AVERAGE DESIGN REQUIREMENT
Retensioned Value
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)
TENDON FORCE (KIPS)
800
750
700
650
600
SEMI-LOGARITHMIC
2 CYCLES X 10 DIVISIONS PER INCH

FIGURE 4-7

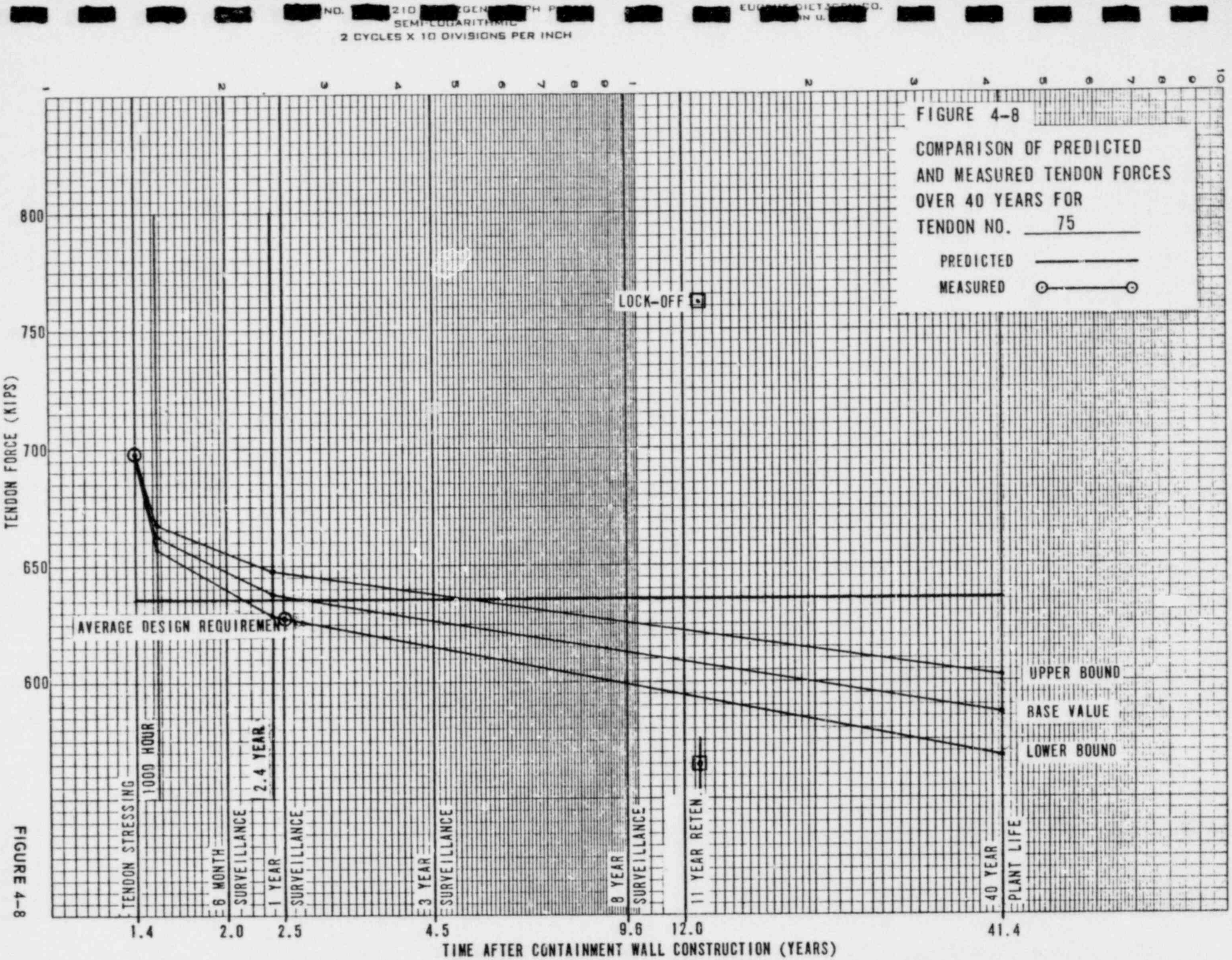

SEMI-LOGARITHMIC
2 CYCLES X 10 DIVISIONS PER INCH
FIGURE 4-8
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES OVER 40 YEARS FOR TENDON NO. 75
PREDICTED
MEASURED
LOCK-OFF
TENDON FORCE (KIPS)
800
750
700
650
600
AVERAGE DESIGN REQUIREMENT
UPPER BOUND
BASE VALUE
LOWER BOUND
TENDON STRESSING
1000 HOUR
6 MONTH SURVEILLANCE
2.4 YEAR
1 YEAR SURVEILLANCE
3 YEAR SURVEILLANCE
8 YEAR SURVEILLANCE
11 YEAR RETEN.
40 YEAR PLANT LIFE
1.4
2.0
2.5
4.5
9.6
12.0
41.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)

FIGURE 4-8

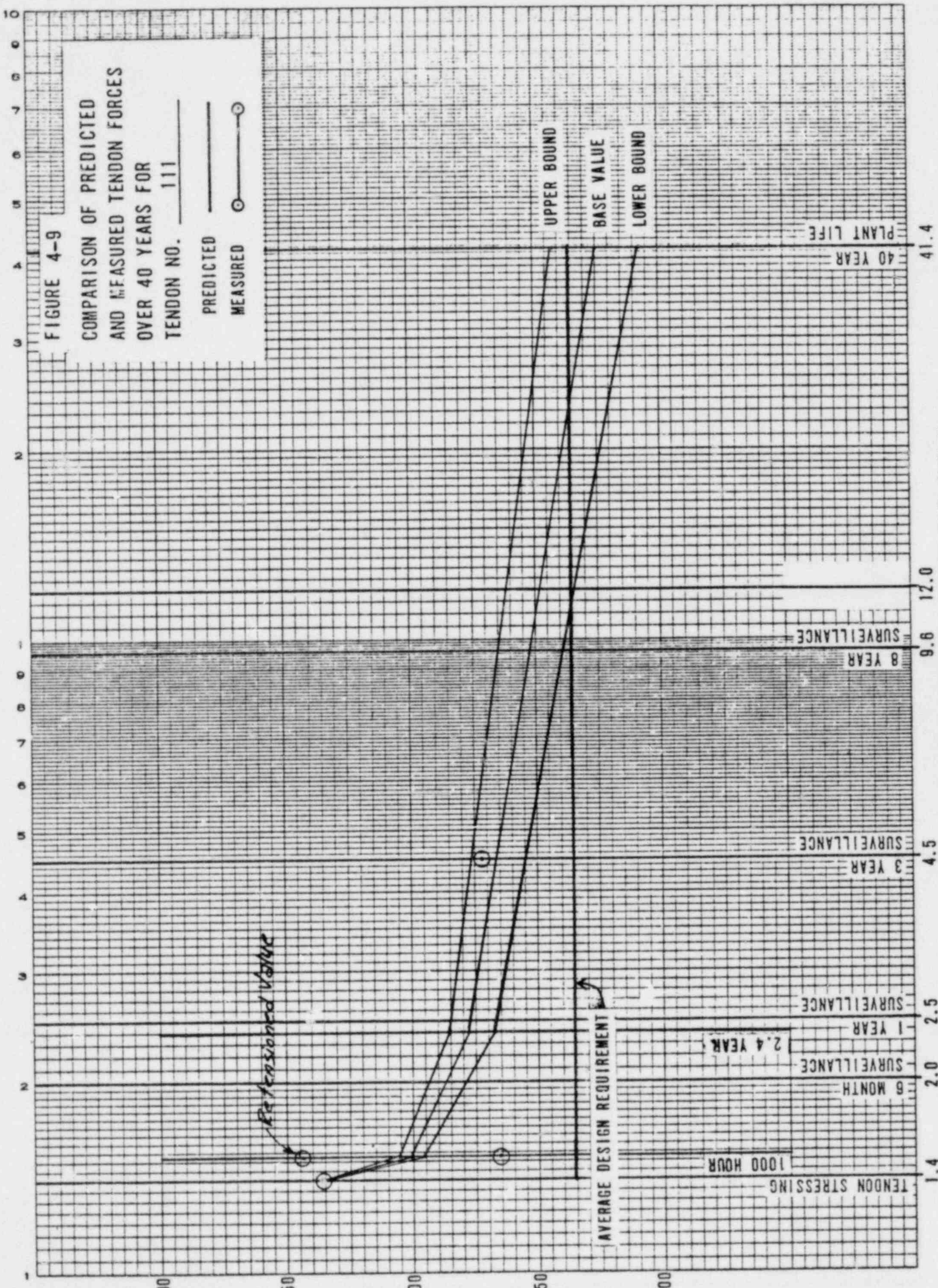


FIGURE 4-9
COMPARISON OF PREDICTED
AND MEASURED TENDON FORCES
OVER 40 YEARS FOR
TENDON NO. 111
PREDICTED
MEASURED
UPPER BOUND
BASE VALUE
LOWER BOUND
PLANT LIFE
40 YEAR
41.4
12.0
SURVEILLANCE
9.6
8 YEAR
SURVEILLANCE
4.5
3 YEAR
SURVEILLANCE
2.5
1 YEAR
2.4 YEAR
SURVEILLANCE
2.0
6 MONTH
1000 HOUR
1.4
TENDON STRESSING
AVERAGE DESIGN REQUIREMENT
Retensioned Value
800
750
700
650
600
TENDON FORCE (KIPS)
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)
SEMI-LOGARITHMIC
2 CYCLES X 10 DIVISIONS PER INCH

FIGURE 4-9

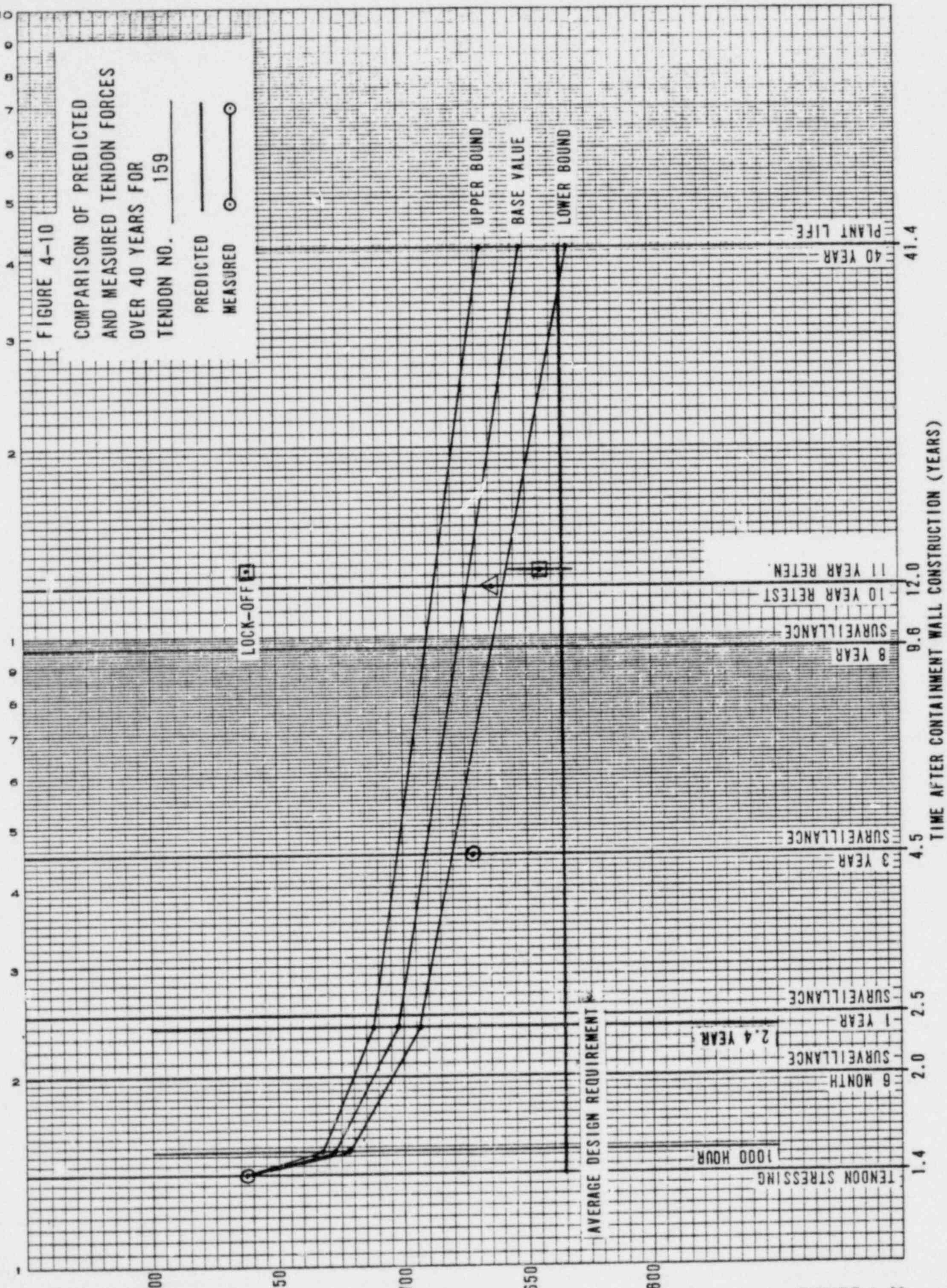


FIGURE 4-10
COMPARISON OF PREDICTED
AND MEASURED TENDON FORCES
OVER 40 YEARS FOR
TENDON NO. 159
PREDICTED
MEASURED
UPPER BOUND
BASE VALUE
LOWER BOUND
PLANT LIFE
40 YEAR
41.4
11 YEAR RETEN.
10 YEAR RETEST
12.0
LOCK-OFF
SURVEILLANCE
8 YEAR
9.6
SURVEILLANCE
3 YEAR
4.5
SURVEILLANCE
1 YEAR
2.5
2.4 YEAR
SURVEILLANCE
6 MONTH
2.0
1000 HOUR
TENDON STRESSING
1.4
AVERAGE DESIGN REQUIREMENT
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)
800
750
700
650
600
TENDON FORCE (KIPS)
SEMI-LOGARITHMIC
2 CYCLES X 10 DIVISIONS PER INCH

FIGURE 4-10

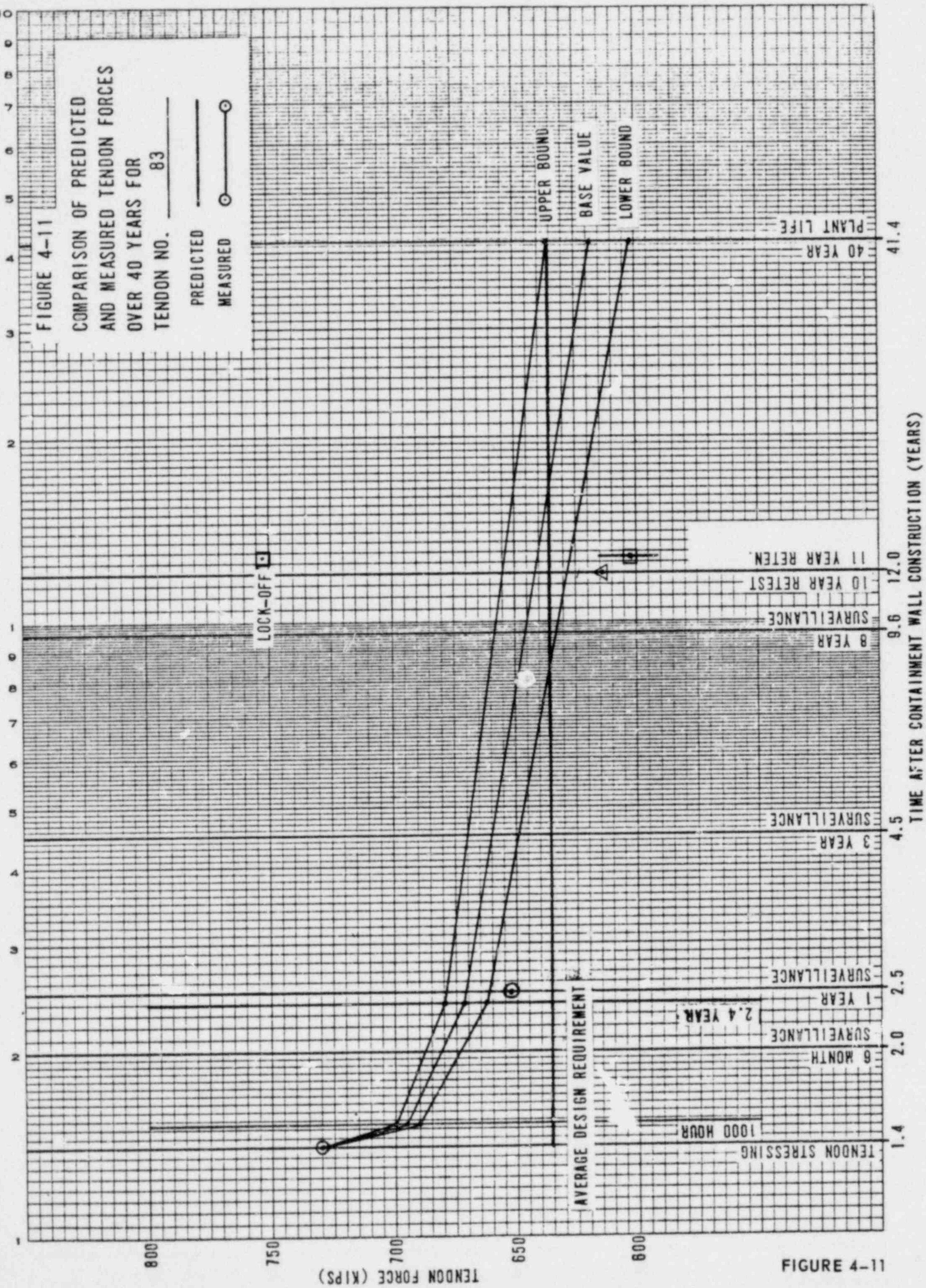


FIGURE 4-11
COMPARISON OF PREDICTED
AND MEASURED TENDON FORCES
OVER 40 YEARS FOR
TENDON NO. 83
PREDICTED
MEASURED
UPPER BOUND
BASE VALUE
LOWER BOUND
LOCK-OFF
AVERAGE DESIGN REQUIREMENT
PLANT LIFE
40 YEAR
11 YEAR RETEN.
10 YEAR RETEST
SURVEILLANCE
8 YEAR
SURVEILLANCE
3 YEAR
SURVEILLANCE
1 YEAR
2.4 YEAR
SURVEILLANCE
6 MONTH
1000 HOUR
TENDON STRESSING
41.4
12.0
9.6
4.5
2.5
2.0
1.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)
800
750
700
650
600
TENDON FORCE (KIPS)
2 CYCLES X 10 DIVISIONS PER INCH

FIGURE 4-11

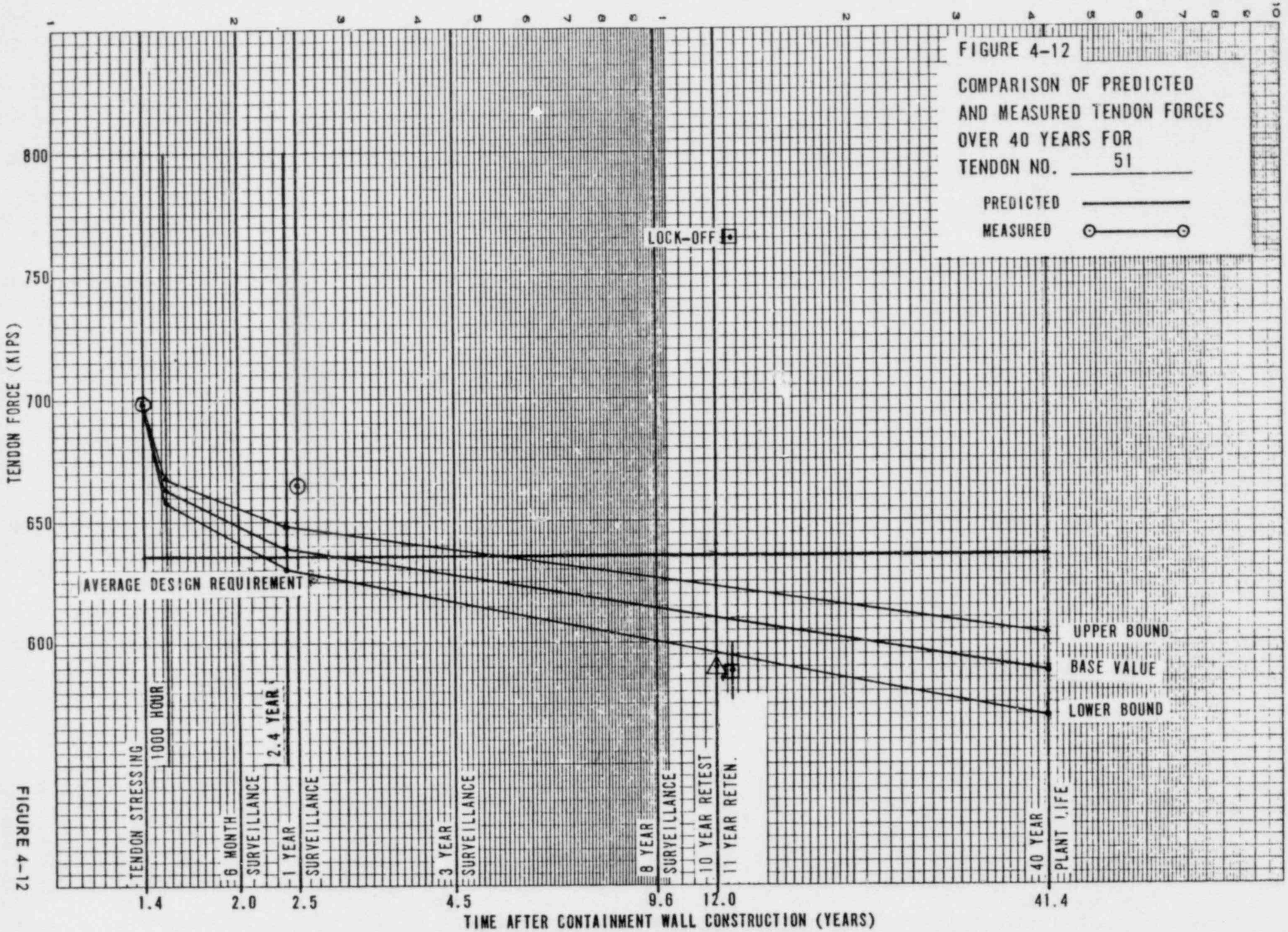
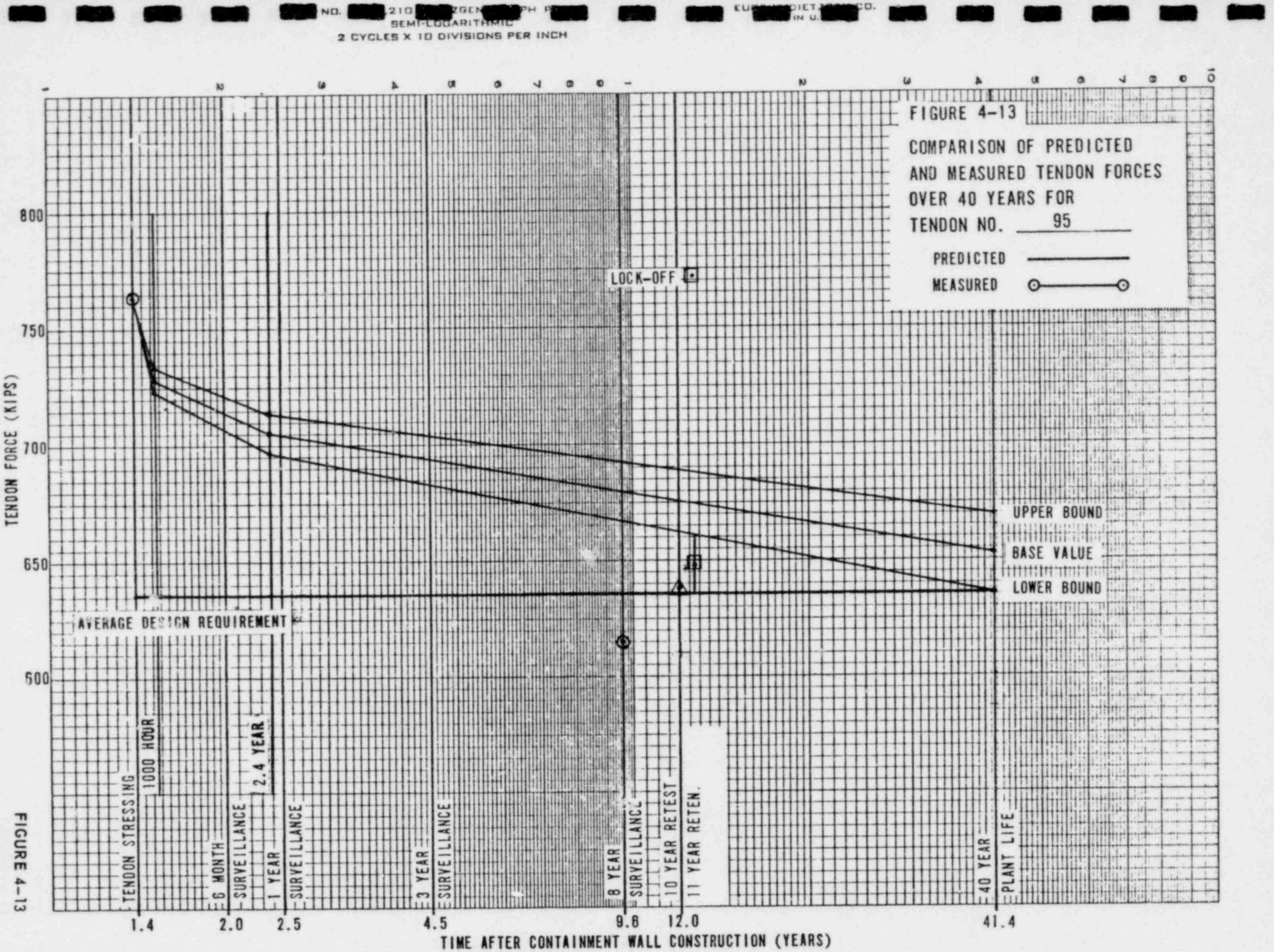


FIGURE 4-12
COMPARISON OF PREDICTED
AND MEASURED TENDON FORCES
OVER 40 YEARS FOR
TENDON NO. 51
PREDICTED
MEASURED
LOCK-OFF
AVERAGE DESIGN REQUIREMENT
UPPER BOUND
BASE VALUE
LOWER BOUND
TENDON STRESSING
1000 HOUR
6 MONTH
SURVEILLANCE
2.4 YEAR
1 YEAR
SURVEILLANCE
3 YEAR
SURVEILLANCE
8 YEAR
SURVEILLANCE
10 YEAR RETEST
11 YEAR RETEN.
40 YEAR
PLANT LIFE
800
750
700
650
600
TENDON FORCE (KIPS)
1.4
2.0
2.5
4.5
9.6
12.0
41.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)

FIGURE 4-12



NO. [redacted] 210 [redacted]
SEMI-LOGARITHMIC
2 CYCLES X 10 DIVISIONS PER INCH
FIGURE 4-13
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES OVER 40 YEARS FOR TENDON NO. 95
PREDICTED
MEASURED
TENDON FORCE (KIPS)
800
750
700
650
600
LOCK-OFF
UPPER BOUND
BASE VALUE
LOWER BOUND
AVERAGE DESIGN REQUIREMENT
TENDON STRESSING
1000 HOUR
6 MONTH SURVEILLANCE
2.4 YEAR
1 YEAR SURVEILLANCE
3 YEAR SURVEILLANCE
8 YEAR SURVEILLANCE
10 YEAR RETEST
11 YEAR RETEN.
40 YEAR PLANT LIFE
1.4
2.0
2.5
4.5
9.8
12.0
41.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)

FIGURE 4-13

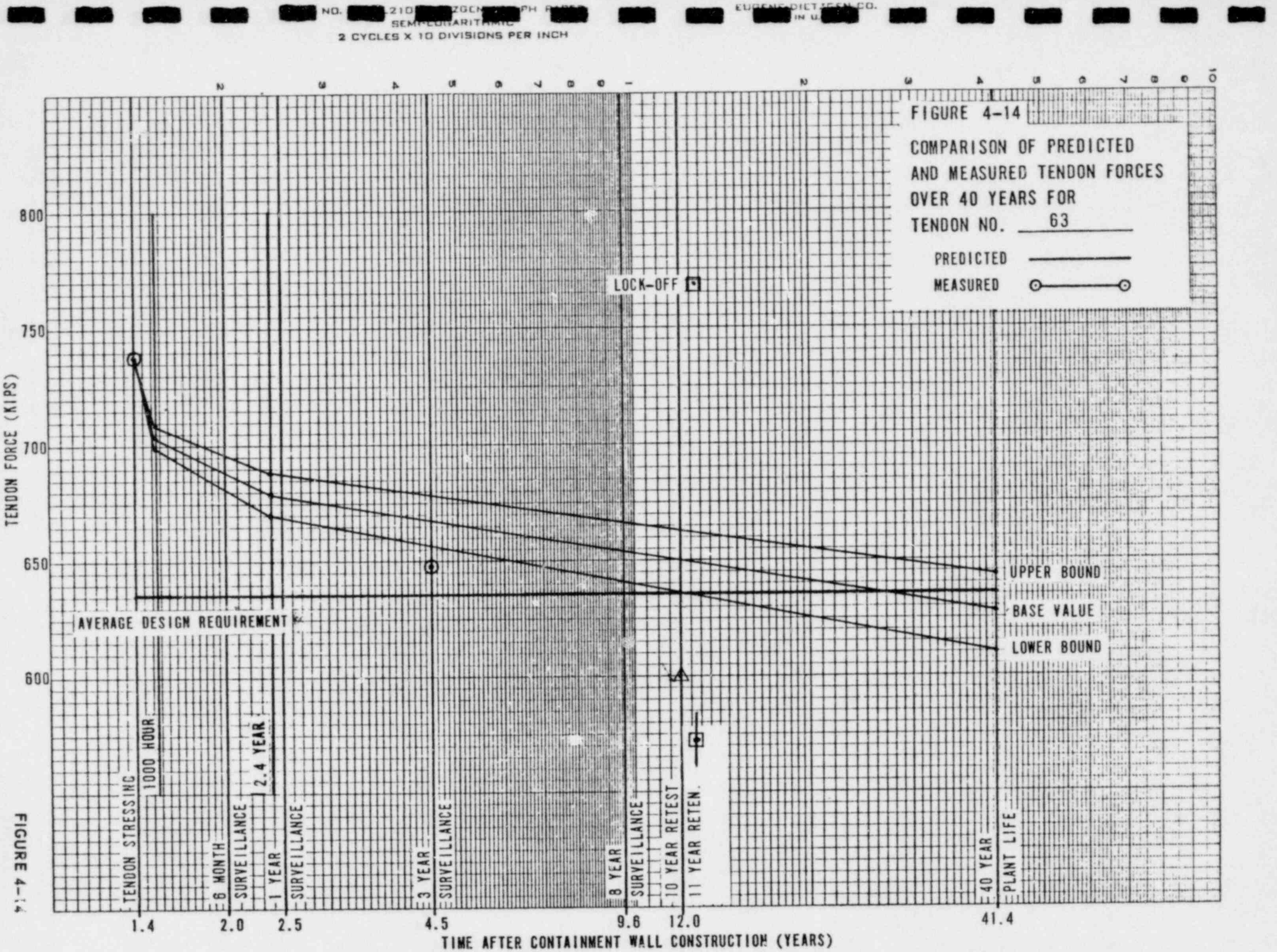


FIGURE 4-14
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES OVER 40 YEARS FOR TENDON NO. 63
PREDICTED
MEASURED
LOCK-OFF
TENDON FORCE (KIPS)
800
750
700
650
600
UPPER BOUND
BASE VALUE
LOWER BOUND
AVERAGE DESIGN REQUIREMENT
TENDON STRESSING
1000 HOUR
6 MONTH SURVEILLANCE
2.4 YEAR
1 YEAR SURVEILLANCE
3 YEAR SURVEILLANCE
8 YEAR SURVEILLANCE
10 YEAR RETEST
11 YEAR RETEN.
40 YEAR PLANT LIFE
1.4
2.0
2.5
4.5
9.6
12.0
41.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)
SEMI-LOGARITHMIC
2 CYCLES X 10 DIVISIONS PER INCH

FIGURE 4-14

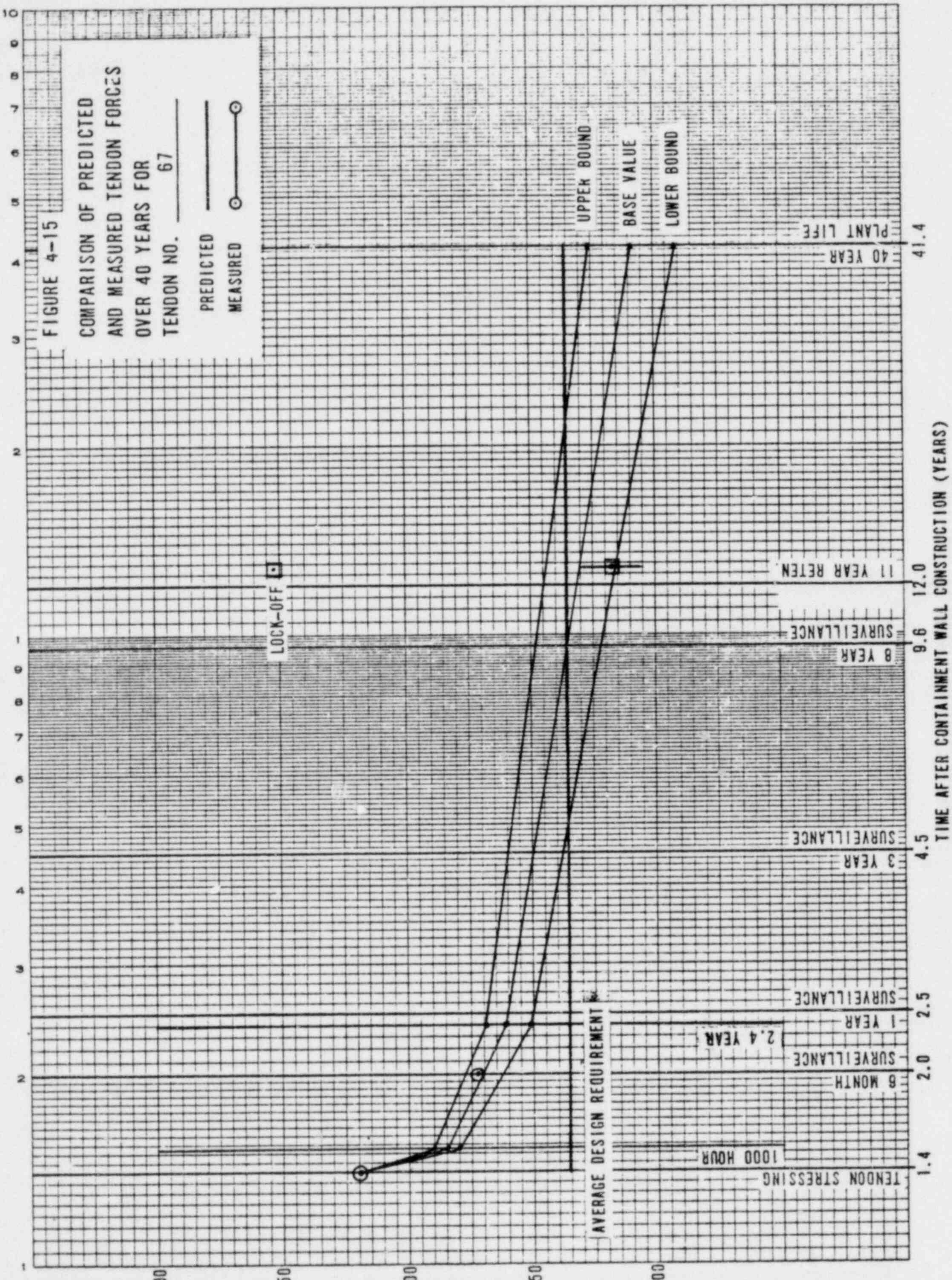


FIGURE 4-15
COMPARISON OF PREDICTED
AND MEASURED TENDON FORCES
OVER 40 YEARS FOR
TENDON NO. 67
PREDICTED
MEASURED
UPPER BOUND
BASE VALUE
LOWER BOUND
PLANT LIFE
40 YEAR
41.4
LOCK-OFF
11 YEAR RETEN
12.0
SURVEILLANCE
8 YEAR
9.6
SURVEILLANCE
3 YEAR
4.5
SURVEILLANCE
1 YEAR
2.5
2.4 YEAR
SURVEILLANCE
6 MONTH
2.0
1000 HOUR
1.4
TENDON STRESSING
AVERAGE DESIGN REQUIREMENT
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)
800
750
700
650
600
TENDON FORCE (KIPS)
SEMI-LOGARITHMIC
2 CYCLES X 10 DIVISIONS PER INCH

FIGURE 4-15

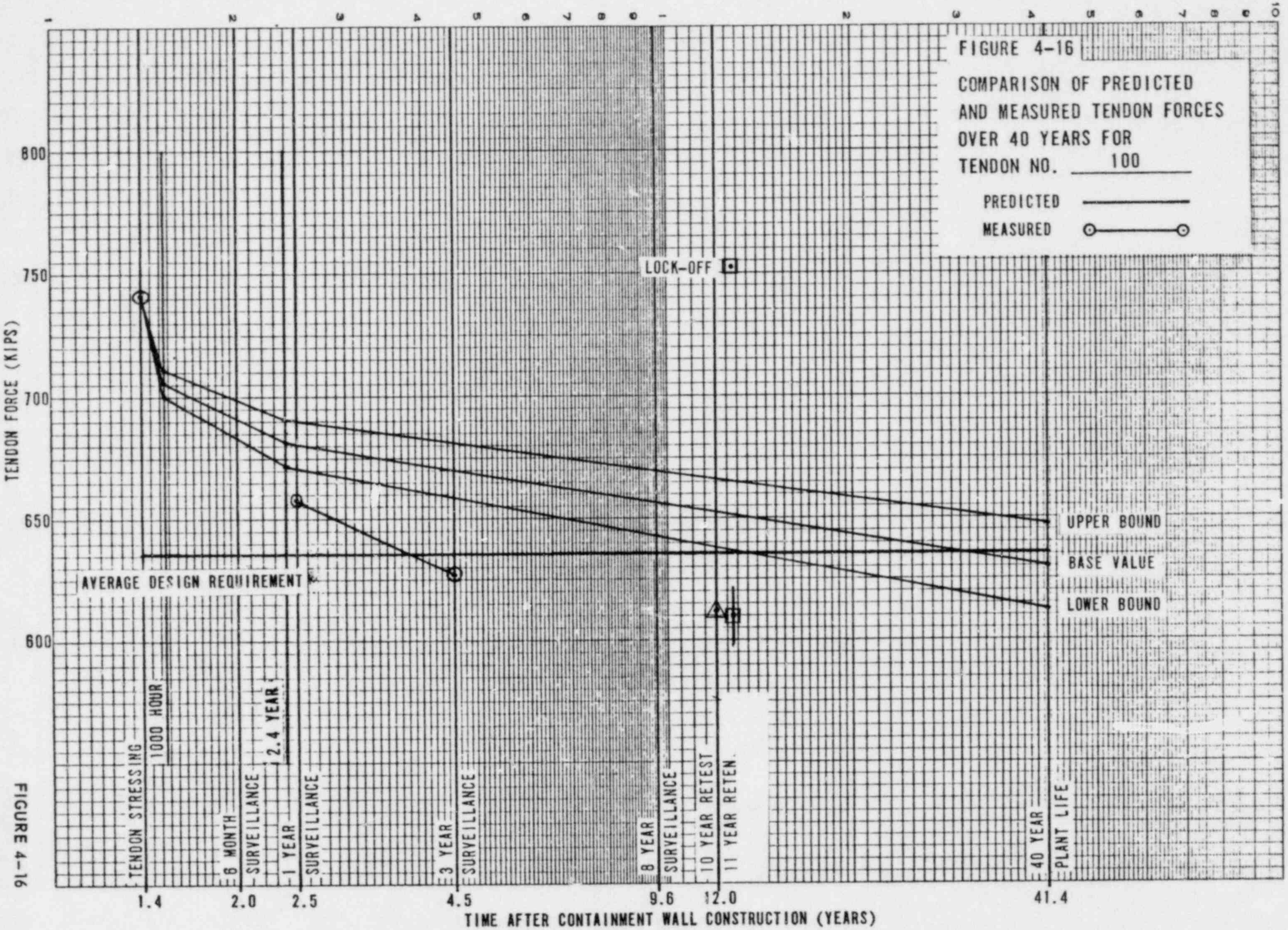


FIGURE 4-16
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES OVER 40 YEARS FOR TENDON NO. 100
PREDICTED
MEASURED
LOCK-OFF
800
750
700
650
600
TENDON FORCE (KIPS)
UPPER BOUND
BASE VALUE
LOWER BOUND
AVERAGE DESIGN REQUIREMENT
TENDON STRESSING
1000 HOUR
6 MONTH SURVEILLANCE
2.4 YEAR
1 YEAR SURVEILLANCE
3 YEAR SURVEILLANCE
8 YEAR SURVEILLANCE
10 YEAR RETEST
11 YEAR RETEN.
40 YEAR PLANT LIFE
1.4
2.0
2.5
4.5
9.6
12.0
41.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)

FIGURE 4-16

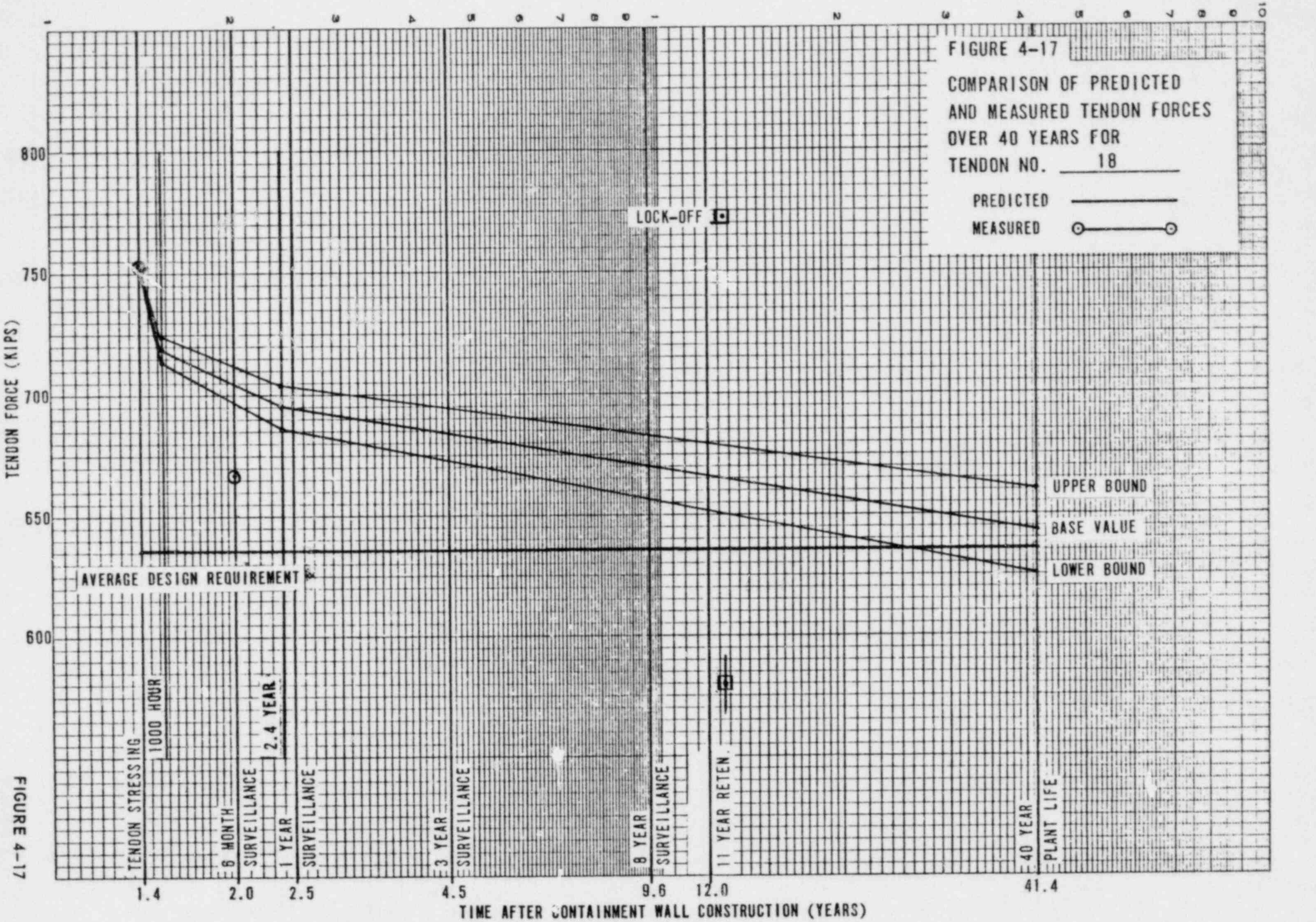


FIGURE 4-17
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES OVER 40 YEARS FOR TENDON NO. 18
PREDICTED
MEASURED
LOCK-OFF
TENDON FORCE (KIPS)
800
750
700
650
600
UPPER BOUND
BASE VALUE
LOWER BOUND
AVERAGE DESIGN REQUIREMENT
TENDON STRESSING
1000 HOUR
6 MONTH SURVEILLANCE
2.4 YEAR
1 YEAR SURVEILLANCE
3 YEAR SURVEILLANCE
8 YEAR SURVEILLANCE
11 YEAR RETEN.
40 YEAR PLANT LIFE
1.4
2.0
2.5
4.5
9.6
12.0
41.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)

FIGURE 4-17

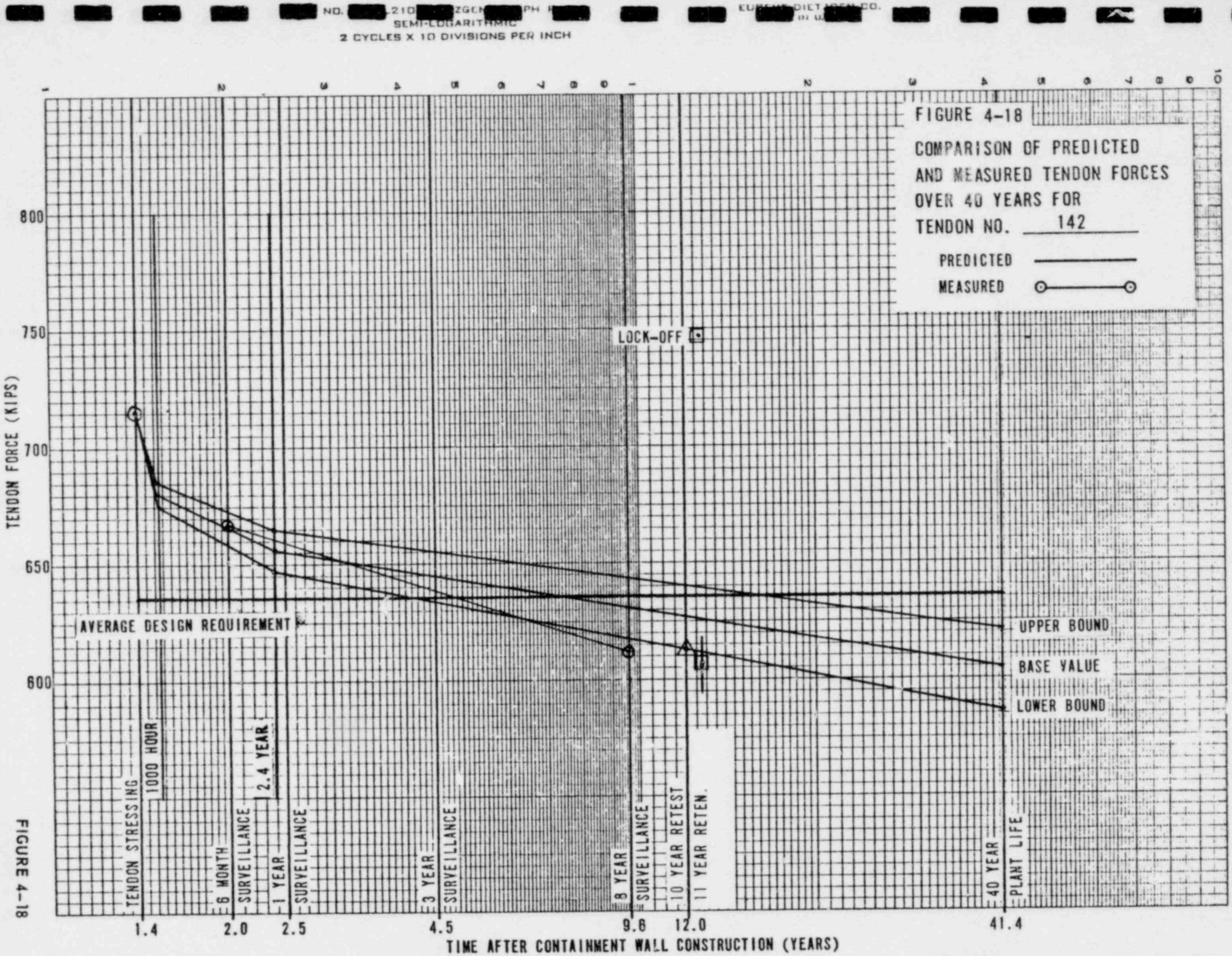

2 CYCLES X 10 DIVISIONS PER INCH
SEMI-LOGARITHMIC
FIGURE 4-18
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES OVER 40 YEARS FOR TENDON NO. 142
PREDICTED
MEASURED
LOCK-OFF
AVERAGE DESIGN REQUIREMENT
UPPER BOUND
BASE VALUE
LOWER BOUND
TENDON STRESSING
1000 HOUR
6 MONTH
SURVEILLANCE
2.4 YEAR
1 YEAR
SURVEILLANCE
3 YEAR
SURVEILLANCE
8 YEAR
SURVEILLANCE
10 YEAR RETEST
11 YEAR RETEN.
40 YEAR
PLANT LIFE
TENDON FORCE (KIPS)
800
750
700
650
600
1.4
2.0
2.5
4.5
9.6
12.0
41.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)

FIGURE 4-18

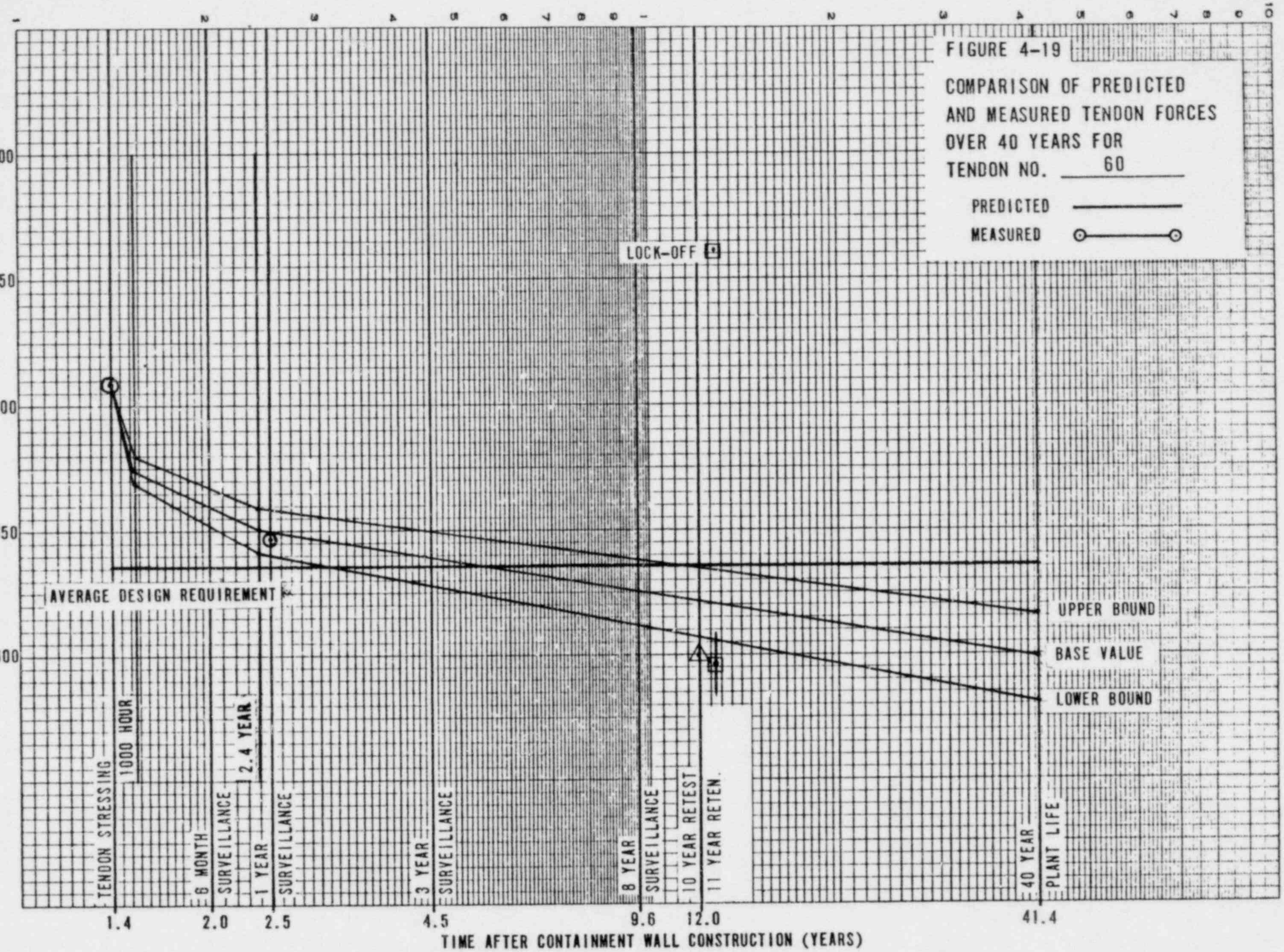


FIGURE 4-19
COMPARISON OF PREDICTED
AND MEASURED TENDON FORCES
OVER 40 YEARS FOR
TENDON NO. 60
PREDICTED
MEASURED
LOCK-OFF
UPPER BOUND
BASE VALUE
LOWER BOUND
AVERAGE DESIGN REQUIREMENT
TENDON STRESSING
1000 HOUR
6 MONTH
SURVEILLANCE
2.4 YEAR
1 YEAR
SURVEILLANCE
3 YEAR
SURVEILLANCE
8 YEAR
SURVEILLANCE
10 YEAR RETEST
11 YEAR RETEN.
40 YEAR
PLANT LIFE
TENDON FORCE (KIPS)
800
750
700
650
600
1.4
2.0
2.5
4.5
9.6
12.0
41.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)

FIGURE 4-19

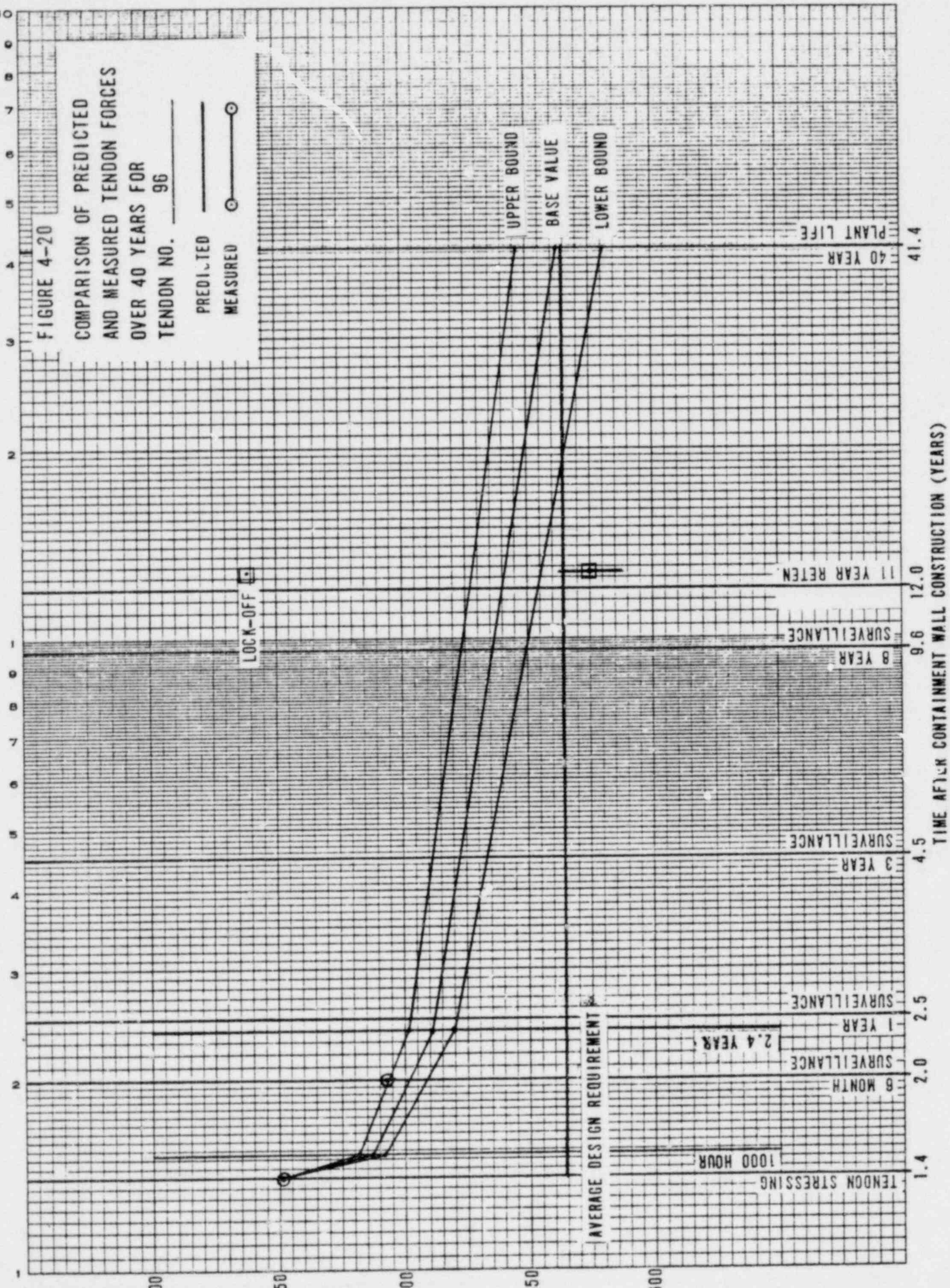


FIGURE 4-20
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES OVER 40 YEARS FOR TENDON NO. 96
PREDICTED
MEASURED
UPPER BOUND
BASE VALUE
LOWER BOUND
LOCK-OFF
AVERAGE DESIGN REQUIREMENT
PLANT LIFE
40 YEAR
11 YEAR RETEN.
SURVEILLANCE
8 YEAR
SURVEILLANCE
3 YEAR
SURVEILLANCE
1 YEAR
2.4 YEAR
SURVEILLANCE
6 MONTH
1000 HOUR
TENDON STRESSING
41.4
12.0
9.6
4.5
2.5
2.0
1.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)
TENDON FORCE (KIPS)
800
750
700
650
600
SEMI-LOGARITHMIC
2 CYCLES X 10 DIVISIONS PER INCH

FIGURE 4-20

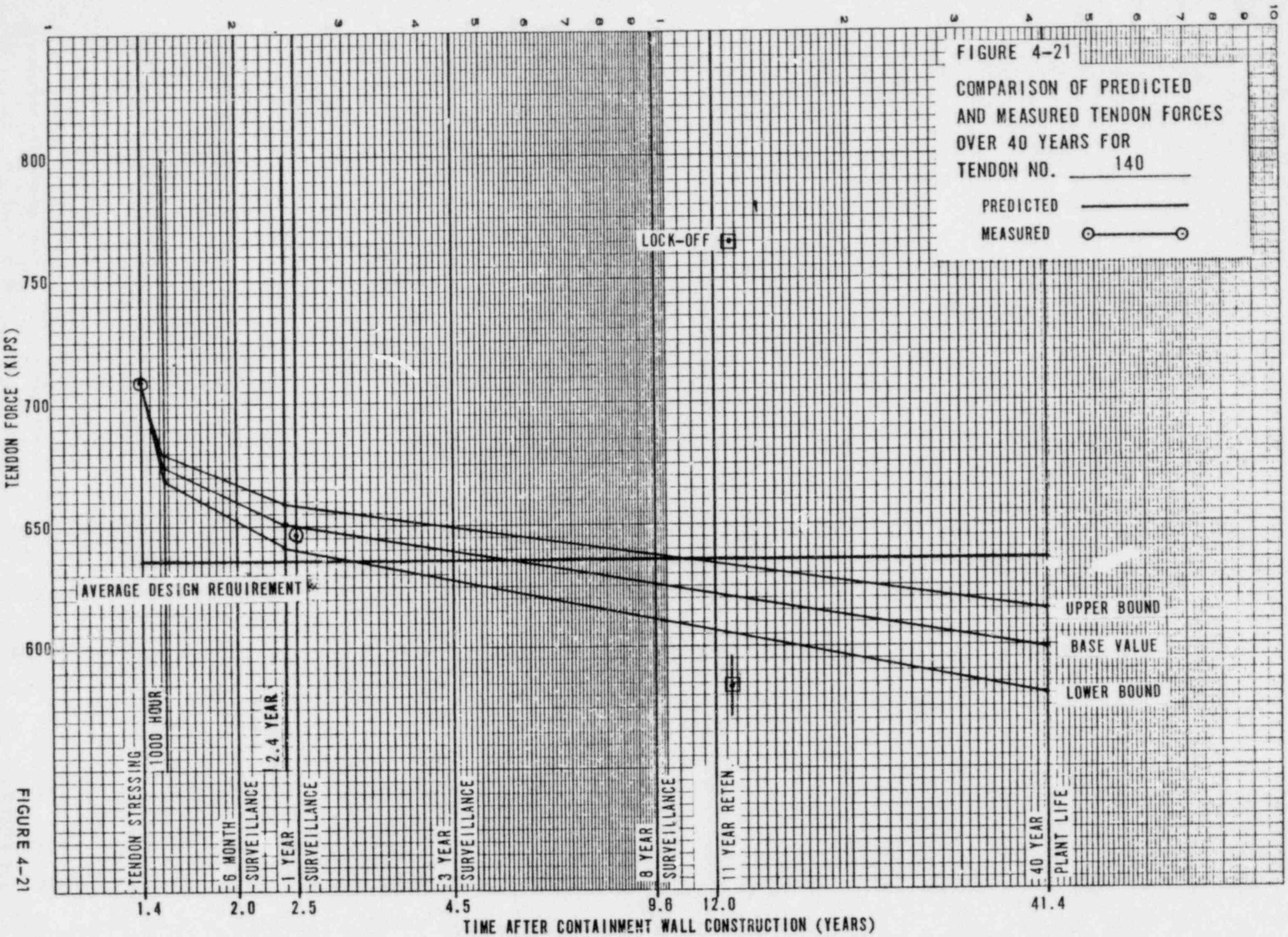


FIGURE 4-21
COMPARISON OF PREDICTED
AND MEASURED TENDON FORCES
OVER 40 YEARS FOR
TENDON NO. 140
PREDICTED
MEASURED
LOCK-OFF
TENDON FORCE (KIPS)
800
750
700
650
600
AVERAGE DESIGN REQUIREMENT
UPPER BOUND
BASE VALUE
LOWER BOUND
TENDON STRESSING
1000 HOUR
6 MONTH SURVEILLANCE
2.4 YEAR
1 YEAR SURVEILLANCE
3 YEAR SURVEILLANCE
8 YEAR SURVEILLANCE
11 YEAR RETEN.
40 YEAR PLANT LIFE
1.4
2.0
2.5
4.5
9.6
12.0
41.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)

FIGURE 4-21

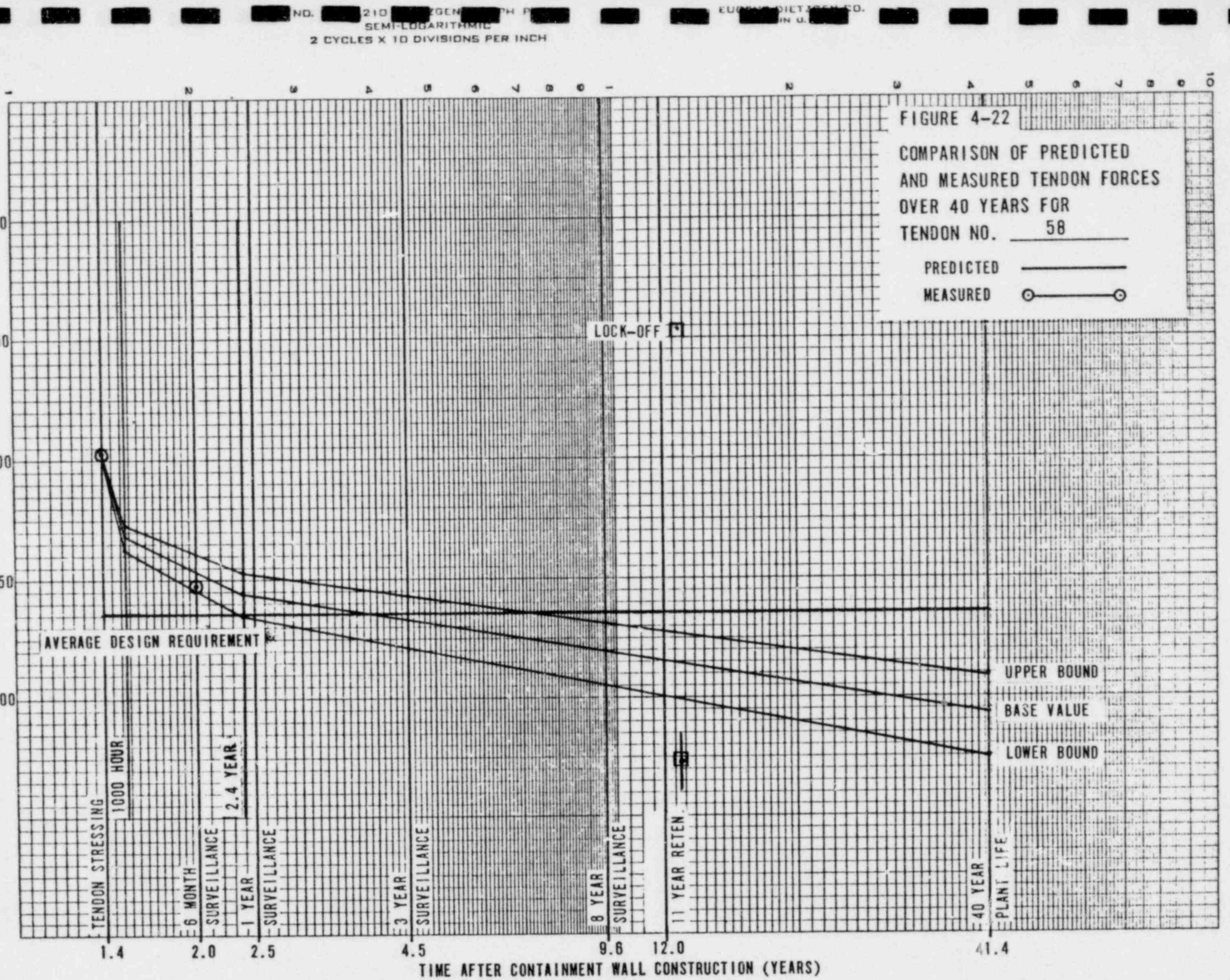


FIGURE 4-22
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES OVER 40 YEARS FOR TENDON NO. 58
PREDICTED
MEASURED
LOCK-OFF
TENDON FORCE (KIPS)
800
750
700
650
600
AVERAGE DESIGN REQUIREMENT
UPPER BOUND
BASE VALUE
LOWER BOUND
TENDON STRESSING
1000 HOUR
6 MONTH SURVEILLANCE
2.4 YEAR
1 YEAR SURVEILLANCE
3 YEAR SURVEILLANCE
8 YEAR SURVEILLANCE
11 YEAR RETEN
40 YEAR PLANT LIFE
1.4
2.0
2.5
4.5
9.6
12.0
41.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)
SEMI-LOGARITHMIC
2 CYCLES X 10 DIVISIONS PER INCH

FIGURE 4-22

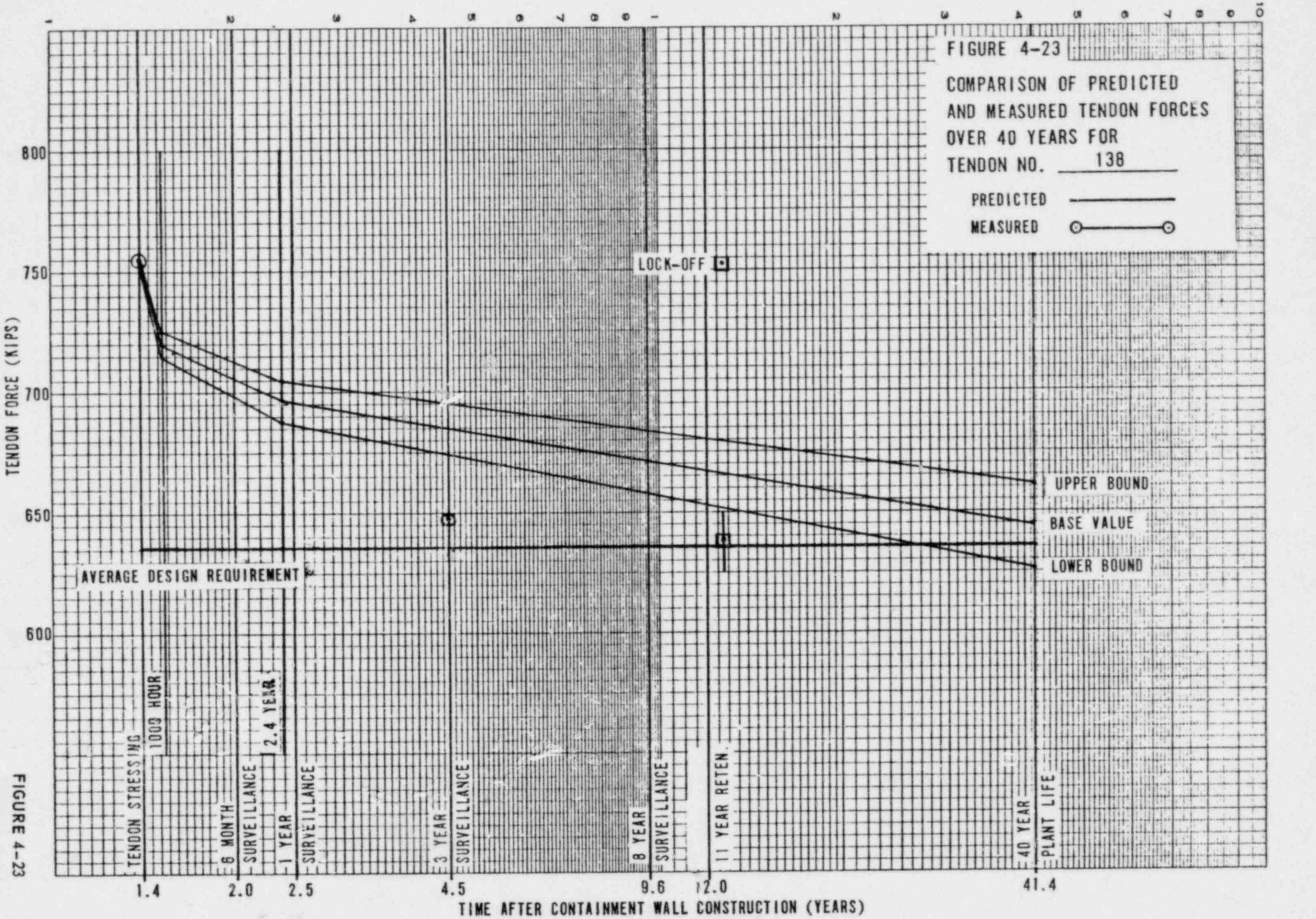
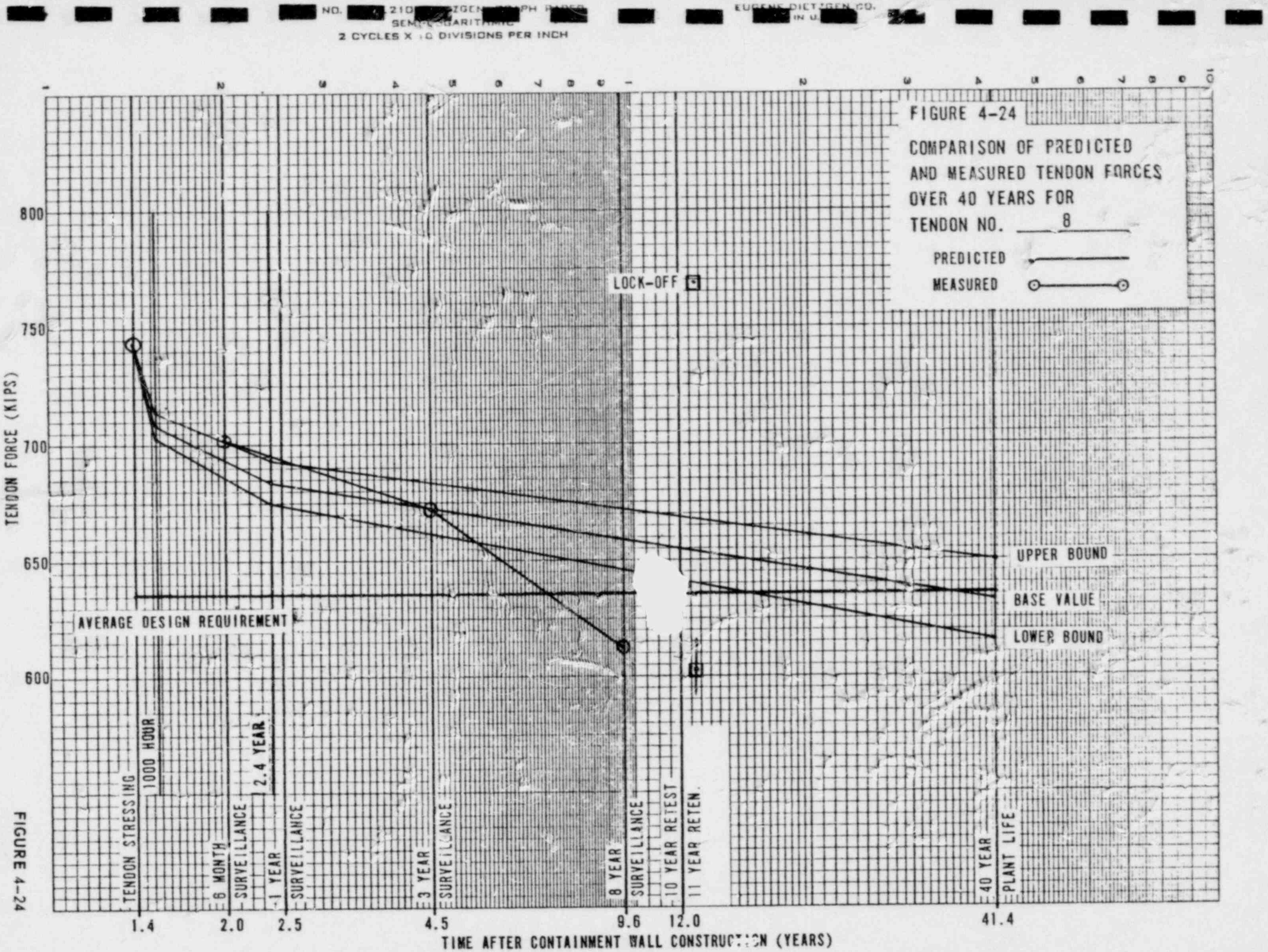


FIGURE 4-23
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES OVER 40 YEARS FOR TENDON NO. 138
PREDICTED
MEASURED
LOCK-OFF
UPPER BOUND
BASE VALUE
LOWER BOUND
AVERAGE DESIGN REQUIREMENT
TENDON FORCE (KIPS)
800
750
700
650
600
TENDON STRESSING
1000 HOUR
6 MONTH SURVEILLANCE
2.4 YEAR
1 YEAR SURVEILLANCE
3 YEAR SURVEILLANCE
8 YEAR SURVEILLANCE
11 YEAR RETEN.
40 YEAR PLANT LIFE
1.4
2.0
2.5
4.5
9.6
12.0
41.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)
SEMI-LOGARITHMIC
2 CYCLES X 10 DIVISIONS PER INCH

FIGURE 4-23



NO. 1210 DIETZGEN GRAPH PAPER
SEMI-LOGARITHMIC
2 CYCLES X 10 DIVISIONS PER INCH
EUGENE DIETZGEN CO.
FIGURE 4-24
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES OVER 40 YEARS FOR TENDON NO. 8
PREDICTED
MEASURED
LOCK-OFF
800
750
700
650
600
TENDON FORCE (KIPS)
UPPER BOUND
BASE VALUE
LOWER BOUND
AVERAGE DESIGN REQUIREMENT
TENDON STRESSING
1000 HOUR
6 MONTH SURVEILLANCE
2.4 YEAR
1 YEAR SURVEILLANCE
3 YEAR SURVEILLANCE
8 YEAR SURVEILLANCE
10 YEAR RETEST
11 YEAR RETEN.
40 YEAR PLANT LIFE
1.4
2.0
2.5
4.5
9.6
12.0
41.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)

FIGURE 4-24

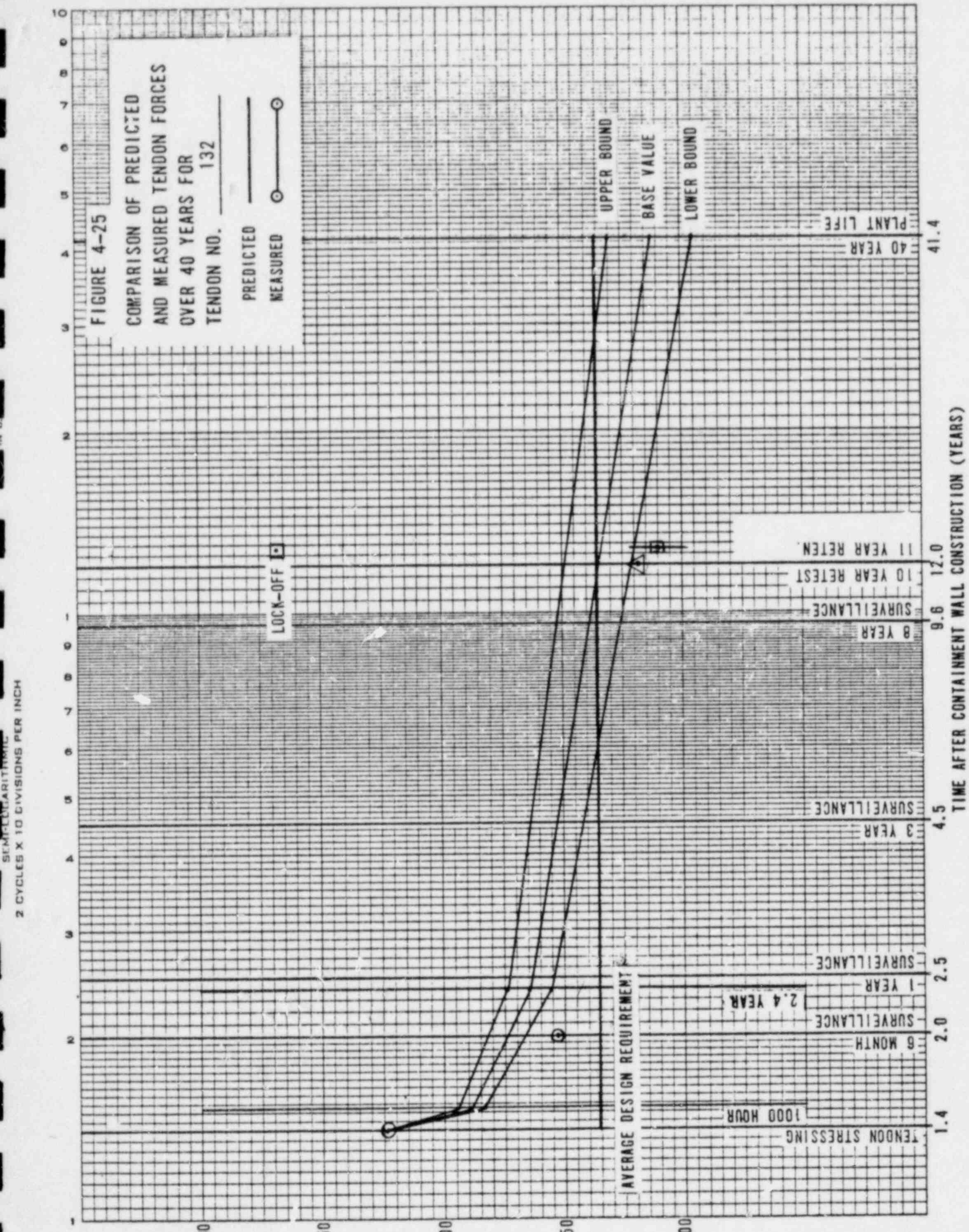


FIGURE 4-25
COMPARISON OF PREDICTED
AND MEASURED TENDON FORCES
OVER 40 YEARS FOR
TENDON NO. 132
PREDICTED
MEASURED
UPPER BOUND
BASE VALUE
LOWER BOUND
LOCK-OFF
AVERAGE DESIGN REQUIREMENT
TENDON STRESSING
1000 HOUR
6 MONTH
SURVEILLANCE
2.4 YEAR
1 YEAR
SURVEILLANCE
3 YEAR
SURVEILLANCE
8 YEAR
SURVEILLANCE
10 YEAR RETEST
11 YEAR RETEN.
40 YEAR
PLANT LIFE
1.4
2.0
2.5
4.5
9.6
12.0
41.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)
800
750
700
650
600
TENDON FORCE (KIPS)
SEMI-LOGARITHMIC
2 CYCLES X 10 DIVISIONS PER INCH

FIGURE 4-25

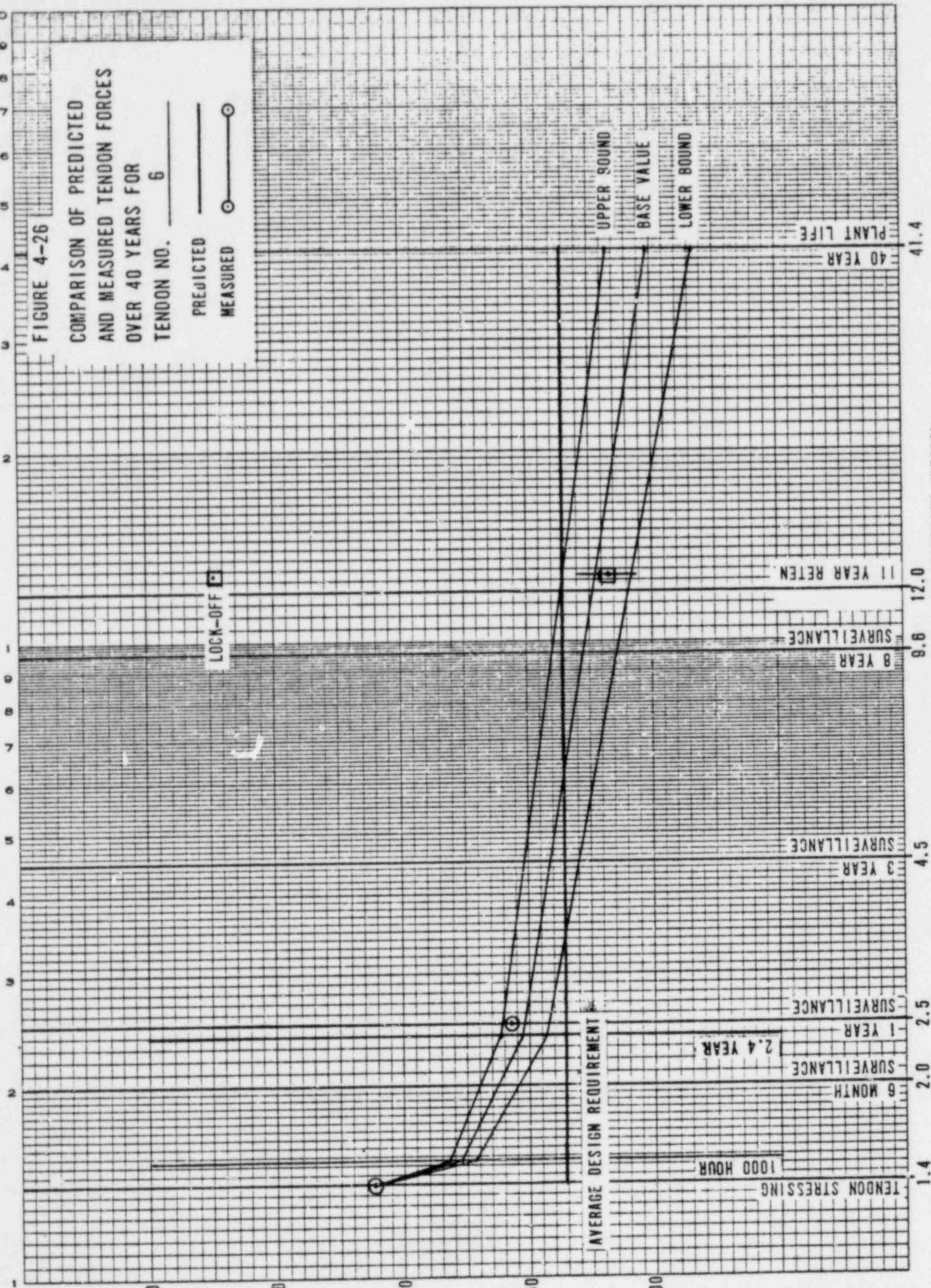


FIGURE 4-26
COMPARISON OF PREDICTED
AND MEASURED TENDON FORCES
OVER 40 YEARS FOR
TENDON NO. 6
PREDICTED
MEASURED
UPPER BOUND
BASE VALUE
LOWER BOUND
LOCK-OFF
AVERAGE DESIGN REQUIREMENT
TENDON STRESSING
1000 HOUR
6 MONTH
SURVEILLANCE
2.4 YEAR
1 YEAR
SURVEILLANCE
3 YEAR
SURVEILLANCE
8 YEAR
SURVEILLANCE
11 YEAR RETEN
40 YEAR
PLANT LIFE
1.4
2.0
2.5
4.5
9.6
12.0
41.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)
TENDON FORCE (KIPS)
800
750
700
650
600
2 CYCLES X 10 DIVISIONS PER INCH

FIGURE 4-26

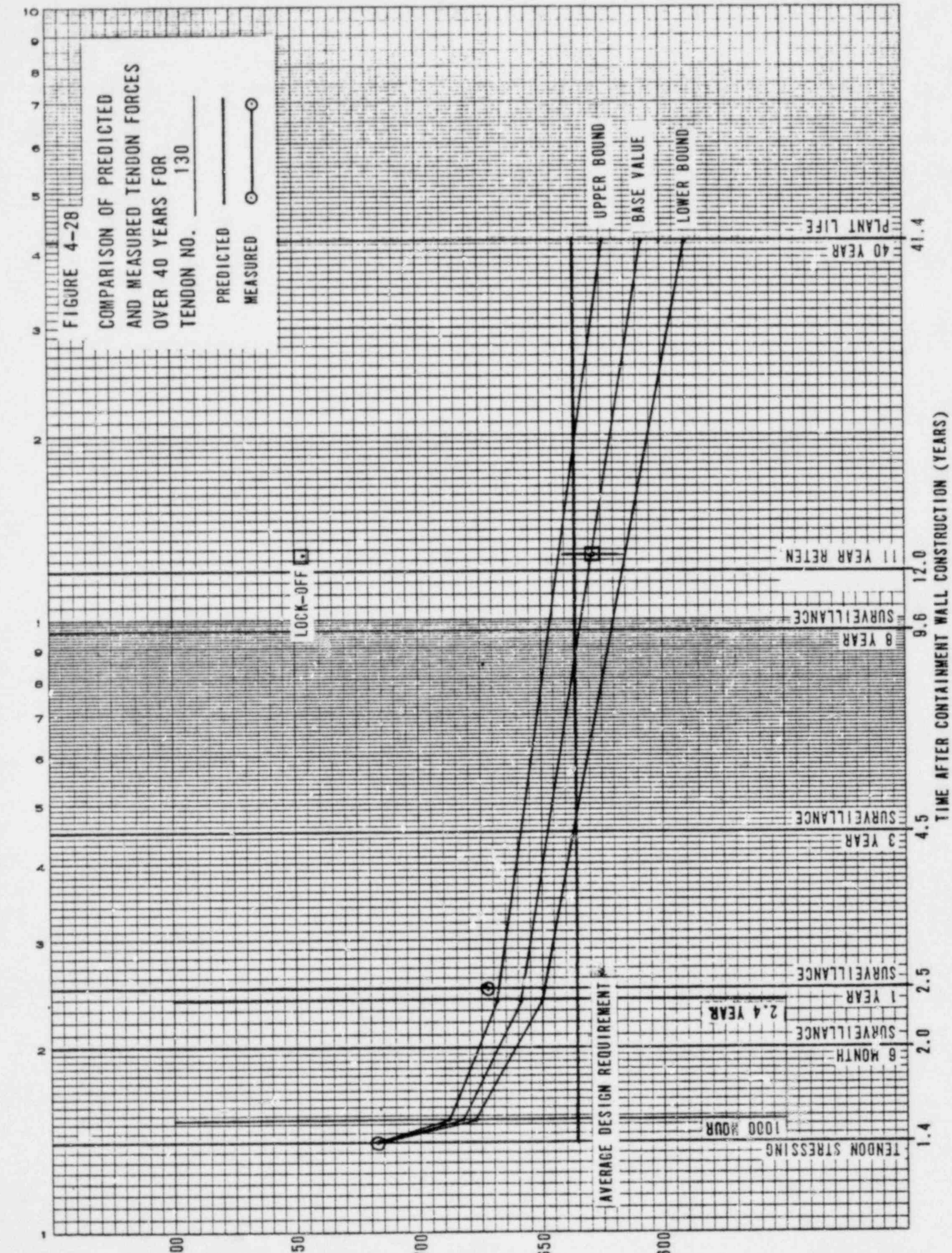


FIGURE 4-28
COMPARISON OF PREDICTED
AND MEASURED TENDON FORCES
OVER 40 YEARS FOR
TENDON NO. 130
PREDICTED
MEASURED
UPPER BOUND
BASE VALUE
LOWER BOUND
PLANT LIFE
40 YEAR
11 YEAR RETEN
SURVEILLANCE
8 YEAR
SURVEILLANCE
3 YEAR
SURVEILLANCE
1 YEAR
2.4 YEAR
SURVEILLANCE
6 MONTH
1000 HOUR
TENDON STRESSING
LOCK-OFF
AVERAGE DESIGN REQUIREMENT
41.4
12.0
9.6
4.5
2.5
2.0
1.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)
800
750
700
650
600
TENDON FORCE (KIPS)
SEMI-LOGARITHMIC
2 CYCLES X 10 DIVISIONS PER INCH

FIGURE 4-28

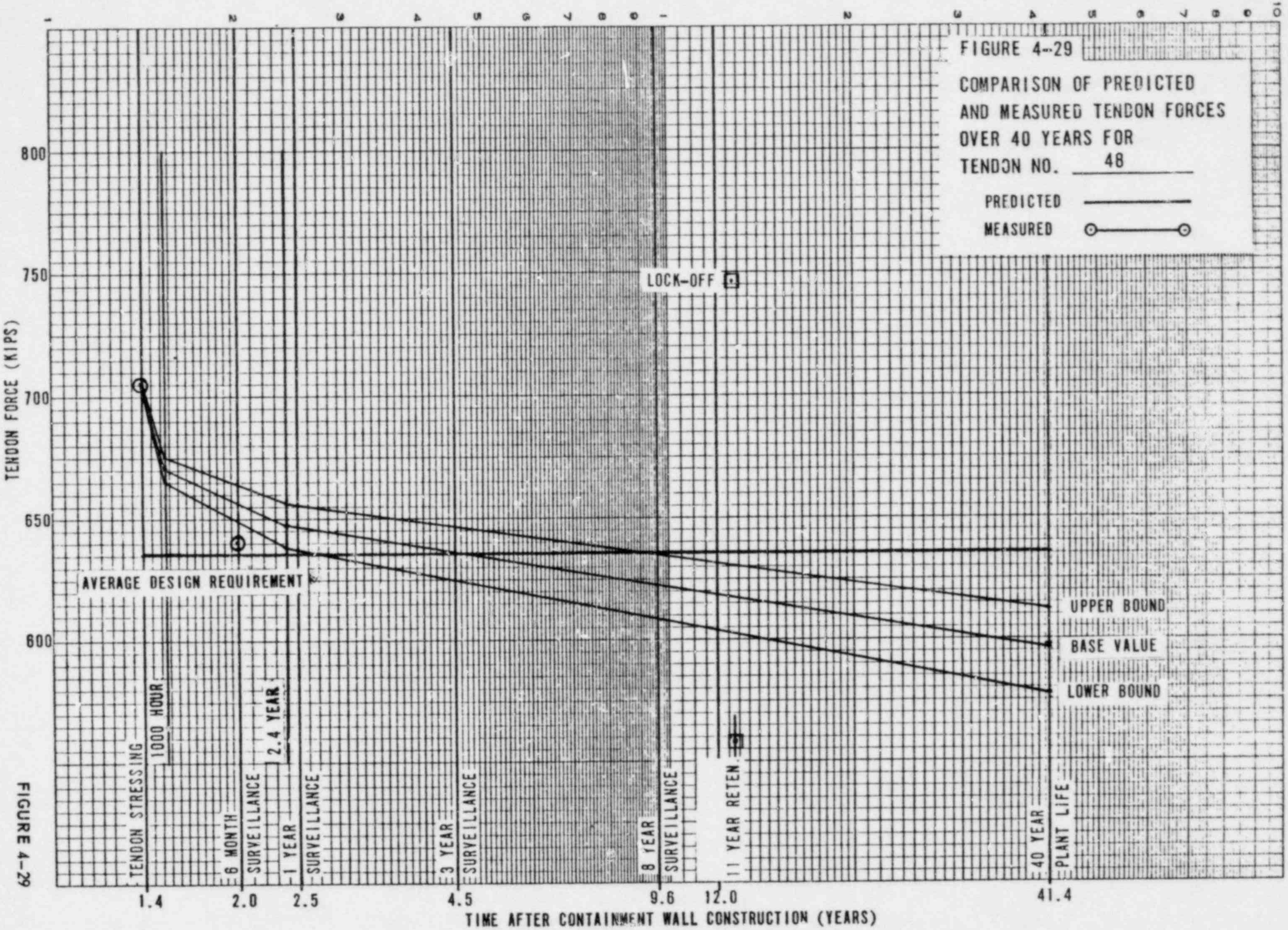


FIGURE 4-29
COMPARISON OF PREDICTED
AND MEASURED TENDON FORCES
OVER 40 YEARS FOR
TENDON NO. 48
PREDICTED
MEASURED
LOCK-OFF
UPPER BOUND
BASE VALUE
LOWER BOUND
AVERAGE DESIGN REQUIREMENT
TENDON STRESSING
1000 HOUR
6 MONTH
SURVEILLANCE
2.4 YEAR
1 YEAR
SURVEILLANCE
3 YEAR
SURVEILLANCE
8 YEAR
SURVEILLANCE
11 YEAR RETEN
40 YEAR
PLANT LIFE
800
750
700
650
600
TENDON FORCE (KIPS)
1.4
2.0
2.5
4.5
9.6
12.0
41.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)

FIGURE 4-29

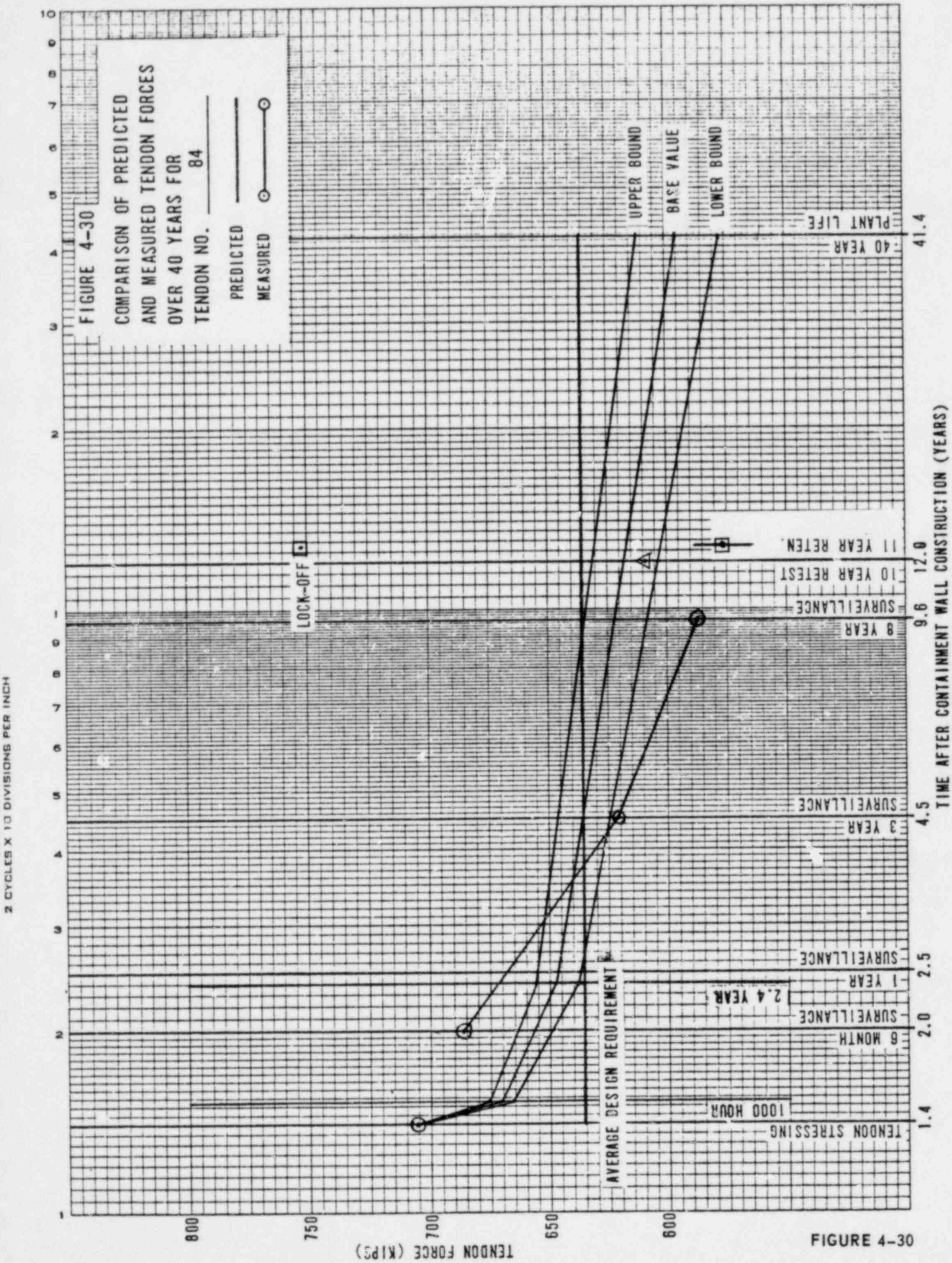


FIGURE 4-30
COMPARISON OF PREDICTED
AND MEASURED TENDON FORCES
OVER 40 YEARS FOR
TENDON NO. 84
PREDICTED
MEASURED
UPPER BOUND
BASE VALUE
LOWER BOUND
PLANT LIFE
40 YEAR
LOCK-OFF
11 YEAR RETEN.
10 YEAR RETEST
SURVEILLANCE
8 YEAR
SURVEILLANCE
3 YEAR
AVERAGE DESIGN REQUIREMENT
SURVEILLANCE
1 YEAR
2.4 YEAR
SURVEILLANCE
6 MONTH
1000 HOUR
TENDON STRESSING
1.4
2.0
2.5
4.5
9.6
12.0
41.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)
TENDON FORCE (KIPS)
800
750
700
650
600
SEMI-LOGARITHMIC
2 CYCLES X 10 DIVISIONS PER INCH

FIGURE 4-30

[redacted] NO. [redacted] 210 [redacted] GEN[redacted]PH P[redacted] EUG[redacted]DIETZ[redacted]CO. [redacted]N U.
SEMI-LOGARITHMIC
2 CYCLES X 10 DIVISIONS PER INCH

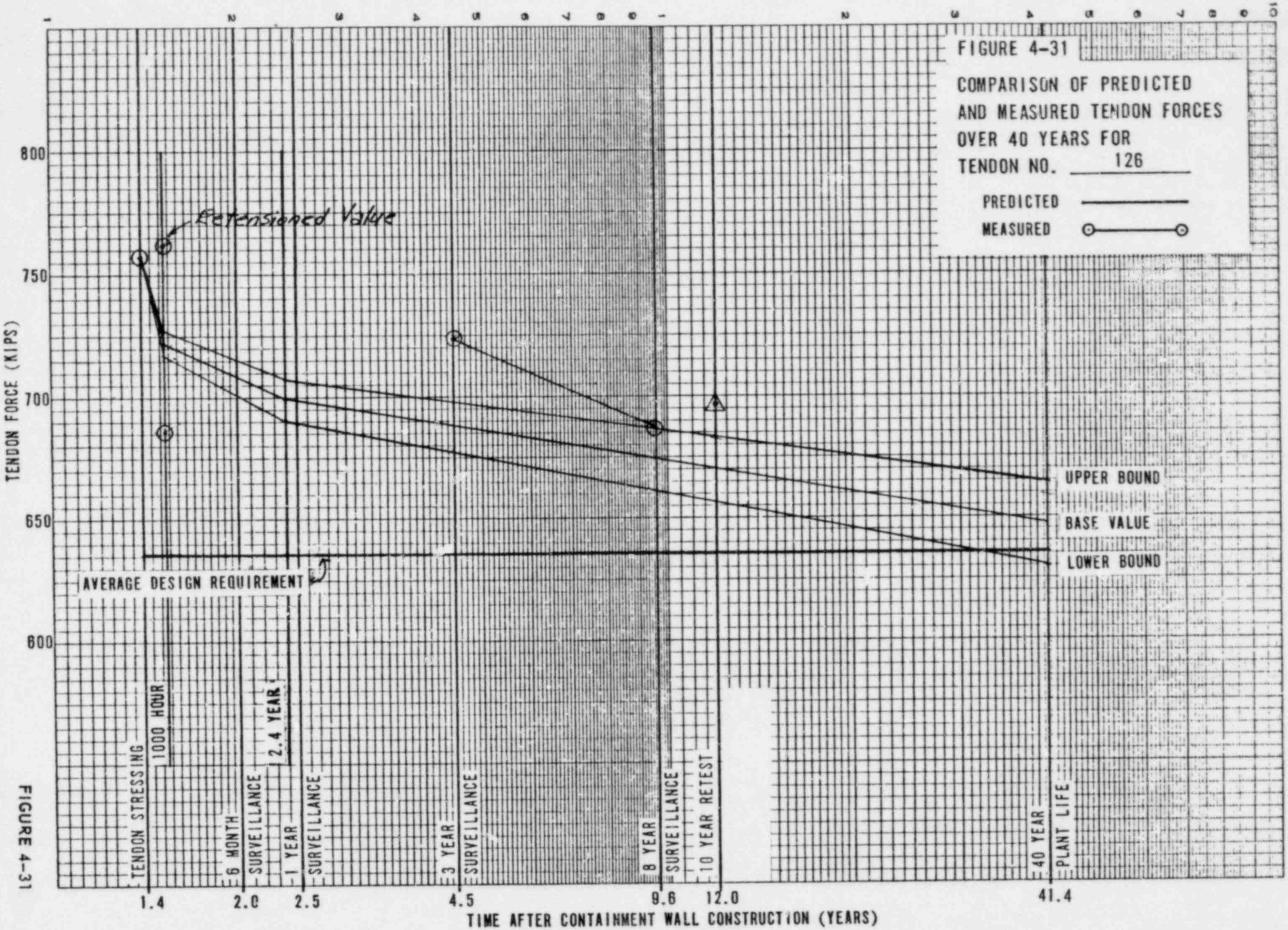


FIGURE 4-31

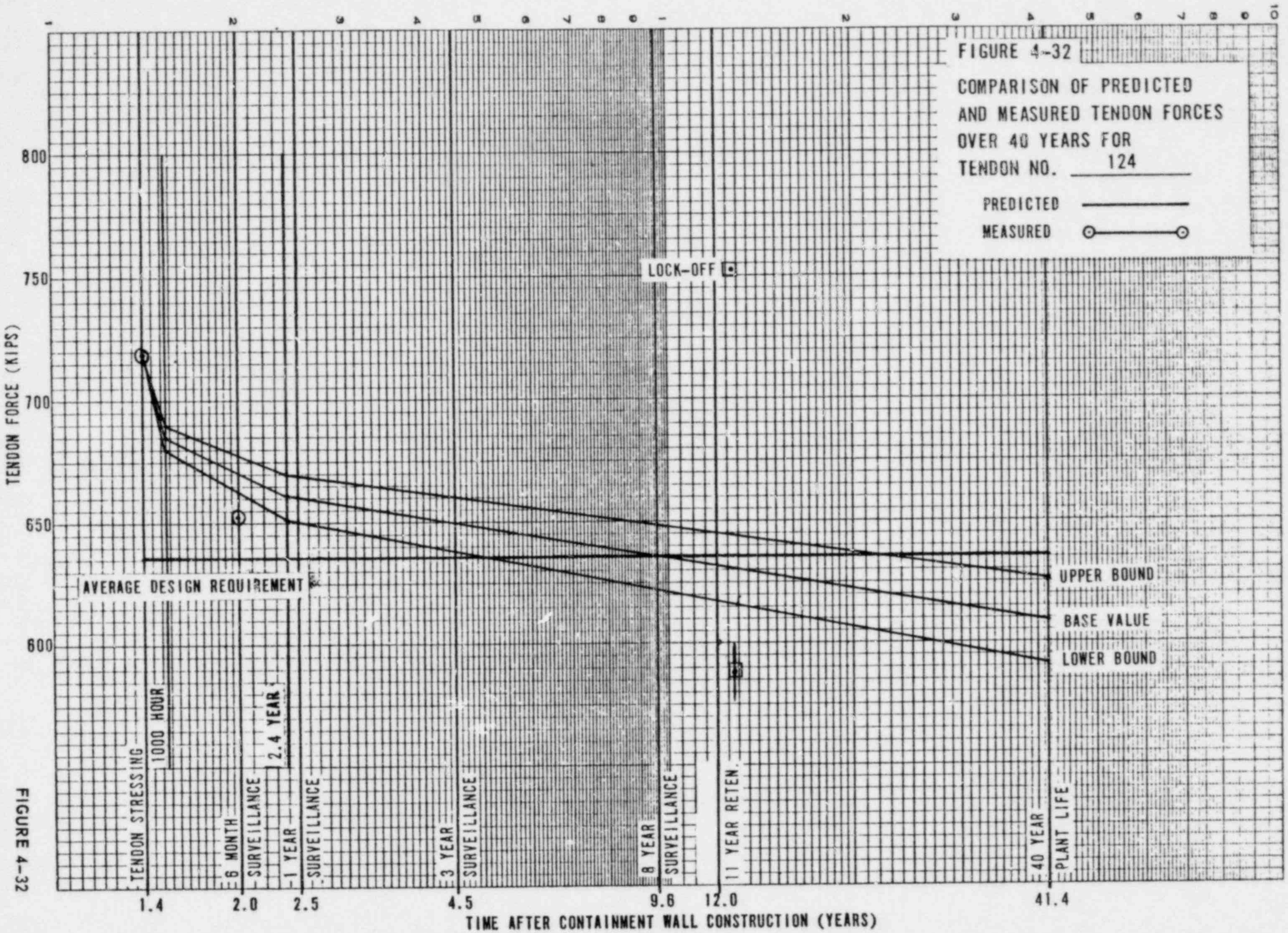


FIGURE 4-32
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES OVER 40 YEARS FOR TENDON NO. 124
PREDICTED
MEASURED
LOCK-OFF
UPPER BOUND
BASE VALUE
LOWER BOUND
AVERAGE DESIGN REQUIREMENT
TENDON STRESSING
1000 HOUR
6 MONTH
SURVEILLANCE
2.4 YEAR
1 YEAR
SURVEILLANCE
3 YEAR
SURVEILLANCE
8 YEAR
SURVEILLANCE
11 YEAR RETEN.
40 YEAR
PLANT LIFE
800
750
700
650
600
TENDON FORCE (KIPS)
1.4
2.0
2.5
4.5
9.6
12.0
41.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)

FIGURE 4-32

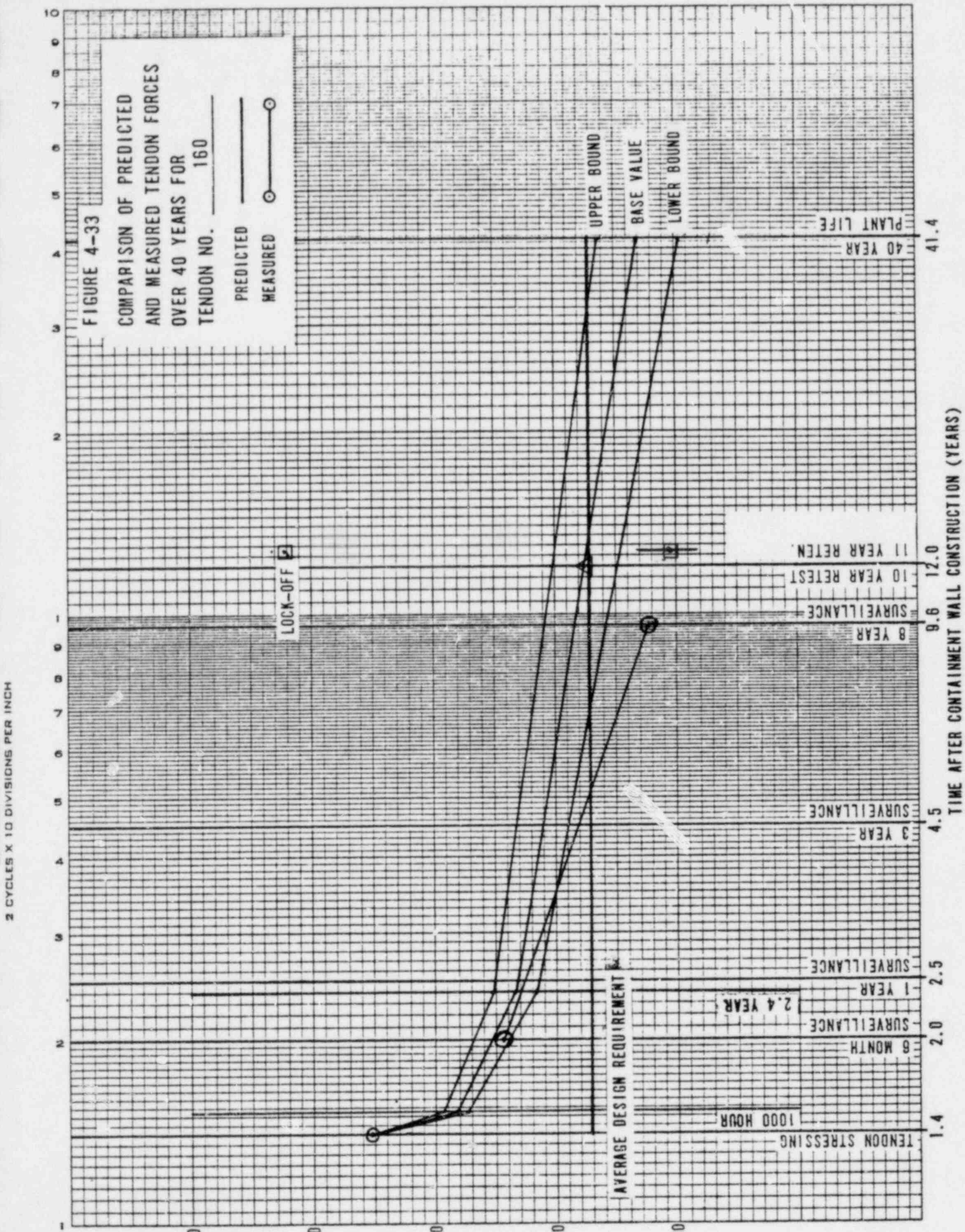


FIGURE 4-33
COMPARISON OF PREDICTED
AND MEASURED TENDON FORCES
OVER 40 YEARS FOR
TENDON NO. 160
PREDICTED
MEASURED
UPPER BOUND
BASE VALUE
LOWER BOUND
LOCK-OFF
AVERAGE DESIGN REQUIREMENT
TENDON STRESSING
1000 HOUR
6 MONTH
SURVEILLANCE
2.4 YEAR
1 YEAR
SURVEILLANCE
3 YEAR
SURVEILLANCE
8 YEAR
SURVEILLANCE
10 YEAR RETEST
11 YEAR RETEN.
40 YEAR
PLANT LIFE
1.4
2.0
2.5
4.5
9.6
12.0
41.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)
800
750
700
650
600
TENDON FORCE (KIPS)
2 CYCLES X 10 DIVISIONS PER INCH

FIGURE 4-33

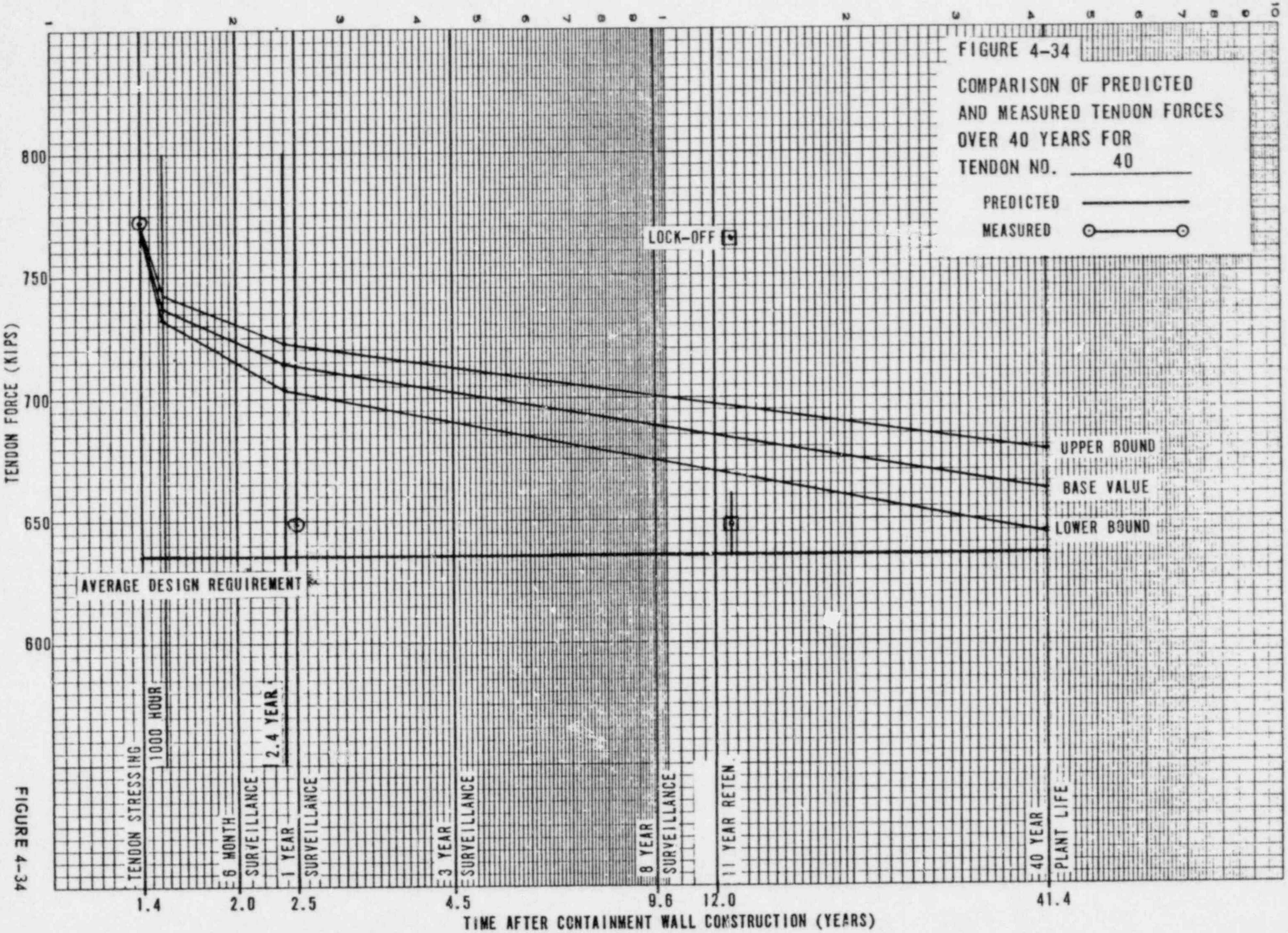


FIGURE 4-34
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES OVER 40 YEARS FOR TENDON NO. 40
PREDICTED
MEASURED
LOCK-OFF
UPPER BOUND
BASE VALUE
LOWER BOUND
AVERAGE DESIGN REQUIREMENT
TENDON FORCE (KIPS)
800
750
700
650
600
TENDON STRESSING
1000 HOUR
6 MONTH SURVEILLANCE
2.4 YEAR
1 YEAR SURVEILLANCE
3 YEAR SURVEILLANCE
8 YEAR SURVEILLANCE
11 YEAR RETEN.
40 YEAR PLANT LIFE
1.4
2.0
2.5
4.5
9.6
12.0
41.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)

FIGURE 4-34

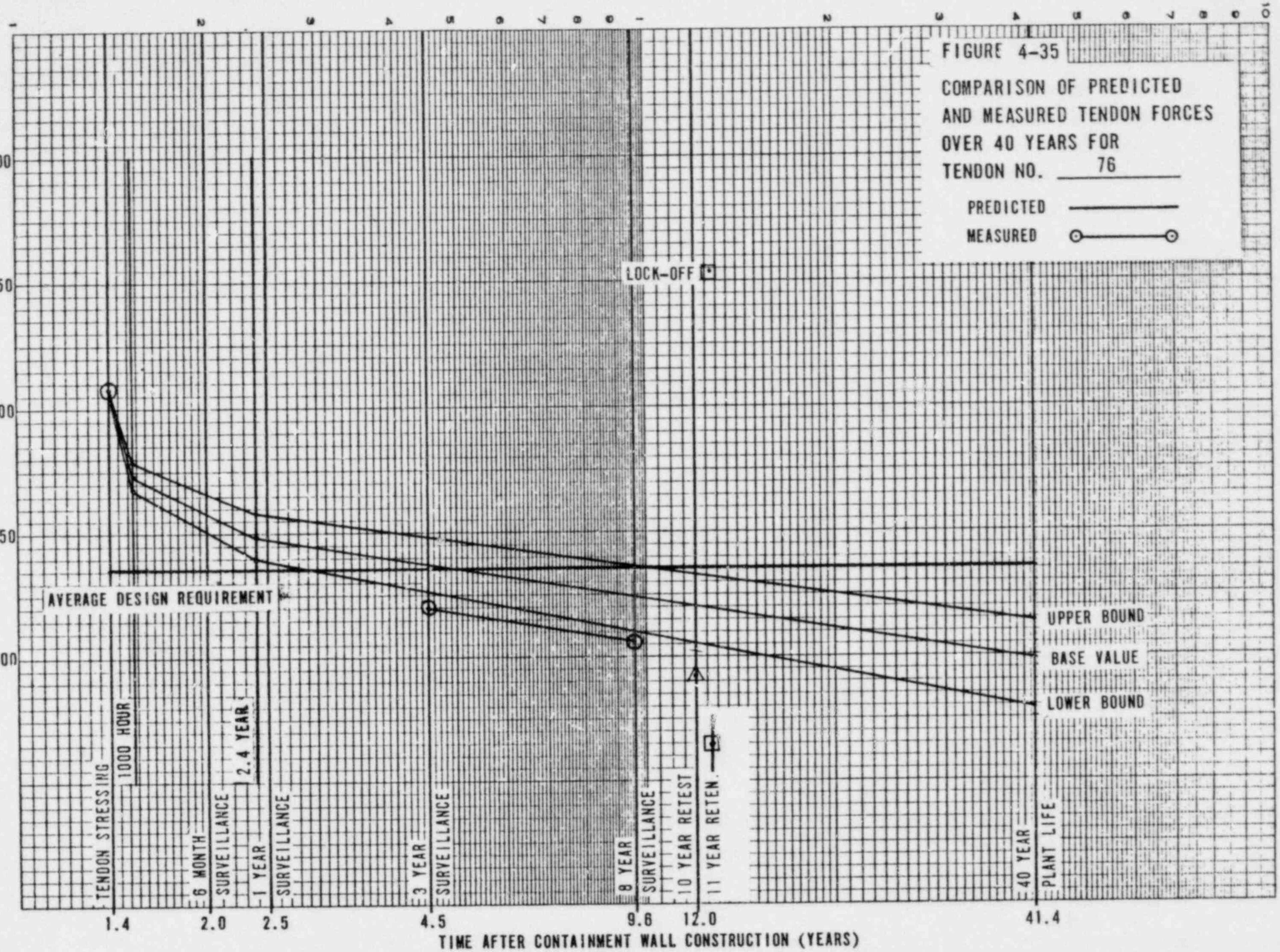


FIGURE 4-35
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES OVER 40 YEARS FOR TENDON NO. 76
PREDICTED
MEASURED
LOCK-OFF
TENDON FORCE (KIPS)
800
750
700
650
600
AVERAGE DESIGN REQUIREMENT
UPPER BOUND
BASE VALUE
LOWER BOUND
TENDON STRESSING
1000 HOUR
6 MONTH SURVEILLANCE
2.4 YEAR
1 YEAR SURVEILLANCE
3 YEAR SURVEILLANCE
8 YEAR SURVEILLANCE
10 YEAR RETEST
11 YEAR RETEN.
40 YEAR PLANT LIFE
1.4
2.0
2.5
4.5
9.6
12.0
41.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)

FIGURE 4-35

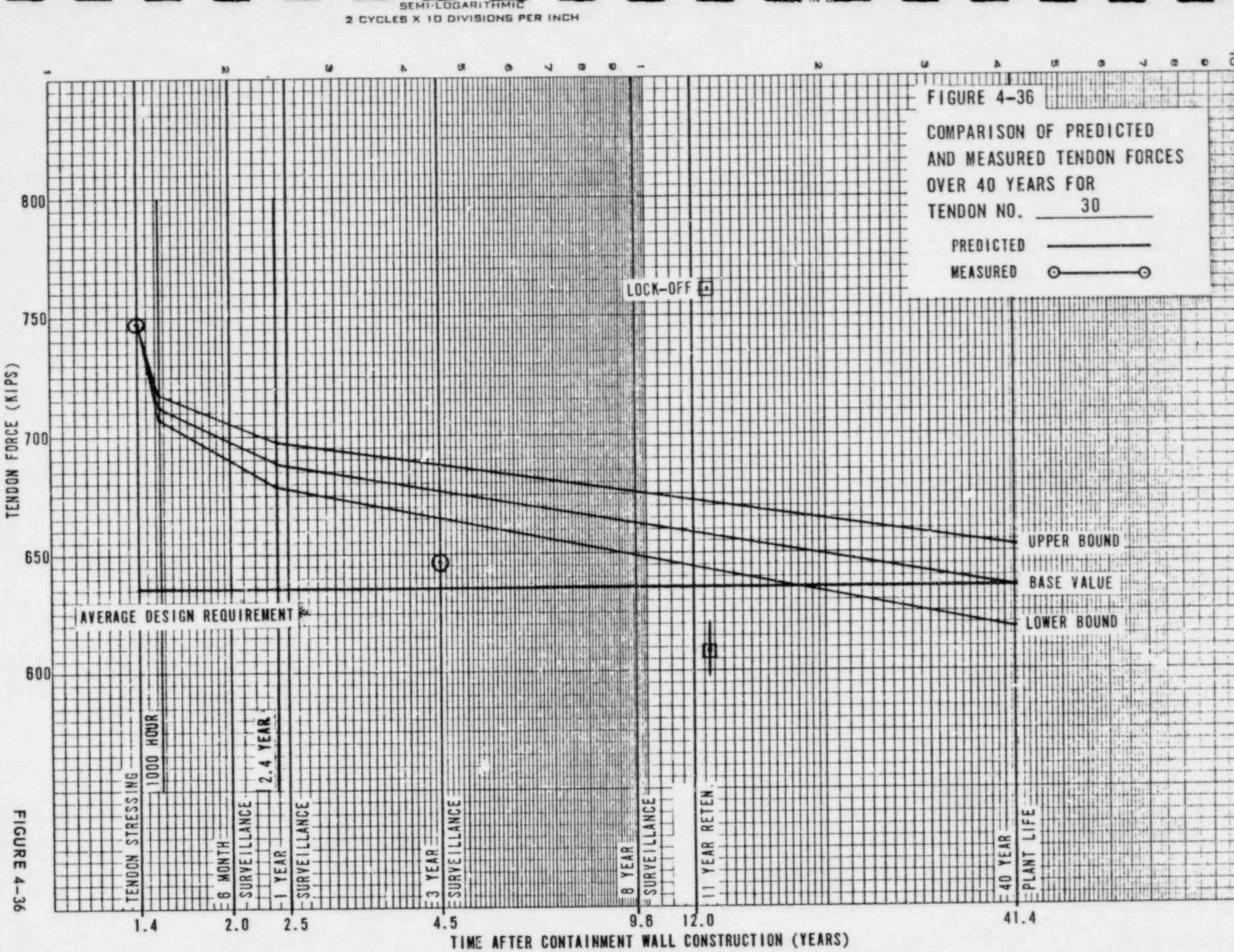

SEMI-LOGARITHMIC
2 CYCLES X 10 DIVISIONS PER INCH
FIGURE 4-36
COMPARISON OF PREDICTED
AND MEASURED TENDON FORCES
OVER 40 YEARS FOR
TENDON NO. 30
PREDICTED
MEASURED
TENDON FORCE (KIPS)
800
750
700
650
600
LOCK-OFF
UPPER BOUND
BASE VALUE
LOWER BOUND
AVERAGE DESIGN REQUIREMENT
TENDON STRESSING
1000 HOUR
6 MONTH
SURVEILLANCE
2.4 YEAR
1 YEAR
SURVEILLANCE
3 YEAR
SURVEILLANCE
8 YEAR
SURVEILLANCE
11 YEAR RETEN.
40 YEAR
PLANT LIFE
1.4
2.0
2.5
4.5
9.6
12.0
41.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)

FIGURE 4-36

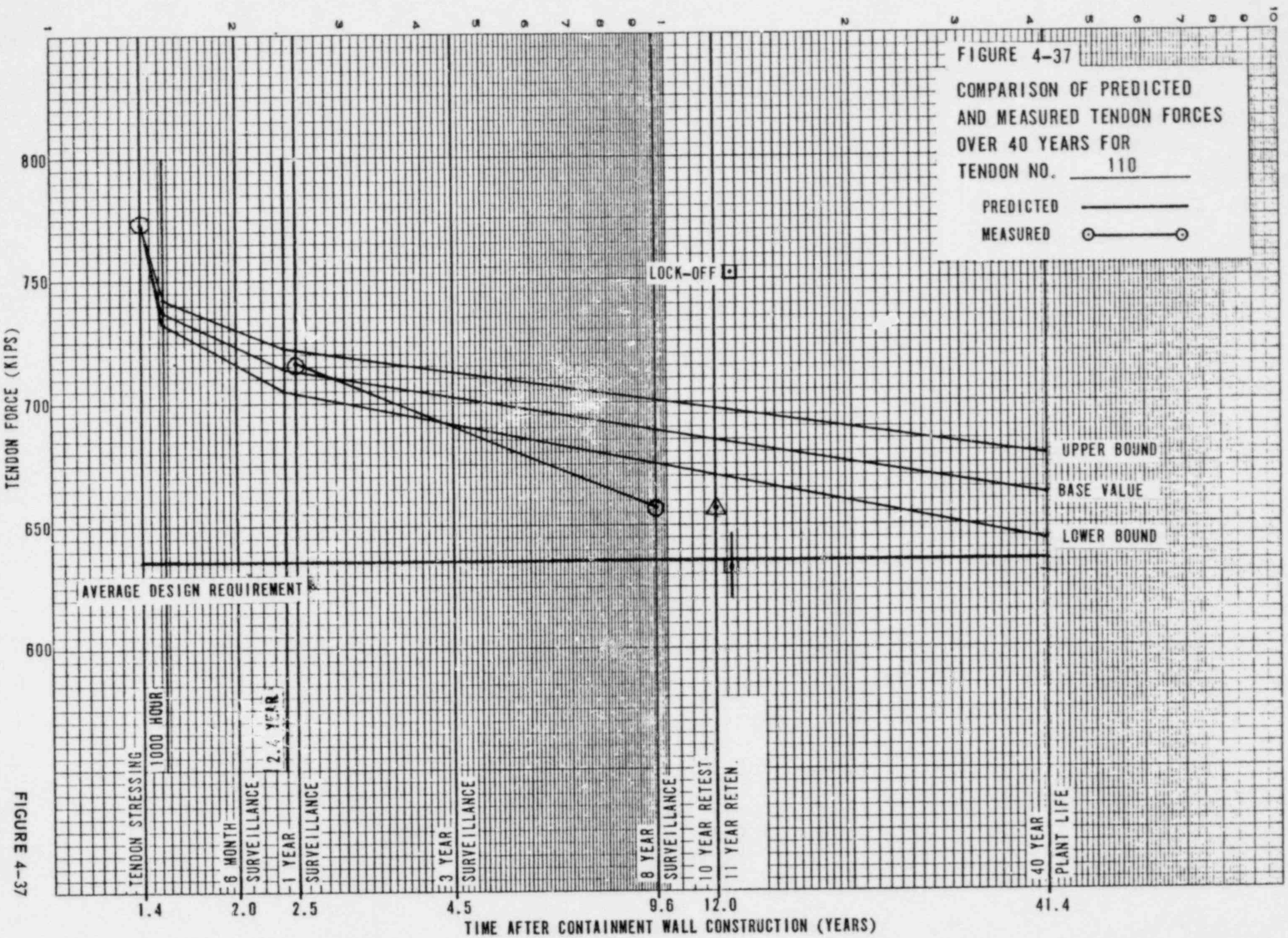

SEMI-LOGARITHMIC
2 CYCLES X 10 DIVISIONS PER INCH
FIGURE 4-37
COMPARISON OF PREDICTED
AND MEASURED TENDON FORCES
OVER 40 YEARS FOR
TENDON NO. 110
PREDICTED
MEASURED
LOCK-OFF
UPPER BOUND
BASE VALUE
LOWER BOUND
AVERAGE DESIGN REQUIREMENT
TENDON FORCE (KIPS)
800
750
700
650
600
TENDON STRESSING
1000 HOUR
6 MONTH
SURVEILLANCE
2.4 YEAR
1 YEAR
SURVEILLANCE
3 YEAR
SURVEILLANCE
8 YEAR
SURVEILLANCE
10 YEAR RETEST
11 YEAR RETEN.
40 YEAR
PLANT LIFE
1.4
2.0
2.5
4.5
9.6
12.0
41.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)

FIGURE 4-37

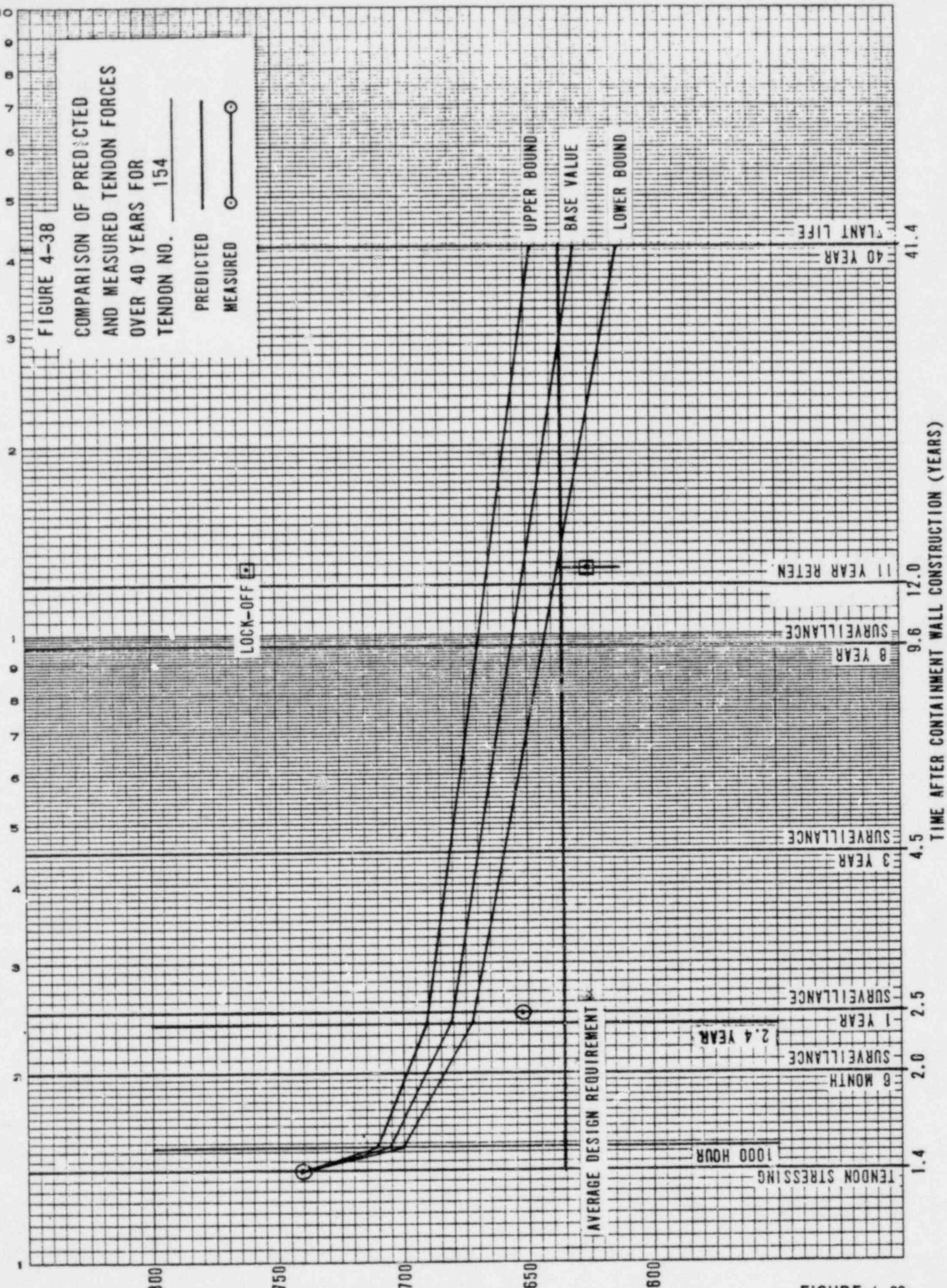
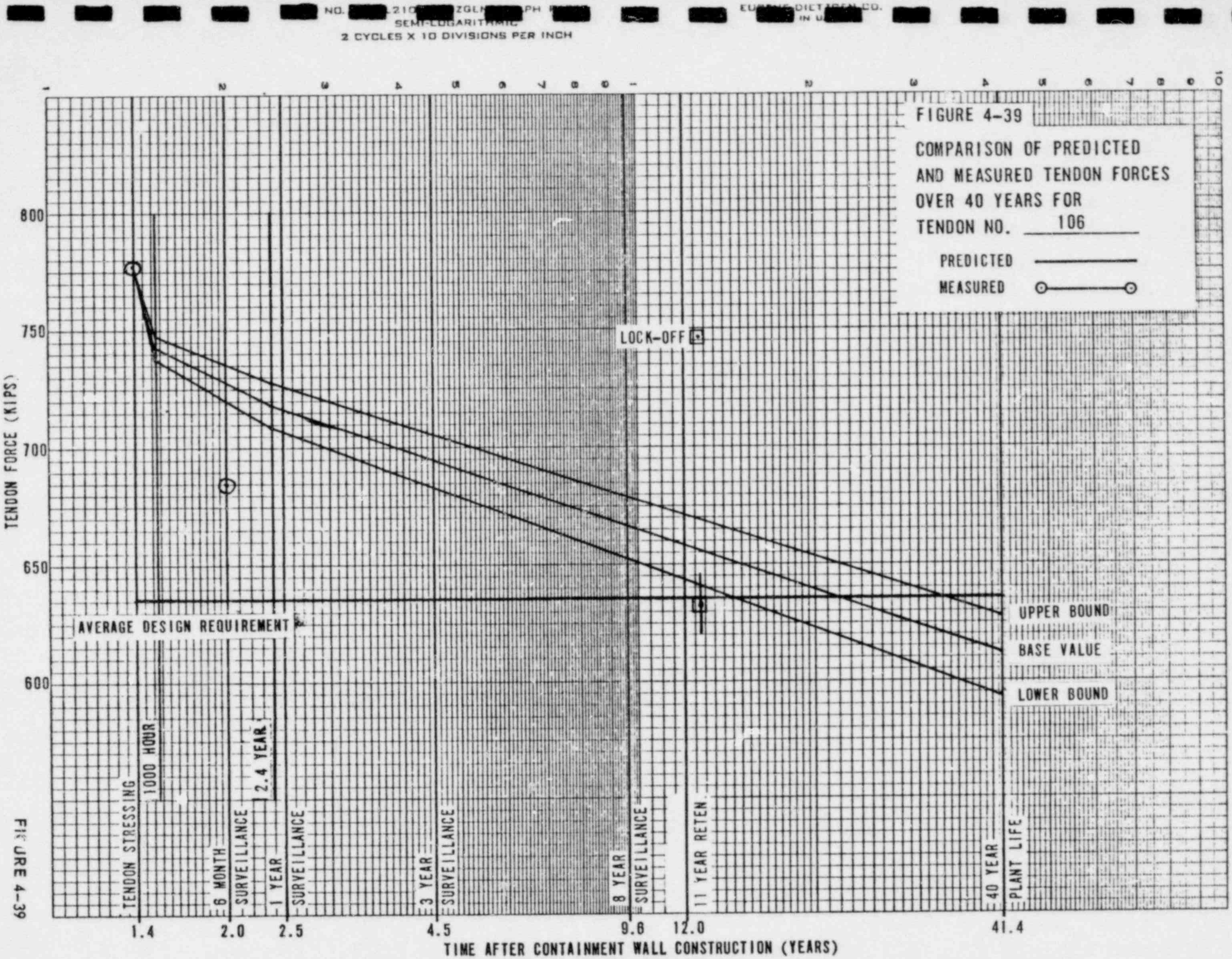


FIGURE 4-38
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES OVER 40 YEARS FOR TENDON NO. 154
PREDICTED
MEASURED
UPPER BOUND
BASE VALUE
LOWER BOUND
LOCK-OFF
AVERAGE DESIGN REQUIREMENT
TENDON STRESSING
1000 HOUR
6 MONTH
SURVEILLANCE
2.4 YEAR
1 YEAR
SURVEILLANCE
3 YEAR
SURVEILLANCE
8 YEAR
SURVEILLANCE
11 YEAR RETEN
40 YEAR
PLANT LIFE
1.4
2.0
2.5
4.5
9.6
12.0
41.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)
TENDON FORCE (KIPS)
800
750
700
650
600
SEMI-LOGARITHMIC
2 CYCLES X 10 DIVISIONS PER INCH

FIGURE 4-38



SEMI-LOGARITHMIC
2 CYCLES X 10 DIVISIONS PER INCH
FIGURE 4-39
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES OVER 40 YEARS FOR TENDON NO. 106
PREDICTED
MEASURED
LOCK-OFF
AVERAGE DESIGN REQUIREMENT
UPPER BOUND
BASE VALUE
LOWER BOUND
TENDON STRESSING
1000 HOUR
6 MONTH
SURVEILLANCE
2.4 YEAR
1 YEAR
SURVEILLANCE
3 YEAR
SURVEILLANCE
8 YEAR
SURVEILLANCE
11 YEAR RETEN.
40 YEAR
PLANT LIFE
TENDON FORCE (KIPS)
800
750
700
650
600
1.4
2.0
2.5
4.5
9.6
12.0
41.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)

FIGURE 4-39

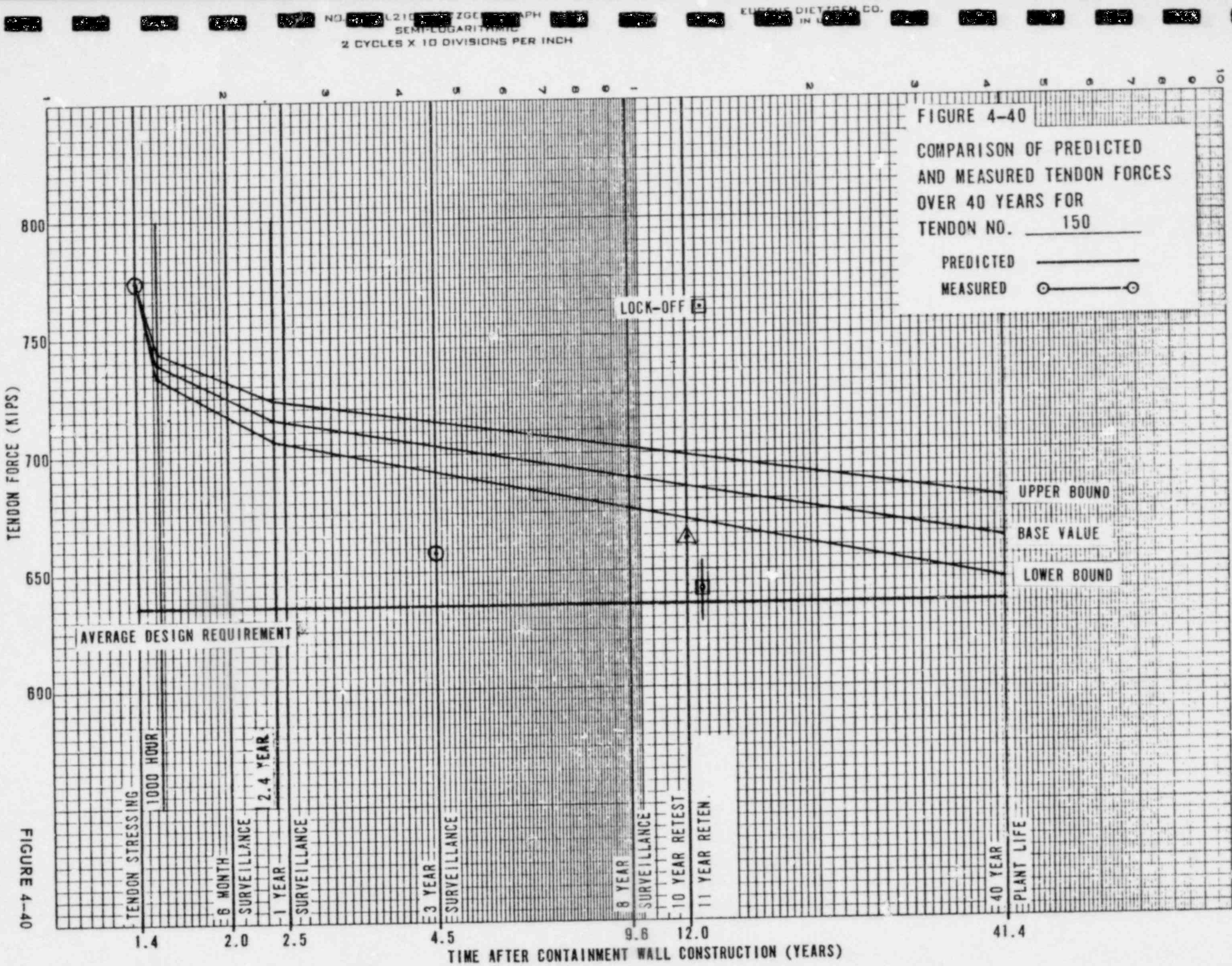
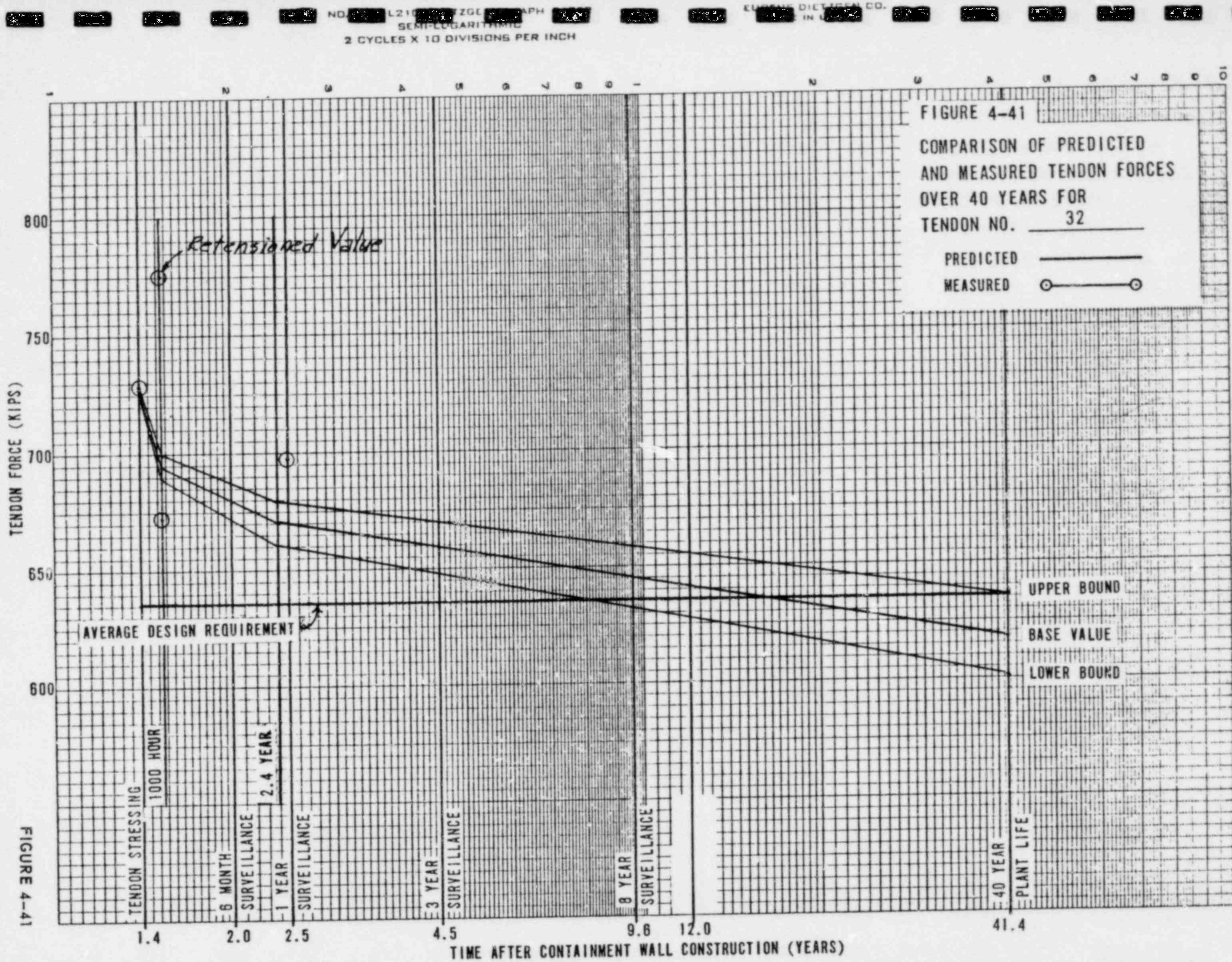


FIGURE 4-40
COMPARISON OF PREDICTED
AND MEASURED TENDON FORCES
OVER 40 YEARS FOR
TENDON NO. 150
PREDICTED
MEASURED
LOCK-OFF
UPPER BOUND
BASE VALUE
LOWER BOUND
AVERAGE DESIGN REQUIREMENT
TENDON FORCE (KIPS)
800
750
700
650
600
TENDON STRESSING
1000 HOUR
6 MONTH
SURVEILLANCE
2.4 YEAR
1 YEAR
SURVEILLANCE
3 YEAR
SURVEILLANCE
8 YEAR
SURVEILLANCE
10 YEAR RETEST
11 YEAR RETEN.
40 YEAR
PLANT LIFE
1.4
2.0
2.5
4.5
9.6
12.0
41.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)
SEMI-LOGARITHMIC
2 CYCLES X 10 DIVISIONS PER INCH

FIGURE 4-40



SEMI-LOGARITHMIC
2 CYCLES X 10 DIVISIONS PER INCH
FIGURE 4-41
COMPARISON OF PREDICTED
AND MEASURED TENDON FORCES
OVER 40 YEARS FOR
TENDON NO. 32
PREDICTED
MEASURED
Retensioned Value
AVERAGE DESIGN REQUIREMENT
UPPER BOUND
BASE VALUE
LOWER BOUND
TENDON FORCE (KIPS)
800
750
700
650
600
TENDON STRESSING
1000 HOUR
6 MONTH
SURVEILLANCE
2.4 YEAR
1 YEAR
SURVEILLANCE
3 YEAR
SURVEILLANCE
8 YEAR
SURVEILLANCE
40 YEAR
PLANT LIFE
1.4
2.0
2.5
4.5
9.6
12.0
41.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)

FIGURE 4-41

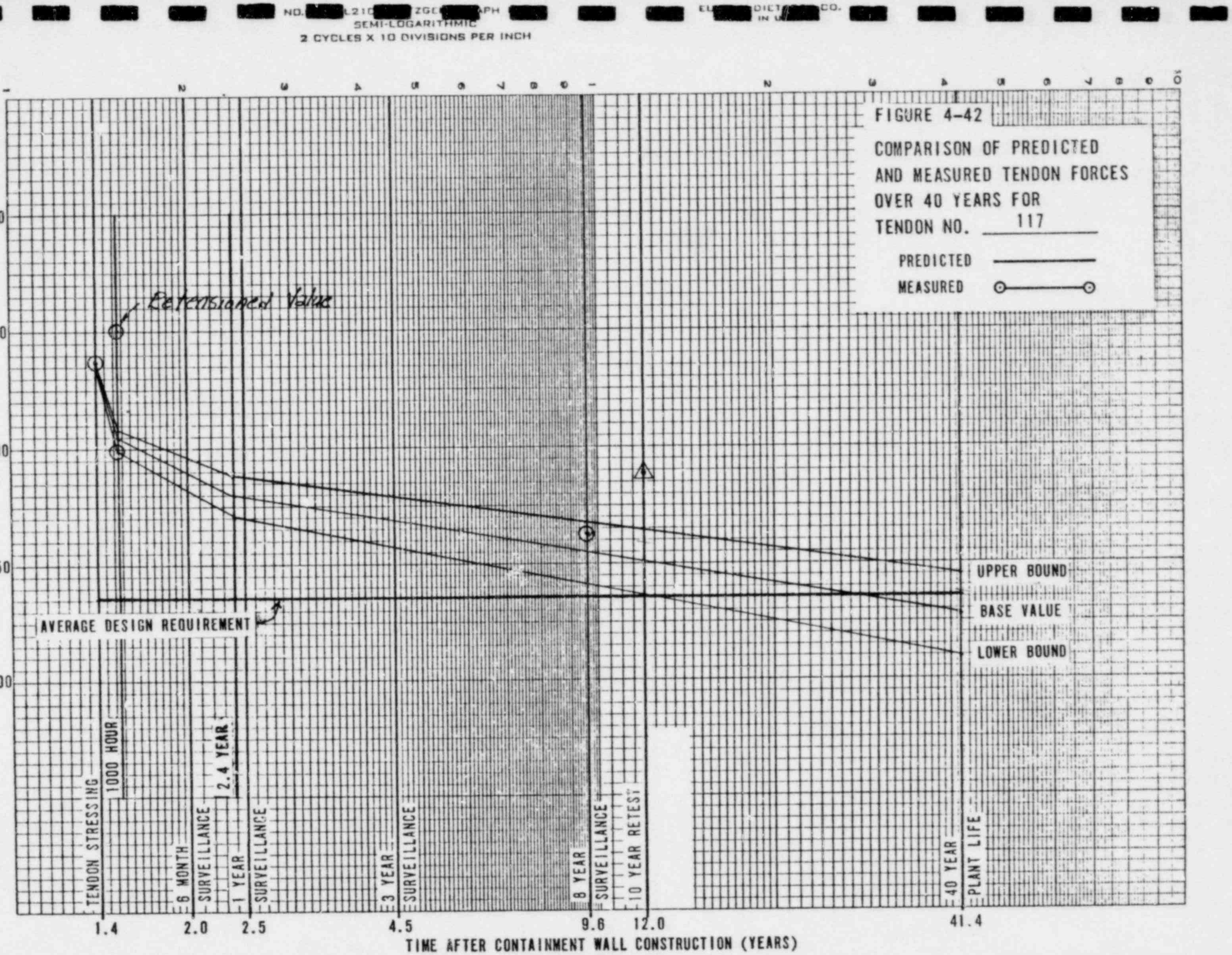

SEMI-LOGARITHMIC
2 CYCLES X 10 DIVISIONS PER INCH
FIGURE 4-42
COMPARISON OF PREDICTED
AND MEASURED TENDON FORCES
OVER 40 YEARS FOR
TENDON NO. 117
PREDICTED
MEASURED
Retensioned Value
UPPER BOUND
BASE VALUE
LOWER BOUND
AVERAGE DESIGN REQUIREMENT
TENDON STRESSING
1000 HOUR
6 MONTH
SURVEILLANCE
2.4 YEAR
1 YEAR
SURVEILLANCE
3 YEAR
SURVEILLANCE
8 YEAR
SURVEILLANCE
10 YEAR RETEST
40 YEAR
PLANT LIFE
TENDON FORCE (KIPS)
800
750
700
650
600
1.4
2.0
2.5
4.5
9.6
12.0
41.4
TIME AFTER CONTAINMENT WALL CONSTRUCTION (YEARS)

FIGURE 4-42

APPENDIX B

COMPRESSION TEST REPORT OF CORED ROCK SAMPLES

Lucius Pitkin INCORPORATED EST. 1885 *Analytical, Metallurgical and Research Laboratories*

50 HUDSON STREET, NEW YORK, N. Y. 10013 • (212) BE 3-2737
CABLE ADDRESS: NIKTIP

REPORT

September 6, 1973

M-2871

Your Ref.: File GINNA

Dames & Moore
14 Commerce Drive
Cranford, New Jersey 07016

Attention: Mr. Adekunle Oguntala

Subject: COMPRESSION TESTS OF CORED ROCK SAMPLES

Two cored rock specimens (204-114-1 & 204-104) were prepared and tested in unconfined axial compression. Strain gages of X-Y configuration were employed to determine axial and lateral strain.

One cored rock specimen (204-125) was prepared and tested in unconfined axial compression-creep. This specimen was loaded to 10,000 psi for four hours. The specimen was then loaded from 10,000 psi to failure.

One cored rock specimen (204-114-2) was prepared and tested in cyclic triaxial compression at a confining pressure of 100 psi. The specimen was loaded and unloaded 10 times to a stress of 6000 psi; 10 times to a stress of 9000 psi, and 10 times to a stress of 12,000 psi. At the completion of cyclic loading, the specimen was tested to failure. Strain gages of X-Y configuration were employed to determine axial and lateral strain.

One cored specimen was prepared from sample 204-125 and returned to Dames & Moore. Cored rock sample 204-86 was cut into two samples and returned to Dames & Moore.

Poisson's ratio for each specimen tested in unconfined axial compression was calculated from the linear portion of the stress-strain curve.

Complete results of all tests performed are appended.

Respectfully submitted,

Approved: A. J. Vecchio
Asst. Chief Metallurgist

LUCIUS PITKIN, INC.

J. Crosson
Metallurgist

FORM 107-11/63

UNCONFINED COMPRESSION TESTS

Sample	Wt. (gms)	Diam. (in)	Length (in)	Area (sq.in.)	Volume (cu.in.)	Density (gms/cu.in.)	Ult. Load (lbs)	Ult. Str., psi	Remarks
204-114-1	491	1.87	4.30	2.75	11.83	41.50	52,500	19,100	violent shat
204-104	489	1.86	4.28	2.72	11.64	42.01	60,500	22,240	violent shat
204-125	483	1.86	4.25	2.72	11.56	41.78	50,500	18,560	violent shat
204-125	485	1.85	4.33	2.69	11.65	41.63	returned to Dames and Moore		

TRIAXIAL COMPRESSION TESTS

Sample	Wt. (gms)	Diam. (in)	Length (in)	Area (sq.in.)	Volume (cu.in)	Density (gms/cu.in.)	Ult. Load (lbs)	Ult. Str., psi	Remarks
204-114-2	497	1.87	4.34	2.75	11.94	41.62	52,000	18,910	violent shat Confining Pressure-100

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Dames & Moore
Attn: Mr A. Oguntala

September 6, 1973
M-2871 File: Ginna

POISSON'S RATIO

Sample	Stress Range For Poisson's Ratio	Poisson's Ratio
204-114	5090-12,730	.25
204-104	5150-11,030	.19

MOISTURE CONTENT

Sample	MOISTURE CONTENT, %
204-114	0.0951
204-125	0.0958

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Dames & Moore
Attn: Mr A. Oguntala

M-2871 File: Ginna
September 6, 1973

Sample: 204-125

UNCONFINED COMPRESSION-CREEP

Axial Load (lbs)	Axial Stress (psi)	Axial Strain (u-in/in)	Lateral Strain (u-in/in)	Elapsed Time (min.)
0	0	0	0	0
1000	370	180	0	0.3
2000	740	390	0	0.7
3000	1100	630	5	1.0
4000	1470	830	10	1.3
5000	1840	1030	15	1.7
6000	2210	1250	25	2.0
7000	2570	1440	45	2.3
8000	2940	1630	55	2.7
9000	3310	1795	65	3.0
10,000	3680	1955	75	3.3
11,000	4040	2110	95	3.7
12,000	4410	2250	110	4.0
13,000	4780	2370	125	4.3
14,000	5150	2500	140	4.7
15,000	5510	2605	155	5.0
16,000	5880	2715	175	5.3
17,000	6250	2820	190	5.7
18,000	6620	2920	205	6.0
19,000	6990	3020	225	6.3
20,000	7350	3120	245	6.7
21,000	7720	3220	265	7.0
22,000	8090	3310	280	7.3

Lucius Pitkin
incorporated

Dames & Moore
Attn: Mr A. Oguntala

M-2871 File: Ginn
September 6, 1973

Sample: 204-125

UNCONFINED COMPRESSION-CREEP

Axial Load (lbs)	Axial Stress (psi)	Axial Strain (u-in/in)	Lateral Strain (u-in/in)	Elasped Time (min.)
23,000	8460	3400	300	7.7
24,000	8820	3490	320	8.0
25,000	9190	3580	345	8.3
26,000	9560	3670	375	8.7
27,000	9930	3760	390	9.0
27,200	10,000	3785	400	10
27,200	10,000	3830	425	20
27,200	10,000	3835	435	30
27,200	10,000	3845	440	40
27,200	10,000	3845	445	50
27,200	10,000	3850	445	60
27,200	10,000	3860	450	70
27,200	10,000	3860	455	80
27,200	10,000	3860	455	90
27,200	10,000	3860	455	100
27,200	10,000	3860	455	110
27,200	10,000	3860	455	120
27,200	10,000	3860	455	130
27,200	10,000	3860	455	140
27,200	10,000	3860	455	150
27,200	10,000	3860	455	160
27,200	10,000	3860	455	170
27,200	10,000	3860	455	180

Lucius Pitkin

incorporated

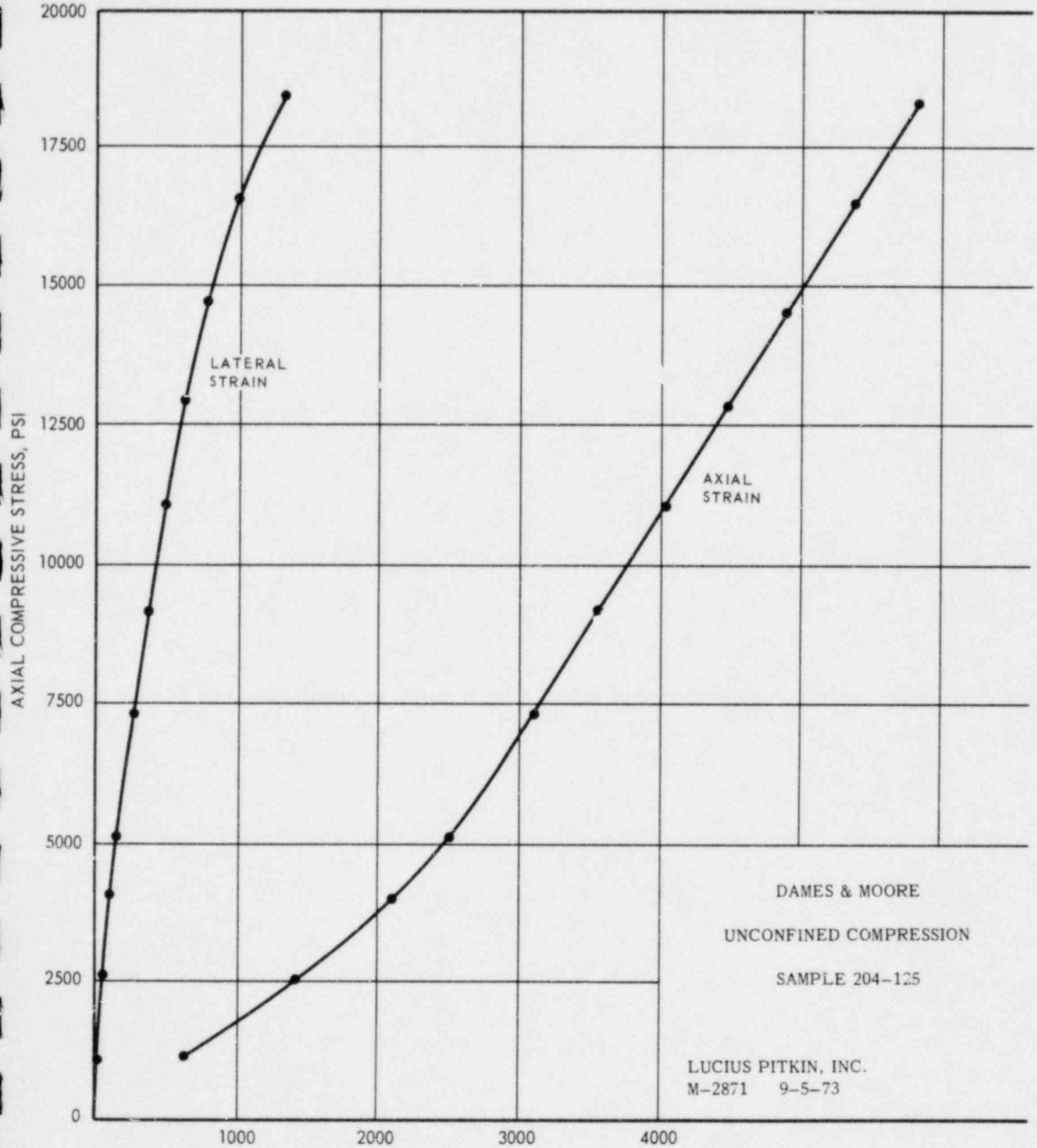
Dames & Moore
Attn: Mr A. Oguntala

M-2871 File: Gin
September 6, 1973

Sample: 204-125

UNCONFINED COMPRESSION-CREEP

Axial Load (lbs)	Axial Stress (psi)	Axial Strain (u-in/in)	Lateral Strain (u-in/in)	Elapsed Time (min.)
27,200	10,000	3860	455	190
27,200	10,000	3860	455	200
27,200	10,000	3865	460	210
27,200	10,000	3865	460	220
27,200	10,000	3865	460	230
27,200	10,000	3865	460	240
27,200	10,000	3870	460	250
28,000	10,290	3925	470	250.5
29,000	10,660	3995	485	251.0
30,000	11,030	4060	505	251.5
35,000	12,870	4450	600	253.5
40,000	14,710	4880	755	255.5
45,000	16,540	5335	985	257.5
50,000	18,380	5860	1340	259.5
50,500	18,560			
Ult. Load				

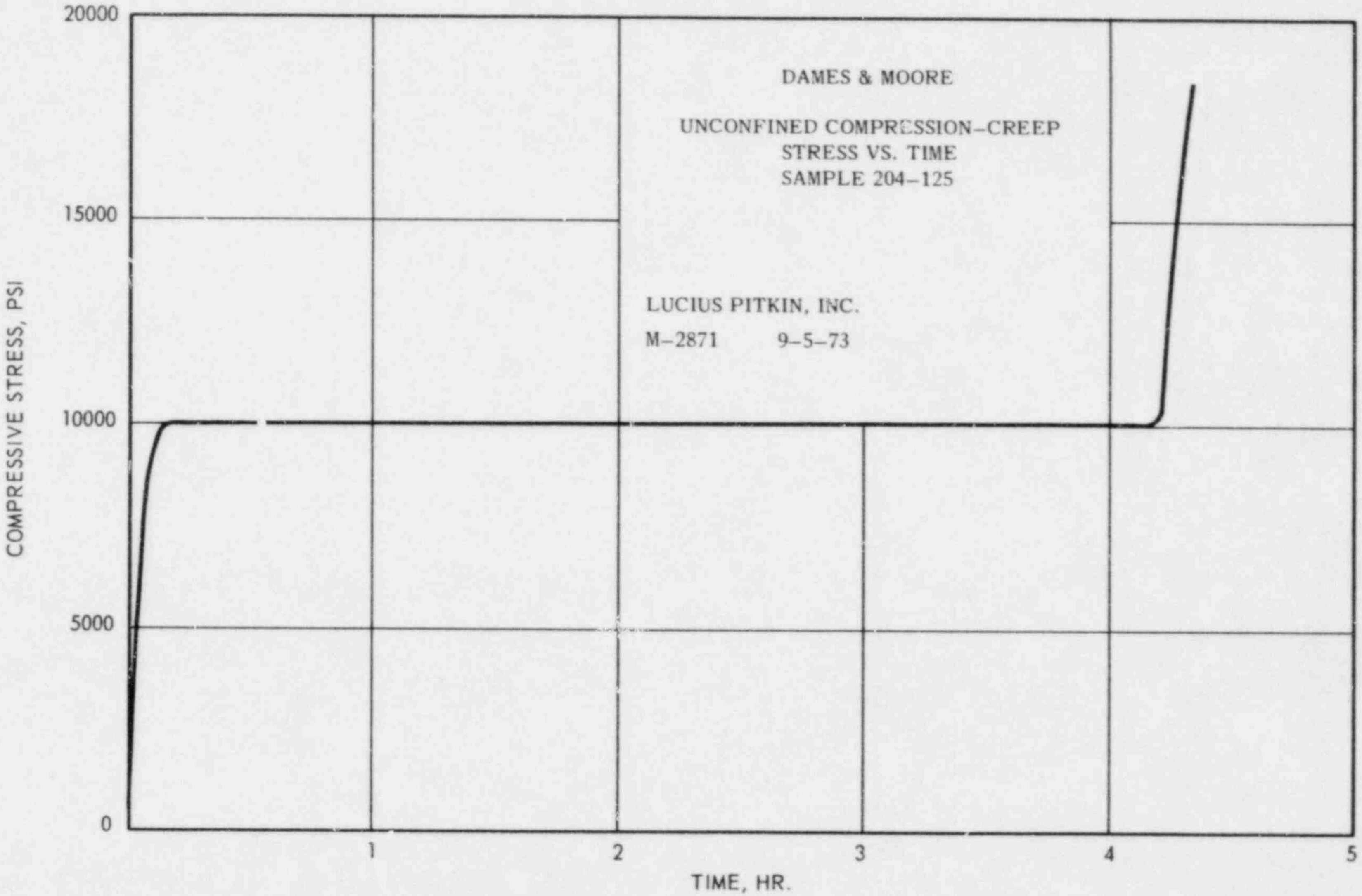


DAMES & MOORE

UNCONFINED COMPRESSION

SAMPLE 204-125

LUCIUS PITKIN, INC.
M-2871 9-5-73


DAMES & MOORE
UNCONFINED COMPRESSION–CREEP
STRESS VS. TIME
SAMPLE 204–125
LUCIUS PITKIN, INC.
M–2871 9–5–73
COMPRESSIVE STRESS, PSI
20000
15000
10000
5000
0
1
2
3
4
5
TIME, HR.

APPENDIX C

JULY 1981 TENDON SURVEILLANCE PROCEDURE

GINNA STATION
UNIT #1
COMPLETED
DATE: 7-22-81
TIME:

ROCHESTER GAS AND ELECTRIC CORPORATION

GINNA STATION

CONTROLLED COPY NUMBER 4

PROCEDURE NO. PT-27.2 REV. NO. 0

TENDON SURVEILLANCE PROGRAM FOLLOWING RE-TENSIONING

PCN 81T-410
81T-411
81T-423

TECHNICAL REVIEW

PORC 7/8/81

J C Bodine 7-13-81
QC REVIEW DATE

APPROVED FOR USE

Bruce Achen 7-13-81
PLANT SUPERINTENDENT DATE

QA X NON-QA ______ CATAGORY 1.0

REVIEWED BY: D Gent

THIS PROCEDURE CONTAINS 9 PAGES

PT-27.2

TENDON SURVEILLANCE PROGRAM FOLLOWING RE-TENSIONING

1.0 PURPOSE:

1.1 To provide the instructions necessary to perform a tendon lift-off surveillance one year after re-tensioning program has been completed to verify that the tendon forces are within Technical Specification limits.

1.2 To provide additional instructions to obtain data needed to continue the investigation into the larger than predicted tendon losses.

2.0 TEST REQUIREMENTS:

2.1 To measure lift-off forces in eighteen (18) selected tendons including the four (4) tendons with load cells.

2.2 To compare lift-off forces with those predicted, using either the existing relaxation data and/or retensioned wire data from the testing currently underway at Lehigh University.

2.3 To compare the two force measuring systems:

2.3.1 Strain gaged stressing rod.

2.3.2 Pressure gauge and effective ram area.

2.4 To test the 6% overstress effect.

2.5 During the tendon surveillance program the elastomeric pad between the vertical wall and the base mat is to be inspected. Since the pad is covered with a concrete grout, the inspection will be concentrated on the grout. Cracks and/or spalled grout should be visible if the elastomeric pad is experiencing any excess movements.

2.6 ACCEPTANCE CRITERIA:

2.6.1 The measured liftoff force of each tendon will be evaluated in accordance with the present "Ginna Technical Specifications."

2.6.2 Any tendon having a liftoff force less than 0.6 GUTS (636 kips) will be considered not acceptable.

2.6.3 Tendons on each side of all unacceptable tendons will be surveyed according to the procedures of 2.6.4 and 2.6.5. They shall be sequenced next after the unacceptable tendon with the lowest numbered tendon being first.

2.6.4 If both adjacent tendons have lift off forces greater than 0.6 GUTS (636 kips) and the average is greater than 636 kips, the group will be considered as meeting the specifications (comments will be included in the surveillance report on this tendon).

2.6.5 If only one adjacent tendon has a liftoff force greater than 0.6 GUTS (636 kips) but the average of all three is greater than 636 kips the group will be considered as meeting the specifications.

2.6.6 If both adjacent tendons have liftoff forces less than 0.6 GUTS (636 kips) or either average in 2.6.4 or 2.6.5 is less than 636 kips, the group will be considered to not meet the specifications.

2.6.7 All tendons evaluated as unacceptable will be retensioned to 0.7 GUTS at the end of the surveillance.

2.7 The tendon selection process will:

2.7.1 Verify that tendon force losses have stabilized.

2.7.2 Survey enough tendons to extend present data base.

2.7.3 Include all four tendons with load cells.

2.7.4 Include tendons retensioned at 1000 hours after initial stressing.

2.7.5 Include tendons from each tendon mark category.

2.7.6 Include two tendons selected by the USNRC.

2.7.7 Include two tendons selected at random.

NOTE: Table 1 contains the complete list of selected tendons and reason for selection.

3.0 REFERENCES:

3.1 Gilbert Associates Inc. (GAI) June, 1981 Tendon Surveillance Program (Rev. 1)

3.2 Ginna Technical Specifications - Section 4.4.4

4.0 INITIAL CONDITIONS:

4.1 Plant may be in any phase of operation. DG

4.2 Pressure gauges have been calibrated. DG

4.3 Hydraulic ram area has been calibrated. C F 7/13/81

4.4 Hydraulic pump and ram are functional and ready for operation. DD

PCN 81T-410

4.5 Load cells and stressing rod ~~have been~~ will be calibrated. during performance of this procedure. DD

4.6 All tendons to be stressed will be inspected for broken wires and corrosion prior to lift off. DD

4.7 Containment structure has been inspected for cracks, spalling, etc. C F 7/13/81

PCN 81T-411

4.8 Test personnel have been qualified in accordance with A-1102. DD

5.0 PRECAUTIONS:

5.1 Observe all RG&E safety rules and regulations.

5.2 Do not exceed 6560 psi gauge pressure for jack and tendons.

5.3 Whenever hydraulic pump is operating, the reservoir vent valve must be open.

5.4 Do not extend ram more than 8 inches.

6.0 GENERAL INSTRUCTIONS:

NOTE: The tendon surveillance sequence is presented in attached Table 2.

6.1 Fill in line 1-4 on the data sheet (sample attached) and record comments from the visual inspection on line 5.

6.2 Move assembled hydraulic jack to position for coupling to the anchor head and place the pump in a convenient location for operation.

6.2.1 Carefully thread stressing adaptor onto tendon anchor head.

NOTE: Leave a minimum of one thread and maximum of three threads on tendon anchor exposed below the lower edge of the stressing adaptor.

6.2.2 Place jack assembly on tendon base plate.

6.2.3 Center jack chair carefully over tendon head and thread stressing rod into stressing adaptor.

6.2.4 Center compression shims and tighten jack rod nut at top (ram) end of jack being careful not to damage strain gaged area and the electrical connector on top of the jack rod.

6.3 Make the appropriate strain gage connections and check for malfunctions.

6.4 Before attaching hoses to jack for the first tendon, check pump and hoses by performing the following:

6.4.1 Set valves to pump position.

6.4.2 Start pump at the same time depress the ball valve.

6.4.3 Pump slowly to fill hose with oil until it comes out of the hose free of bubbles.

6.4.4 Release ball valve and start pumping again. Continue pumping; hose will become stiff; gauge pressure will rise rapidly and then hold constant.

6.5 Reduce pressure and connect hoses to jack.

6.6 Record all initial readings in the appropriate columns on the data sheet.

6.7 Start pump and increase pressure to 2,000 psi.

6.7.1 Record stressing rod reading in column 3a on data sheet.

6.7.2 Record load cell reading in column 4a on the data sheet if tendon has load cell.

6.7.3 Record ram position in inches in column 5 on data sheet.

6.7.4 Calculate and record force values for the stressing rod, pressure gauge and load cell.

6.8 Increase pressure up to 4,000 psi and hold.

6.8.1 Inspect for leakage of hydraulic fluid and note if leakage is excessive.

6.8.2 Record stressing rod and load cell (if tendon has load cell) readings in the appropriate columns on the data sheet.

6.8.3 Calculate and record force for the stressing rod, pressure gauge and load cell.

6.9 Increase pressure until a 0.035 (1/32) inch thick feeler shim can be inserted into the shim stack at two equally spaced positions around the shim stack.

6.10 Reduce ram pressure 1000 psi or until the feeler shims cannot be removed. Increase pressure until both feeler shims can be removed. Note in the comment section if there is a large difference in the load at which each feeler shim can be removed. This is defined as liftoff.

6.10.1 Record the pressure gauge reading on the data sheet in column 2a.

6.10.2 Record the stressing rod reading on the data sheet in column 3a.

6.10.3 Record the load cell reading for load cell tendons in column 4a.

6.10.4 Record the ram position in column 5 of the data sheet.

6.10.5 Calculate and record force values.

6.11 Stress tendons 13 and 133 an additional 6% over recorded liftoff pressure.

6.11.1 Record computed 6% overstress pressure on data sheet in column 2a.

6.11.2 Increase pressure to computed 6% over stressing pressure and record stressing rod reading, load cell reading and ram position on the data sheet.

6.11.3 Place two .035 (1/32) inch thick feeler shims in the shim pack and reduce ram pressure to approximately 2900 psi.

6.11.4 Slowly increase pressure until the feeler shims can be withdrawn from shim stack. This is defined as liftoff. Record load cell, pressure gauge, strain gage and ram position on data sheet.

6.11.5 Calculate and record force values on data sheet.

6.12 Decrease pressure to approximately 4,000 psi.

6.12.1 Record stressing rod reading, load cell and ram position on the data sheet.

6.12.2 Calculate and record force values on data sheet.

6.13 Decrease pressure to approximately 2,000 psi.

6.13.1 Record stressing rod reading, load cell reading and ram position on the data sheet.

6.13.2 Calculate and record force values on the data sheet.

6.14 Decrease pressure until all load is removed from jack rod.

6.14.1 Record stressing rod reading, load cell reading and ram position on the data sheet.

<u>NOTE</u>: Strip chart recordings of force from load cell tendons will begin when the jack assembly is moved from that tendon and continue for 500 hours.

6.15 Remove jack assembly from tendon.

6.15.1 Disconnect strain gage equipment.

6.15.2 Unthread stressing rod from coupler.

6.15.3 Remove jack chair and stressing rod assembly.

6.15.4 Remove adapter from tendon head.

6.16 Record any comments concerning liftoff on the data sheet.

6.17 Move to next tendon.

COMPLETED BY: D. Gent

DATE COMPLETED: 7-22-81

SHIFT SUPERVISOR: [illegible]

RESULTS & TEST REVIEW: D. Gent DATE: 8-7-81

COMMENTS: (1) The Test Personnel qualification for Clyde Forbes was not completed on the first day of testing (7-14-81), however there is no reason to believe he was any less qualified at this time than he was the next day. The only liftoff which was performed on 7-14-81 was tendon #13.

(2) A change in test sequence was made for convenience to prevent having to move jack completely around containment. See memo attached to this procedure.

TABLE 1

TENDON SELECTION

TENDON NUMBER	TENDON MARK	COMMENTS
13	A	LOAD CELL
17	C	MAXIMUM RECORDED DATA
21	A	RANDOM FROM 0 TO 40
33	GS	RETENSIONED AT 1000 HOURS
36	HT	RETENSIONED AT 1000 HOURS
51	A	AVERAGE 11 YEAR LOSS
53	A	LOAD CELL
62	A	LARGE 11 YEAR LOSS
63	A	USNRC SPECIFIED
74	C	USNRC SPECIFIED
76	B	LARGE 11 YEAR LOSS
84	A	MAXIMUM RECORDED DATA
93	A	LOAD CELL
111	A2	RETENSIONED AT 1000 HOURS
116	FR	RETENSIONED AT 1000 HOURS
[illegible]	BI	RANDOM FROM 120 - 160
133	A	LOAD CELL
155	A	SMALL 11 YEAR LOSS

TABLE 2

TENDON SURVEILLANCE SEQUENCE

SEQUENCE NUMBER	TENDON NUMBER	SPECIAL INSTRUCTIONS
1	13	LOAD CELL AND 6% OVERSTRESSING
2	17	
3	21	
4	51	
5	53	LOAD CELL
6	62	
7	63	
8	74	
9	76	
10	84	
11	93	LOAD CELL
12	125	
13	133	LOAD CELL AND 6% OVERSTRESSING
14	155	
15	33	
16	36	
17	111	
18	116	

81T-411
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1) DATE: ____________ TENDON NO.: ____________ SHIM STACK THICKNESS: ____________

2) HYDRAULIC JACK NO.: ____________ RAM AREA*: ____________

3) HYDRAULIC PUMP NO.: ____________ PRESSURE GAUGE NO.: ____________

4) LOAD CELL FACTOR**: ____________ STRESSING ROD GAGE FACTOR***: ____________

5) TENDON INSPECTION COMMENTS: ____________

(1) CONDITION	(2) PRESSURE GAUGE (a) Pressure (psi)	(2) PRESSURE GAUGE (b) Force* (lbs)	(3) STRESSING ROD (a) Strain (μ in/in)	(3) STRESSING ROD (b) Force** (lbs)	(4) LOAD CELL (a) Strain (μ in/in)	(4) LOAD CELL (b) Force*** (lbs)	(5) RAM POSITION incnes	(6) COMMENTS
INITIAL:	0							
INCREASING:	2000							
INCREASING:	4000							
LIFTOFF:								
LIFTOFF + 6%: (TENDONS 13 & 133)								
LIFTOFF:								
DECREASING:	4000							
DECREASING:	2000							
DECREASING:	0							

NOTES: (*) Ram area to be used to calcualte ram force in column 2b: Force = ~~Ram Area x Pressure~~ 3.05 +0.12761 [GAGE PRESSURE (PSIG)]

(**) Load Cell Factor to be used to calculate force in column 4b: ~~Force = Load cell Factor x (Strain Reading - Initial Strain Reading)~~ (See Attachment 1)

(***) Stressing Rod Gage Factor to be used to calculate force in rod in column 3b: Force = stressing rod gage factor x (Strain - Initial Strain Reading)

COMPLETEDCF

COMPLETED BY: ____________ DATE: ____________

ATTACHMENT 1

INDIVIDUAL LOAD CELL FACTORS

#13) FORCE = 722.4 - 0.15137 (Δ LOAD CELL READING)

#53) FORCE = -51.6 - 0.1561 (LOAD CELL READING)

#93) FORCE = -40.6 - 0.1495 (LOAD CELL READING)

#133) FORCE = 20.9 - 0.1413 (LOAD CELL READING)

APPENDIX D

LOAD CELL PROCEDURES

APPENDIX D

LOAD CELL DATA COLLECTION PROCEDURE

1. Obtain initial system readings:

   a. Load cell - millivolts (mv)
   b. Input voltage
   c. Voltage at terminal box at load cell (between white and blue leads)

2. Turn off power to load cell at the data logger.

3. Setup hydraulic jacking system to do standard lift-off of the tendon.

4. Setup and zero Vishay strain gage recorder for:

   a. Stressing rod strain gages
   b. Load cell - Vishay readout

5. Slowly transfer tendon load from shims to the hydraulic jack and record the following for every 500 psig from 0 to 5500 psig:

   a. Pressure gauge
   b. Stressing rod - Vishay readout
   c. Load cell - Vishay readout

6. Continue load transfer until lift-off, then record:

   a. Pressure gage
   b. Stressing rod - Vishay readout
   c. Load Cell - Vishay readout

7. Disconnect load cell from Vishay system.

8. Turn on power to load cell at data logger.

9. Record zero load cell reading (should be zero - no load).

10. Repeat Steps 2 through 9 until two consistent sets of data are obtained.

11. Check to see if data logger is recording at proper time interval before leaving.

12. Reduce data and perform necessary adjustments.

To complete the load cell calibration, the data must be reduced and appropriate adjustments made in the load cell recording system (data logger). The following procedure was used:

LOAD CELL DATA REDUCTION AND CALIBRATION PROCEDURE

1. Calculate load from stressing rod readings at each pressure level.

2. For both data sets plot load cell reading (micro inches per inch) vs stressing rod load (kips) and visually fit the data with a straight line.

3. Calculate best fit representation of both data sets using linear regression for each data set.

4. Compare lines from Steps 2 and 3.

5. Compare linear regression determined slopes and intercepts of both data sets; if close, average for voltage calculation. If not close, re-run test calibration.

6. Using the average slope (m) from Step 5, which has units of micro inches per inch per kip (μ in./in./kip), calculate reading for the 800 kip maximum force.

$$A = m \times 800 \qquad [\mu \text{ in./in.}]$$

7. Divide A by the load cell constant 2000, which has units of μ in./in per volts/mv,

$$B = \frac{A}{2000} \qquad [\text{mv/volt}]$$

8. The factor 20 kips/mv is selected as a convenient multiplier to apply to the load cell reading to obtain the force in kips. Therefore, the 800 kip force from Step 6 should produce a 40 mv output reading:

$$(20 \text{ kips/mv})(40 \text{ mv output}) = 800 \text{ kips}$$

9. Calculate the input voltage required to produce 40 mv output, which corresponds to the 800 kip maximum force:

$$\text{Input Volts} = \frac{40\text{mv}}{B} \qquad (\text{volts})$$

Note: This input voltage applies <u>at</u> the load cell.

10. Measure voltage at junction box near load cell between white and blue leads - this voltage should be what is calculated in Step 9; if not, adjust voltage at recorder to receive proper voltage at junction box.

11. Record old and new values of voltage at load cell box and recorder.

12. Record load cell reading, multiply by 20, and compare with lift-off. The readings should be identical.

13. Record all changes made to the data system.