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ROBERT E. GINNA NUCLEAR POWER STATION

CONTAINMENT VESSEL TENDONS

STRESS RELAXATION PROPERTIES OF RETENSIONED WIRES

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1.0 INTRODUCTION

The R. E. Ginna containment structure is post tensioned by 160 vertical tendons. The tendons were originally stressed in March and April 1969, and lift-off tests were performed on six occasions subsequent to this date over a period of 11 years. From these tests, it was found that the measured tendon lift-off forces were generally lower than the predicted values. As a result, Gilbert Associates, Inc. (GAI) was requested to investigate the possible causes for the lower-than-predicted tendon forces. Reference 1 describes the details of this investigation, from which it was concluded that stress relaxation of the tendon wires is the only significant cause for the lower-than-predicted tendon forces.

By the time of the eight year surveillance in 1977, the average force of the tendons was marginally above the design requirement of 636 kips. Rochester Gas and Electric Corporation (RG&E) decided to retension 137 of the 160 tendons. This work was completed in June 1980. The 23 tendons which were not included in the June 1980 retensioning program had been retensioned previously in May 1969, approximately 1000 hours after their original stressing.

In order to develop data which would enable a determination of the stress relaxation property for the retensioned tendons, retensioning tests on sample tendon wires were conducted at the Fritz Engineering Laboratory of Lehigh University. The retensioning test program was actually an extension of the original wire relaxation tests initiated in March 1980 at the same laboratory. After the specimens had been under load for a specified duration, seven (7) were restressed to their initial stress level. Table 1 presents the test conditions of the seven (7) retensioned tendon wires.

As discussed later in this report, the relaxation property of a retensioned wire is significantly different from that of an unretensioned wire. In general, the former exhibits a lower stress relaxation. Therefore, using stress relaxation property data from unretensioned wires to predict the stress relaxation in the retensioned tendons will lead to an over-estimation of the stress loss. As a result, the predicted tendon forces based on these losses will be artifically low, which is unconservative for purposes of comparison with forces measured at future surveillances.

This report evaluates the Lehigh retensioning test data for the purpose of determining how to establish a representative retensioned stress relaxation curve for the Ginna tendons. Two prediction techniques, referred to as the Superposition Method and Factor Method, were evaluated. The Superposition Method basically assumes that superposition principles apply to the stress relaxation property and, consequently, relies only on unretensioned data. The Factor Method, on the other hand, relies on the test results from both the unretensioned and retensioned wires. The Lehigh retensioning test results were compared with those predicted by both the Superposition Method and the Factor Method. The method providing the best representation of the retensioned stress relaxation property was concluded to be the Factor Method, and this method was then applied to reevaluate the data from the July 1981 surveillance. The Factor Method was also used for predicting the forces for the tendons selected for the July 1983 surveillance.

2.0 RETENSIONED WIRE TEST RESULTS

The results of the original stress relaxation tests and the retensioning tests have been summarized in a Lehigh report entitled "Relaxation Tests on 1/4" Prestressing Wires," which is included in this report as Appendix A. Some later data, not

included in the Lehigh report, was subsequently received under the cover of a transmittal letter dated March 23, 1983 from Professor Roger G. Slutter to GAI. This data is also included in Appendix A. The combined data set was used in the present analysis.

2.1 Curve Extrapolations

The test data from the seven (7) retensioned wires reported in Appendix A was replotted on a log-log scale. These are shown in Figures 1-A through 1-G. In the figures, the curves designated "BASE" represent the stress relaxation versus time-under-load prior to retensioning. The curves designated "RETENSIONED" represent the stress relaxation versus time-under- load after the wires were retensioned. The time corresponding to the last data point on the Base curve is the time at which the wire was retensioned. From the figures, all the results display the fundamental characteristic that the stress relaxation of a retensioned wire is less than its Base relaxation.

The dashed lines beyond the last data point represent the extrapolations out to 350,000 hrs. (40 years). The extrapolations shown in the figures for the Base curves were determined visually, and they are consistent with those in the semi-log plots in Reference 1. The extrapolations for the Retensioned curves were also determined visually. For both sets of curves, a linear extrapolation was used as a reasonable approximation. As a way of "smoothing out" the data, the circled data points on the Retensioned curves are those selected as the reference points for the linear extrapolation. This approach applies well to the curves of Wire #3 (51-B) in Figure 1-A, Wire #9 (76-B1) in Figure 1-E, and Wire #7 (76-B) in Figure 1-C. Their retensioned stress relaxations at 40 years are predicted as 12%, 16% and 10%, respectively. Some judgement, however, was required for the extrapolation of the curves for Wire #8 (76-C), Wire #10 (76-B2),

Wire #4 (51-C) and Wire #12 (150-C2). These are discussed separately below.

2.1.1 Wires #8 and #10 (Figure 1-D and Figure 1-F)

Table 1 indicates that sample wires #8, #9, and #10 are all from the same test wire pulled from Tendon 76 and were tested at the same temperature, 104° F, and the same initial stress, 70% GUTS. The only difference is that Wire #9 was retensioned at 100 hrs., Wire #10 at 1,000 hrs. and Wire #8 at approximately 10,000 hrs.

Figures 1-D, 1-E, and 1-F show the Base and Retensioned curves for Wires #8, #9, and #10, respectively. Figure 1-H presents the Base curves and the extrapolations of the three wires on a single plot. In the figure, all three curves lie very close together. This confirms that the three wires exhibited the same stress relaxation property before retensioning. The Retensioned curves of the three wires are plotted together on Figure 1-I. A deviation among these three curves is evident. The curves start separating at around 5 hours after retensioning, and out to approximately 10,000 hours under load the amount of relaxation which the wires experience is inversely proportional to the time at which they were retensioned. However, beyond 1000 hours the relaxation values of the wires which were retensioned at 1000 hours (#10) and 10,000 hours (#8) slowly converge. By approximately 15,000 hours, it appears that Wires #8 and #10 exhibit the same retensioned stress relaxation. However, the relaxation for Wire #9, retensioned at 100 hours, does not display a tendency to converge to the values of Wires #8 and #10.

Figure 1-I also presents linear extrapolations consistent with those made in Figures 1-D, 1-E and 1-F. From the figure, the extrapolated curve of Wire #8 appears to cross over that of Wire #10. However, there is no reason to believe that the wires would actually exhibit this characteristic. It is more reasonable

to interpret the data as indicating that somewhere in the 15,000 hour to 20,000 hour time range, the retensioned curves for Wire #8 and Wire #10 converge to approximately the same curve and continue as one curve thereafter. In light of this, the extrapolations for Wires #8 and #10 were adjusted. Since data beyond 20,000 hours was not available, the average of the two extrapolation curves was constructed as the extrapolation curve estimated for Wires #8 and #10. This adjusted extrapolation curve predicts a 13% stress relaxation at 40 years. This curve was used, as indicated in Figures 1-D and 1-F.

2.1.2 Wire #4 (Figure 1-B)

Figure 1-B shows two possible extrapolations for the Retensioned curve of Wire #4, indicated as dashed lines A and B. Extrapolation A represents an extension of the straight line which passes through most of the data points located within the range from 1,000 hrs. to 10,000 hrs. This line crosses over the Base curve and gives a 24% stress relaxation at 40 years. Extrapolation B was based on the last two data points marked by squares. This extrapolation gives a 13% stress relaxation at 40 years.

Line B is considered to be more realistic than line A for two reasons. First, line B seems to be more consistent with the concave-downward shape of the retensioned curve between 200 hrs. and 10,000 hrs. Secondly, the figure shows that the Base and Retensioned curves start approaching each other at 200 hrs., and they seem very likely to converge together somewhere in the 10,000 to 20,000 hr. range. There is no reason to expect the Retensioned relaxation to become greater than the Base relaxation, which would occur if curve A were used. Therefore, it was decided to use extrapolation B for Wire #4, as indicated in Figure 1-B.

2.1.3 Wire #12 (Figure 1-G)

It is seen from Figure 1-G that the two data points on the Retensioned curve at around 8000 hrs. and 10,000 hrs. are displaced higher than would be expected based on the trend of the data between 1000 hrs. and 6000 hrs. Because of this, there exists a wide range of possible extrapolations, depending on the reference points selected. One possible extrapolation is to extend a straight line which connects the data points at 8000 hrs. and 10,000 hrs. (line A) out to 40 years, at which time it becomes equal to the Base curve. This extrapolation gives a 3.8% stress relaxation at 40 years. Another possibility is to use the two data points at approximately 6000 hrs. and 4000 hrs. for extrapolation. Line B was drawn through these two points and extended out to 40 years. This results in a 2.5% stress relaxation at 40 years. Other possible extrapolations give a 40-year stress relaxation of somewhere between 1.7% to 3.8%. By inspection, line B seems to agree better with the overall trend of the Retensioned curve, and is therefore considered as the representative extrapolation for Wire #12. The extrapolated line A was considered as an upper bound.

All the extrapolations discussed above were made linearly on a log-log scale. To aid in the visual extrapolation process, the test results from the seven (7) retensioned wires were re-plotted on the semi-log plots in Figures 2-A through 2-I.

2.2 Factor Method

As discussed earlier, the test results indicate that the stress relaxation of the retensioned wires is generally lower than that for the unretensioned wires. Therefore, the retensioned stress relaxation may be obtained from the unretensioned results by applying a multiplying factor of between 0 and 1. The

determination of the appropriate factors is the key point of this method. These factors rely on the test data presented in Figures 1-A through 1-I or, alternatively, Figures 2-A through 2-I, which were used in this work.

At any time-under-load the original stress relaxation and the retensioned stress relaxation of each wire can be read from the Base curve and the Retensioned curve, respectively. The factor corresponding to a particular time is obtained as the stress relaxation value from the Retensioned curve divided by the value from the Base curve. Factors from each of the seven retensioning tests were plotted on a semi-log scale, as shown in Figures 3-A through 3-H. The vertical axis represents the factor value, which is referred to as the stress relaxation "retensioning ratio". The horizontal axis represents the time at which the wire was retensioned. Each of the figures represents the retensioning ratio values at a particular time after retensioning. Data exists for 104° F (four specimens) and 68° F (three specimens).

In each figure, it is apparent that the retensioning ratio varies with the time of retensioning and the temperature. Based on the data points, curves were established and used to predict the retensioning ratio values for the wires with different temperatures and different retensioning times. Before describing the curve fitting process that was used, the effect of several parameters will be evaluated.

2.2.1 Retensioning Time - Wires #8, #9, and #10

As listed in Table 1, wire specimens #8, #9 and #10 came from the same test wire and were subjected to the same test temperature and initial stress; only the time of retensioning varied. It is reasonable to consider these three wires collectively for evaluating the retensioning time effect. Wires #8, #10 and #9 were retensioned at approximately 10,000, 1,000 and 100 hours, respectively. As Figures 3-A through 3-H indicate, generally the

retensioning ratio values for Wire #8 are the lowest, and the ratio values for Wire #10 are lower relative to Wire #9. From this it can be concluded that, generally, a lower percentage of the original unretensioned stress relaxation occurs for later retensioning times. However, after a sufficient duration (time after retensioning), the effect of the retensioning time becomes less significant to the extent that as the retensioning time increases beyond a particular range, the retensioning ratio tends to approach a constant value. This is seen from Figures 3-E through 3-H where beyond 10,000 hours after retensioning, Wire #10 and Wire #8 have approximately the same retensioning ratio values although they were retensioned at different times. The data from Wire #3 provides supporting evidence, which is discussed in the next section.

The condition described above apparently does not hold true for very early retensioning times. Wire #9, retensioned at 100 hrs., still exhibits retensioning ratio values that are higher than those for Wires #8 and #10 even at 350,000 hrs. after retensioning (Figure 3-H).

2.2.2 Wire Heat

Figures 3-A through 3-H indicate that the retensioning ratio values for Wire #8 and Wire #3 are in the same neighborhood. As can be seen from Table 1, Wire #3 has the same test temperature and initial stress as that of Wire #8. But Wire #3 is from a different heat and it was retensioned at a different time: 6000 hours versus approximately 10,000 hours for Wire #8. Recall that Wire #10 was retensioned at 1000 hours and its retensioning ratio is slightly larger than that of Wire #8 when the duration after retensioning is less than 10,000 hours. For duration longer than 10,000 hours, there exists no difference in the retensioning ratio values between Wire #10 and Wire #8. Therefore, it would be expected that for Wire #3 and Wire #8, the difference in

retensioning time of 6000 hrs. versus 10,000 hrs. would not produce any significant difference in retensioning ratio values, after 10,000 hrs., if there were no effect of the different wire heats. In fact, the retensioning ratio data indicates that this is indeed the case, even as early as 1000 hrs. after retensioning (Figure 3-C). Also, comparing Figure 2-A with Figure 2-D, it is interesting to note that the shapes of the Base curve and Retensioned curve of Wire #3 are very similar to those of Wire #8, although there exists a significant difference in magnitude of the stress relaxation curves.

Based on the preceding observations, it seems reasonable to conclude that the retensioning ratio values are the same for different wire heats, all other parameters being equal.

2.2.3 Temperature

Since the comparison above for Wires #3 and #8 indicates that the wire heat has no effect on the retensioning ratio, it is reasonable to consider Wires #4, #12, and #7 as one group all with the same temperature of 68° F, and Wires #9, #10, #3 and #8 as another group all with the same temperature of 104° F, even though more than one wire heat is involved in each group. Figures 3-A through 3-H show that the wires at 68° F generally have higher retensioning ratio values than the wires at 104° F. The data of Wires #4, #12, and #7 are comparable with those of Wires #10, #3, and #8 in the sense that they were retensioned at about the same times, respectively.

The figures indicate that the retensioning ratio data points for 68° F do not behave quite as well as those at 104° F, particularly at the relatively early times after retensioning of 10 hrs. and 100 hrs (Figures 3-A and 3-B). For these times, the 68° F retensioning ratio values increase, rather than decrease, with the time of retensioning. However, beyond 1000 hrs. after retensioning (Figure 3-C through Figure 3-H), the 68° F data

exhibits the same basic characteristic of the 104° F data, namely a generally decreasing retensioning ratio as the time of retensioning increases. Another observation is that after about 4000 hours (Figure 3-D), the data for Wires #12 and #7, retensioned at 5500 hrs. and 11,600 hrs., approach the 104° F results; and at a time after retensioning of 100,000 hours (Figure 3-G) and thereafter, the temperature effect becomes insignificant. From Figure 3-G and Figure 3-H, Wires #10, #3, #8, #12 and #7 all have the same retensioning ratio at 100,000 hrs. and beyond, regardless of the time at which they were retensioned. However, Wire #4 which was retensioned at 1000 hrs. still exhibits a different retensioning ratio, apparently due to its temperature difference (compare Wires #4 and #10).

Based on the observations above, two groups of curves, each group representing a temperature condition, were established as shown in Figures 3-I and 3-J. Each curve represents, for a particular retensioning time, the retensioning ratio versus time after retensioning. These were based on the curves in Figures 3-A through 3-H. The procedure used for connecting the data points in Figures 3-A through 3-H for each temperature condition is described below.

2.2.4 Curves for 104° F

Since the quantity of data was somewhat limited, only a linear connection of the data points was considered to be practical. As shown in Figures 3-A through 3-H, data points 9R, 10R and 8R are connected with straight lines since the test conditions and heat numbers of these wires are the same. Data point 3R (different heat) lies only slightly below the 10R-8R line for times after retensioning up to 100,000 hrs., and the data point is only slightly above the line at 350,000 hrs. after retensioning. These deviations are regarded as insignificant, and data point 3R is considered to be a confirmation of the retensioning ratio values set by the results from Wire #8. A horizontal line was extended

from point 8R out to 350,000 hours as the extrapolation. This seems to be justified as discussed in the preceding section. The retensioning ratio becomes a constant as the retensioning time increases beyond a particular value. A comparison between points 3R and 8R indicates this occurs for retensioning times as early as 6000 hours for the 104° F condition. Certainly the results indicate that for retensioning times beyond 10,000 hours, the retensioning ratio has reached a constant value at each specific time after retensioning. However, it is seen that the retensioning ratio increases as the time after retensioning increases.

The curves for the 104° F data were replotted in Figure 3-I. In this figure, the retensioning ratio is plotted as a function of the time after retensioning, and each curve represents a particular retensioning time.

2.2.5 Curves for 68° F

A similar approach was used to establish 68° F curves. Three data points 4R, 12R, 7R were first connected by straight lines. The lines were extended for extrapolations to 100 hrs. and out to 350,000 hrs. However, upper and lower bounds to the extrapolated lines were imposed as indicated below.

As the retensioning ratio is defined, it cannot exceed a value of 1. Thus, the linear extrapolations back to 100 hrs. in Figures 3-D through 3-H are cut-off at a ratio value of 1. In the extrapolation out to 350,000 hrs., the line for the 68° F curve appears to intersect with the horizontal line for 104° F. Beyond the intersection point, it is conservative to assume that the 68° F curve will merge into, but not fall below, the 104° F curve. The data alone is not sufficient to indicate if this assumption is justified. Nevertheless, there is no reason to expect the retensioning ratio data for 68° F to reverse its previous trend and become less than the 104° F values.

Figures 3-A and 3-B are particularly discussed here. Obviously from the figures it is very difficult, if at all possible, to justify a reasonable extrapolation curve for the 68° F condition when the time after retensioning is less than 1000 hrs. However, in this work, it is really not necessary to determine the retensioning ratio values at times after retensioning any less than 1000 hrs. since none of the tendons were retensioned prior to this time. Therefore, the curves in Figures 3-A and 3-B were not considered in the tendon force predictions. Only the 68° F and 104° F curves shown in Figures 3-C through 3-H were used and these are replotted in Figure 3-J. In the figure, the time after retensioning now appears on the horizontal coordinate line, and each curve represents a particular retensioning time.

With Figures 3-I and 3-J, the retensioned stress relaxation can be predicted by applying the retensioning ratio values to the Base curves. The Base curves appear in Figures 2-A through 2-G. At any particular time after retensioning, the retensioning ratio for a particular temperature and time of retensioning can be directly read or obtained by interpolation using both Figure 3-I and Figure 3-J. This ratio value can then be used as a multiplier on the stress relaxation value from the Base curve obtained at the same time as the time of interest after retensioning. The resulting value is the predicted stress relaxation for the retensioned wire at a particular temperature, and a particular retensioning time and time after retensioning.

For comparison, the Retensioned curves which were predicted by the Factor Method described above are identified as "F.M." and shown together with the Lehigh test data in the Figures 2-A through 2-G. Also shown in the figures are the Retensioned curves predicted by the Superposition Method (labeled by S.M.). This method is discussed below.

3.0 TENDON FORCE PREDICTIONS

Up to this point, the discussions have been limited to the Lehigh test program on the retensioned wires. By using the retensioned test data, a prediction technique called the Factor Method was developed which offers a reasonable approach for determining the retensioned stress relaxation in the test wires. However, the final objective is to apply this technique to the prediction of stress loss in the retensioned tendons. For this purpose, retensioning ratio values which are suited to temperature conditions of the actual tendons, and Base curves which represent the stress relaxation properties of the tendons were established in the manner described below.

3.1 Retensioning Ratio Values for Actual Tendons

During plant operation the air temperature inside the containment is approximately 100° F, and the temperature of the tendons is expected to range as high as 85° F to 95° F (page 2-38, Reference 1). It is believed that this temperature range has been experienced by the tendons during most of their life. Therefore, an average temperature of 90° F was selected as the representative temperature for the prediction of tendon relaxation. As a result, it was necessary to establish retensioning ratio values corresponding to 90° F in order to apply the Factor Method to the actual tendons. Either Figures 3A through 3H, or alternatively Figures 3I and 3J, may be interpolated to obtain the ratio values for 90° F. Figures 3A through 3H were actually used, for better accuracy. The resulting 90° F curves are presented in Figure 3K.

3.2 Base Curves for Actual Tendons

Figures 3-1 and 3-2 of Reference 1 show the unretensioned (Base) stress relaxation of all the specimens involved in the Lehigh Test

Program. The wires for these specimens were extracted from Tendons 51, 76 and 150. In the figures it is seen that the unretensioned relaxation property varies depending on test temperature, initial stress, and material heat. Among these curves, four representative ones were selected and replotted in Figure 4 herein. They are curves 76-C (Wire #8, 0.7 GUTS, 104° F), 76-B (Wire #7, 0.7 GUTS, 68° F), 51-B (Wire #3, 0.7 GUTS, 104° F) and 51-C (Wire #4, 0.7 GUTS, 68° F). The Base curves for tendon 150 were not used because, as explained in Reference 1, the data of interest at 0.7 GUTS and 104° F was suspect.

By using a linear interpolation between the curves at 68° F and 104° F, the curves for Tendon 76 at 90° F and Tendon 51 at 90° F were established. They are labeled as 76-90° F and 51-90° F in Figure 4. These two curves are considered as representative unretensioned relaxation curves, or Base curves, at 90° F for tendons 76 and 51. The figure shows that curves 76-90° F and 51-90° F are very similar in shape, although somewhat different in magnitude (16.6% versus 14.2% at 100,000 hours).

From Figures 2.9-2, 2.9-3, and 2.9-4 in Reference 1, it was shown that the average effective stress relaxation at 100,000 hours for all tendons comprised solely of wires from any of the three different test heats was in the neighborhood of 15%. This value is noted between the curves 76-90° F and 51-90° F in Figure 4. The 15% value for average effective stress relaxation is within 10 percent of the test values of 16.6% (Curve 76-90° F) and 14.2% (Curve 51-90° F). Therefore, it seems feasible to establish a single Base curve for use in determining the stress losses in all tendons. At the very least, all the Base curves, if there exists more than one, should have a shape similiar to the 76-90° F or 51-90° F Base curves. To investigate this further, two different approaches to establishing unretensioned relaxation curves (Base curves) for the tendons were considered, which are discussed below.

3.2.1 16% Relaxation Curve

It was assumed that a common unretensioned relaxation curve (Base curve) can be used for all the tendons. This common Base curve has a relaxation of 15% at 100,000 hours, and has a shape similar to Curve 76-90° F. The shape of Curve 76-90° F was selected over Curve 51-90° F because longer-term test data was available for this curve, which would provide a more accurate extrapolation out to 40 years. At 100,000 hrs. the ratio of 0.9 was established (15% divided by 16.6%), and the 15% curve was constructed by scaling Curve 76-90° F by this factor. The resulting curve is shown in Figure 5 and is noted as "16% Base Curve", since the 40 year relaxation turned out to be nearly 16%. The other two curves shown in Figure 5 were constructed by applying the retensioning ratio values, obtained from the 1,000 hr. and 100,000 hr. curves in Figure 3-K, to the 16% Base Curve. Thus, the two resulting curves in Figure 5 represent the retensioned stress relaxation property of a 16% relaxation grade of wire after the wire is restressed either at 1,000 hrs. or 100,000 hrs. following its original stressing.

3.2.2 Effective Stress Relaxation Curve

As an alternative to using a common relaxation curve, a unique Base curve was determined for each tendon. The effective stress relaxation which each tendon had exhibited as of June 1980 (100,000 hrs.) was determined first. Then, a scaling factor similar to that obtained for the 16% curve was determined for each tendon, based on its unique effective stress relaxation value at 100,000 hrs. Based on the value of the factor, the 76-90° F curve in Figure 4 was scaled to provide a corresponding Base curve for each tendon.

For comparison, both types of Base curves described in sections 3.2.1 and 3.2.2 were used to reevaluate the stress loss in the

tendons for the July 1981 surveillance. The approach which results in the best agreement with the lift-off forces, using the retensioning ratio values described in Section 3.1, can be used for force predictions at future surveillances.

3.3 Predicted Tendon Forces at July 1981 Surveillance

The July 1981 surveillance was performed one year and one month (9490 hours) after the June 1980 retensioning. Eighteen tendons were selected for the surveillance. Among the 18 tendons under surveillance, 14 were from the tendons retensioned in June 1980, and the remaining four tendons were from those retensioned in May 1969. The tendon numbers, lift-off sequences, last lock-off forces, and measured lift-off forces at the surveillance, are presented together with the predicted results in Table 2.

The retensioning ratio values described in Section 3.1 were used for predicting the stress relaxation in the tendon wires. These ratio values were obtained from Figure 3K and applied to the two different types of Base curves discussed in Section 3.2. Other force losses due to such as shrinkage, creep, and elastic shortening in concrete were calculated using the methodology described in Reference 1. The combined force loss was then substracted from each tendon lock-off force appearing in column (1) of Table 2. The results are listed in either column (3) or column (4), depending on whether the 16% Base curve or an Effective Stress Relaxation curve was used as the Base curve. These forces are to be compared with the measured values appearing in column (2) of Table 2. A comparison of the percent difference between measured and predicted forces for the two types of Base curves is presented in columns (1) and (2) of Table 3. The mean of the absolute sum of the percent differences for the 16% Base curve approach is 1.64%, compared to 2.64% for the individual Base curve approach (Effective Stress Relaxation curves). Without considering Tendon 74, because its effective

stress relaxation value was somewhat questionable, the values reduce to 1.55% compared to 2.21%. Comparing all the results in columns (1) and (2), it seems reasonable to conclude that both types of Base curves result in predicted tendon forces that generally agree about equally well with the forces measured.

The predicted force-versus-time curves for each tendon are shown in Figure 6. The solid curves represent predicted forces based on (1) the Effective Stress Relaxation (E.S.R.) of the particular tendon, modified by the retensioning ratio values, and (2) 16% relaxation, modified by the retensioning ratio values. The 1981 surveillance data are also indicated in Figure 6.

Returning to Table 3, columns (3) and (4) show the percent difference between the measured forces and 95% times the predicted forces. The 95% predicted force value is the acceptance limit that is specified in a new subsection in the ASME Code on Inservice Inspection of Concrete Containments (2). It is seen from columns (1) and (2) that the measured forces are generally slightly below their predicted values for 9 of the tendon forces predicted using the 16% Base curve and for 7 of the tendons using the Effective Stress Relaxation Base Curves. However, all but one of the measured forces are greater than 95% of the predicted values for both approaches.

4.0 CONCLUSIONS

1. Compared to the Superposition Method, the Factor Method, which uses retensioning ratio values, provides the best means for accounting for the retensioning effect on stress relaxation in the tendon force prediction process.

2. The curves for the retensioning ratio values presented in Figure 3K are to be applied to a Base curve relaxation for future force predictions for the Ginna tendons.

3. Both the 16% Relaxation Base Curve and the Effective Stress Relaxation Base Curve resulted in predicted tendon forces that generally agree about equally well with the forces measured at the July 1981 Surveillance. Although the 16% Base Curve has the advantage of simplicity, since one curve applies for all the tendons, both types of Base curves will be used for the July 1983 Surveillance in order to provide a further comparison.

REFERENCES

1. Robert E. Ginna Nuclear Power Station, Containment Building Tendon Investigation, GAI Report No. 2347, February 1982.

2. ASME Boiler and Pressure Vessel Code, Section XI - Rules for Inservice Inspection of Nuclear Power Plant Components, Draft Subsection IWX - Inservice Inspection of Concrete Containments, May 1982.

TABLE 1

STRESS RELAXATION TEST CONDITIONS OF RETENSIONED WIRES

Tendon I.D.	Specimen No.	Heat No.	Stress (%GUTS)	Temperature (°F)	Time at Retensioning (Hours)	Retensioned Duration (Hours)
51-B	3	19477	70	104	6000	18214
51-C	4	19477	70	68	1000	11137
76-C	8	30091	70	104	10190	14229
76-B1	9	30091	70	104	100	8635
76-B2	10	30091	70	104	1000	19229
76-B	7	30091	70	68	11600	3575
150-C2	12	10355	70	68	5500	9720

TABLE 2

JULY 1981 SURVEILLANCE FORCES COMPARED WITH PREDICTIONS

Tendon No.	Sequence of Lift-Off	Last[1] Lock-Off (Kips) (1)	Measured Lift-Off (Kips) (2)	Predicted Lift-Off Force (Kips): 16% Relexation with Retensioning (3)	Predicted Lift-Off Force (Kips): Eff. Stress Relax. with Retensioning (4)
June 1980 Retensioned Tendons					
13	1	761	730	721	707
155	2	754	738	713	718
17	3	776	727	734	738
21	4	765	725	723	723
51	5	765	710	723	728
53	6	761	734	722	710
62	7	773	716	730	733
63	8	769	722	730	717
74	9	749	731	708	664
76	10	754	713	714	707
84	11	753	714	713	711
93	12	761	713	721	714
125	13	768	705	726	746
133	14	757	734	718	712
May 1969 Retensioned Tendons					
33	15	770	679	670	679
36	16	763	657	664	689
111	17	744	646	647	660
116	18	757	690	658	663

1) In June 1980, except for the tendons retensioned in May 1969

TABLE 3

PERCENT DIFFERENCE IN MEASURED VERSUS PREDICTED FORCES

Tendon No.	Predicted		95% Predicted	
	16% Relax. with RT	E.S.R. with RT	16% Relax. with RT	E.S.R. with RT
	(1)	(2)	(3)	(4)
13	1.2	3.3	6.6	8.7
155	3.5	2.8	9.0	8.2
17	-1.0	-1.5	4.3	3.7
21	0.3	0.3	5.6	5.6
51	-1.8	-2.5	3.4	2.7
53	1.7	3.3	7.0	8.8
62	-1.9	-2.3	3.2	2.8
63	-1.1	0.7	4.1	6.0
74	3.2	10.1	8.7	15.9
76	-0.1	0.8	5.1	6.2
84	0.1	0.4	5.4	5.7
93	-1.1	-0.1	4.1	5.1
125	-2.9	-5.5	2.2	-0.5
133	2.2	3.1	7.6	8.5
33	1.3	0	6.7	5.3
36	-1.1	-4.6	4.2	0.4
111	-0.2	-2.1	5.1	3.0
116	4.9	4.1	10.4	9.5
$\frac{\sum_{n=1}^{N} \lvert A_n \rvert}{N}$	1.64	2.64	5.71	5.92
$\frac{\sum_{n=1}^{N} \lvert A_n \rvert}{N}$ W.O. TENDON 74	1.55	2.21	5.53	5.33

FIGURES

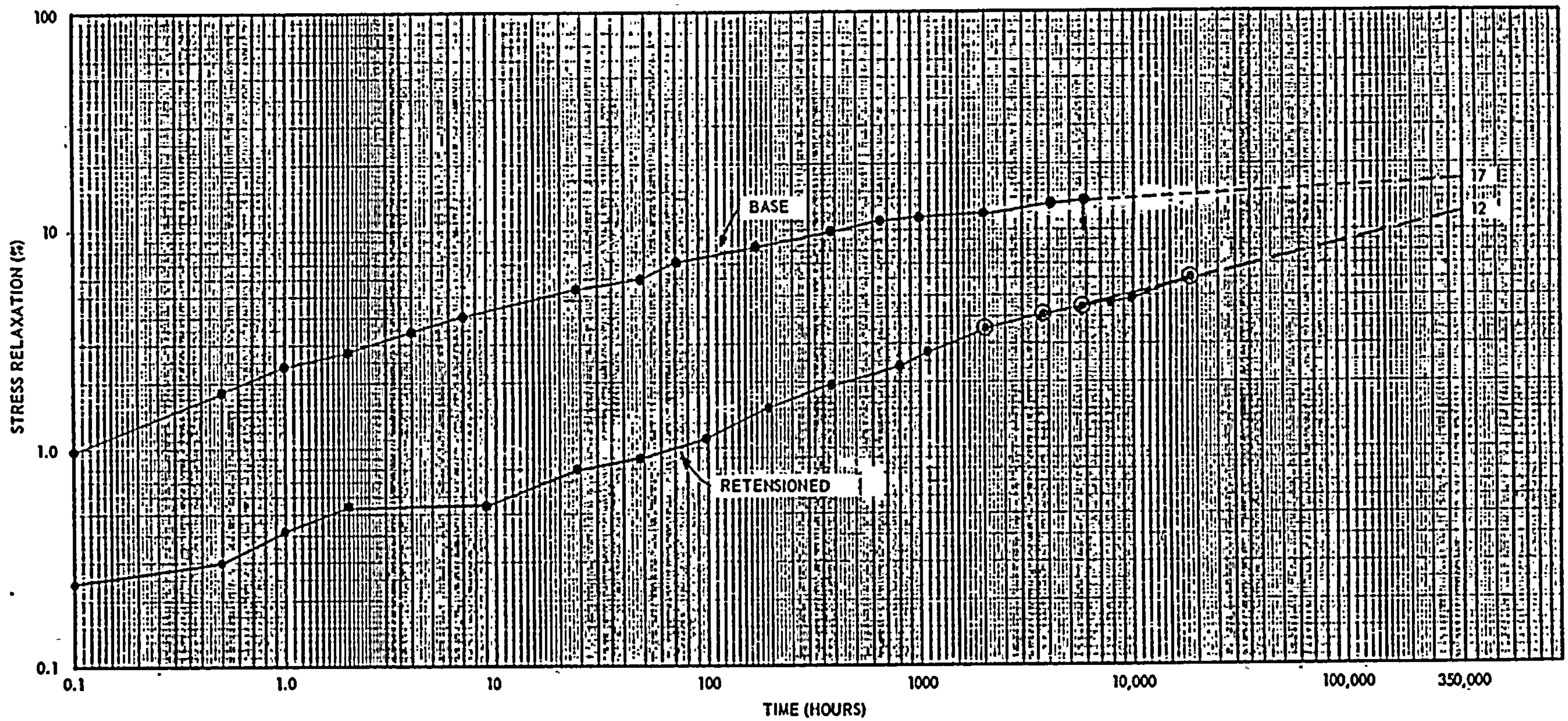


FIGURE 1–A BASE AND RETENSIONED STRESS RELAXATION FOR WIRE #3 (51–B)

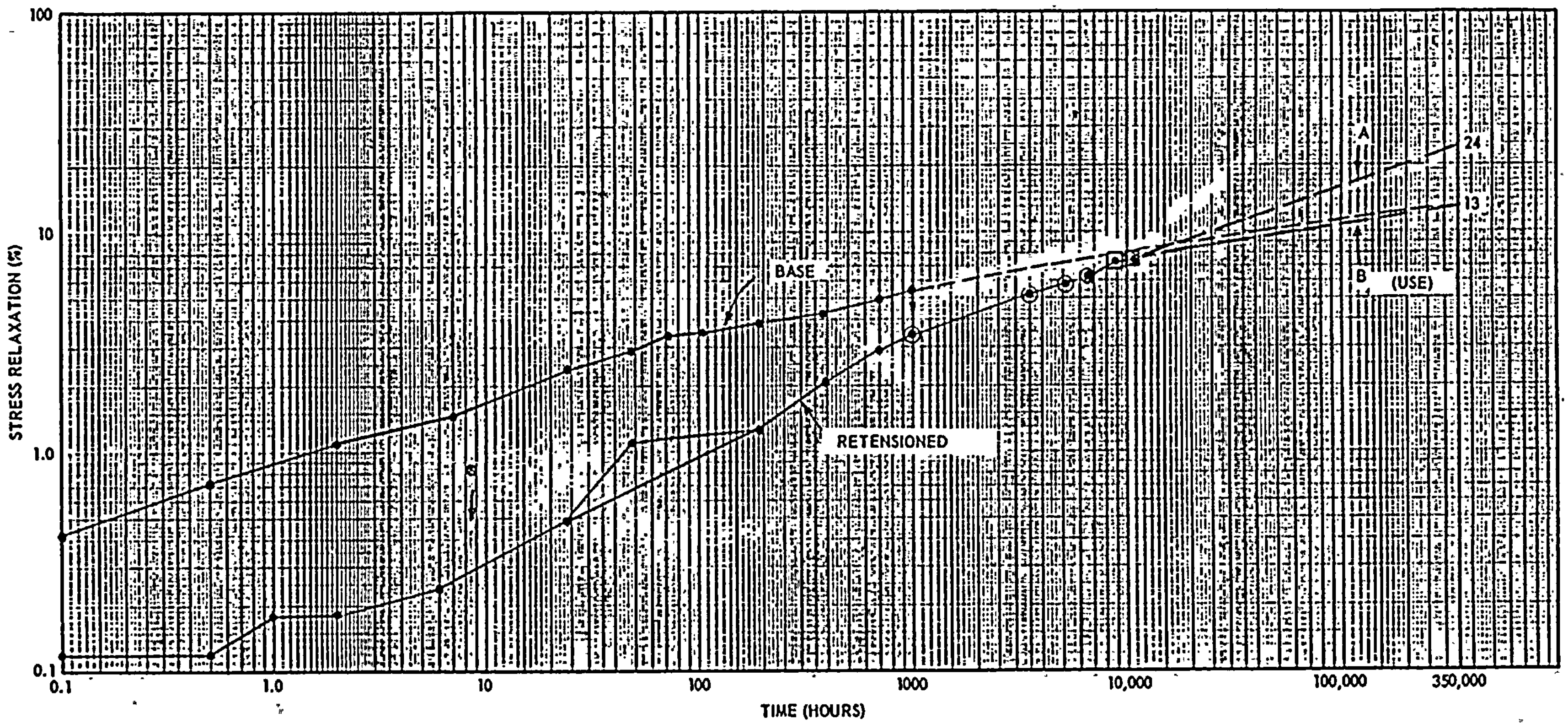


FIGURE 1-B BASE AND RETENSIONED STRESS RELAXATION FOR WIRE #4 (51-C)

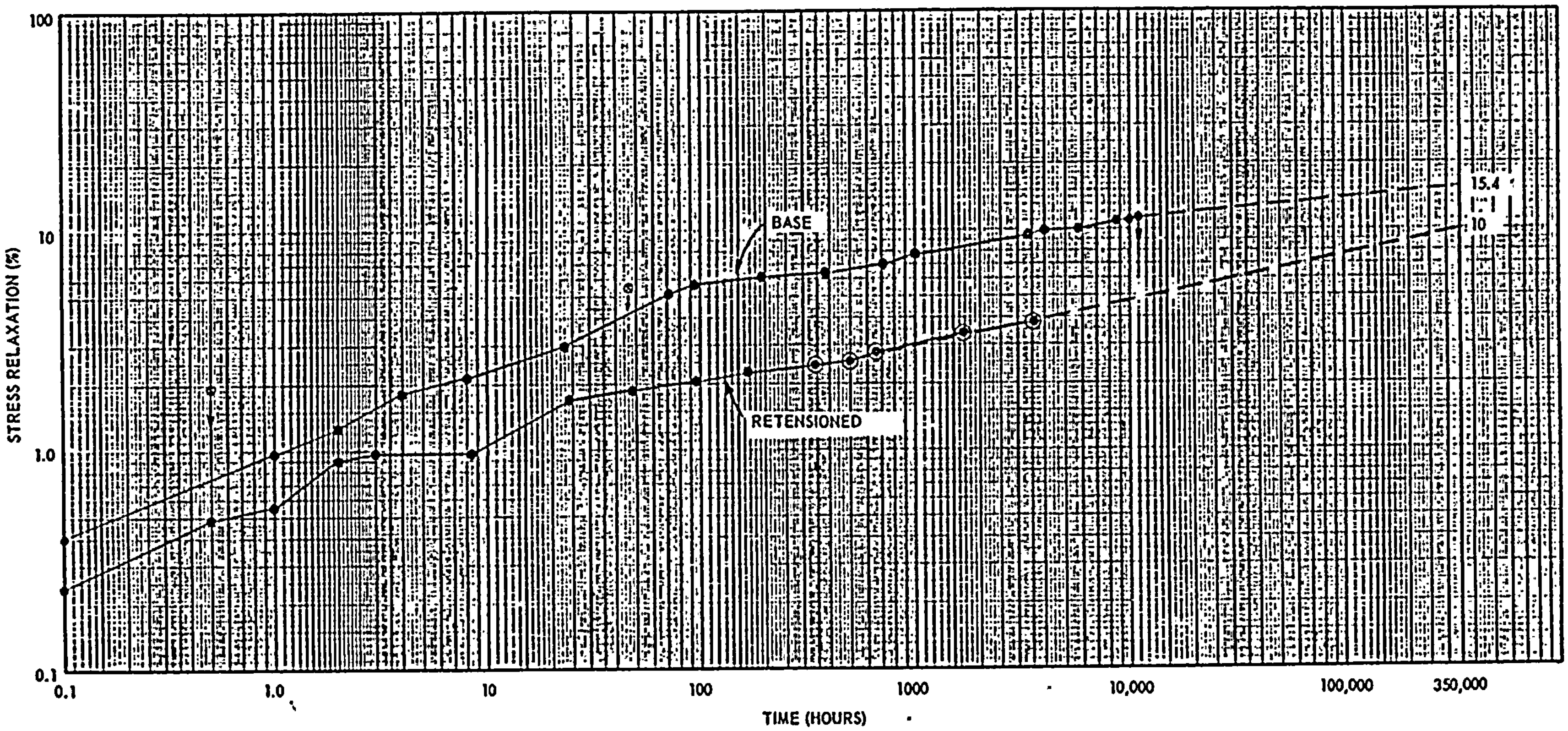


FIGURE 1-C BASE AND RETENSIONED STRESS RELAXATION FOR WIRE #7 (76-B)

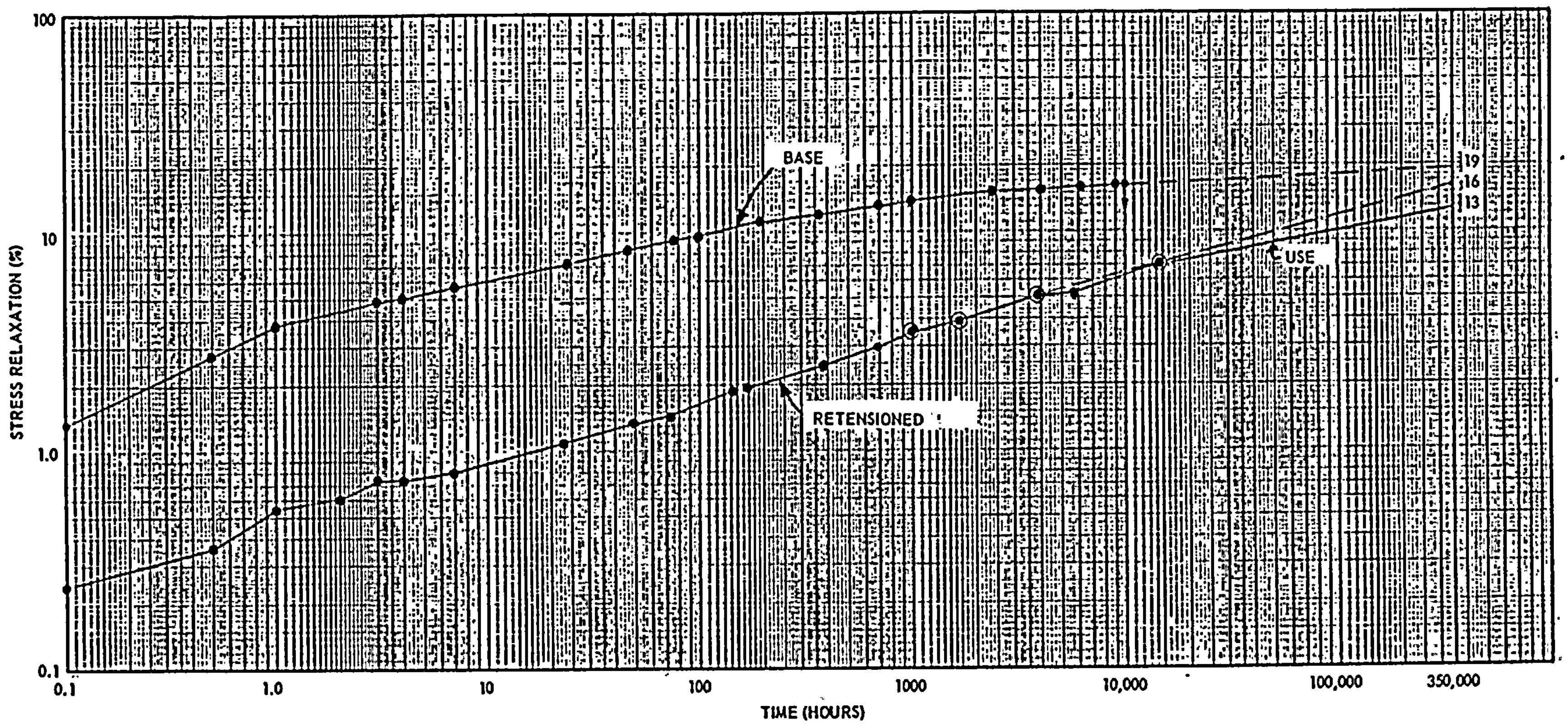


FIGURE 1-D BASE AND RETENSIONED STRESS RELAXATION FOR WIRE #8 (76-C)

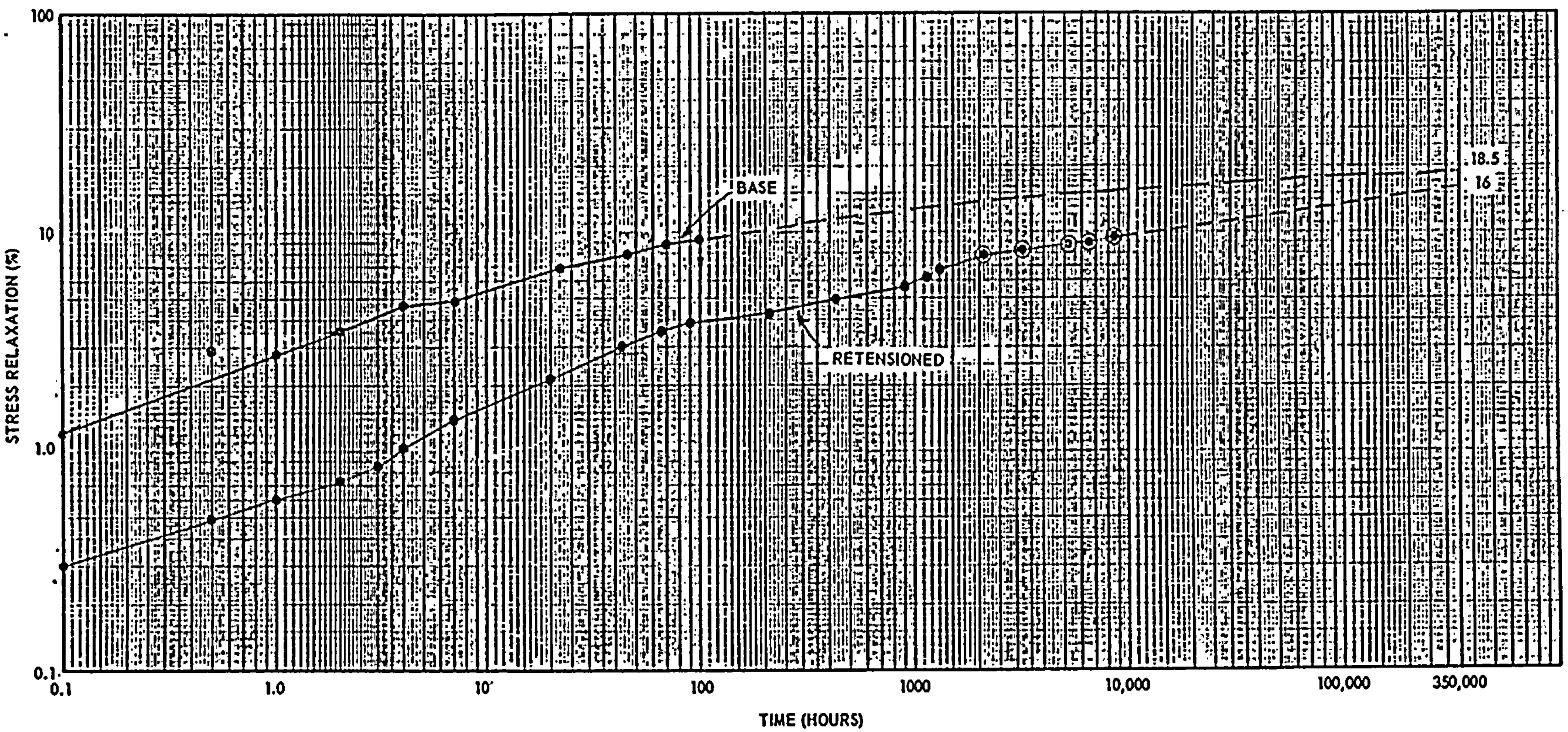


FIGURE 1-E BASE AND RETENSIONED STRESS RELAXATION FOR WIRE #9 (76-B1)

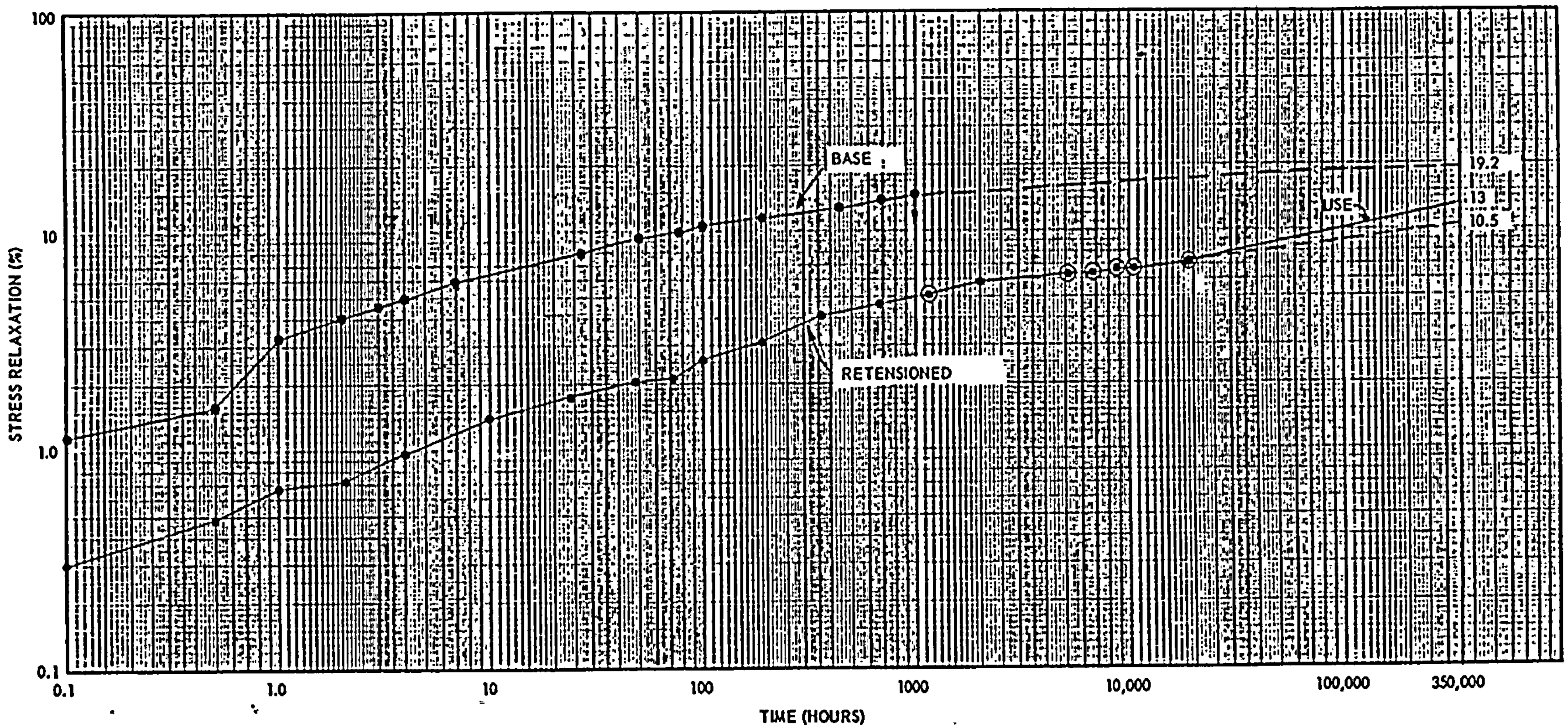


FIGURE 1-F BASE AND RETENSIONED STRESS RELAXATION FOR WIRE #10 (76-B2)

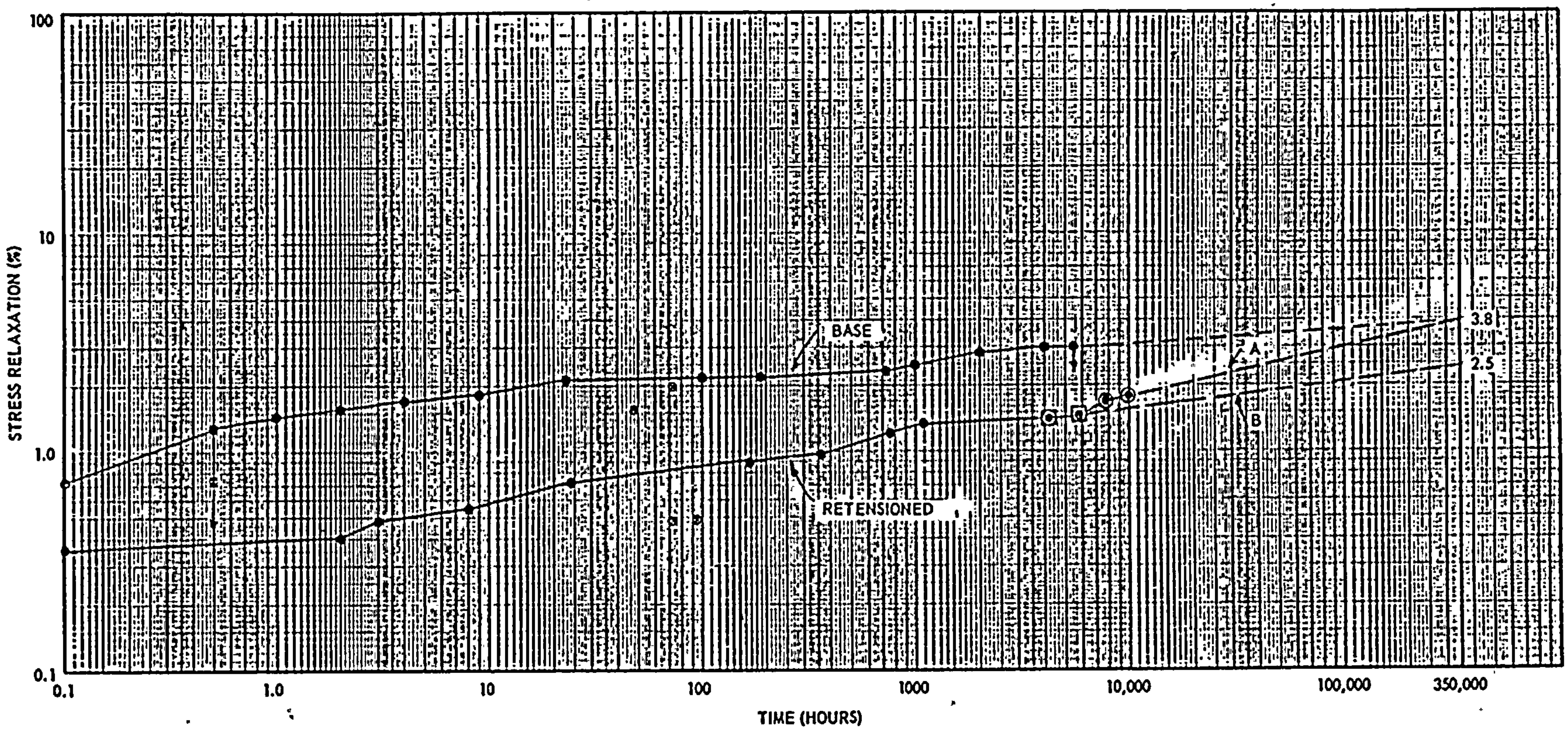


FIGURE 1-G BASE AND RETENSIONED STRESS RELAXATION FOR WIRE #12 (150-C2)

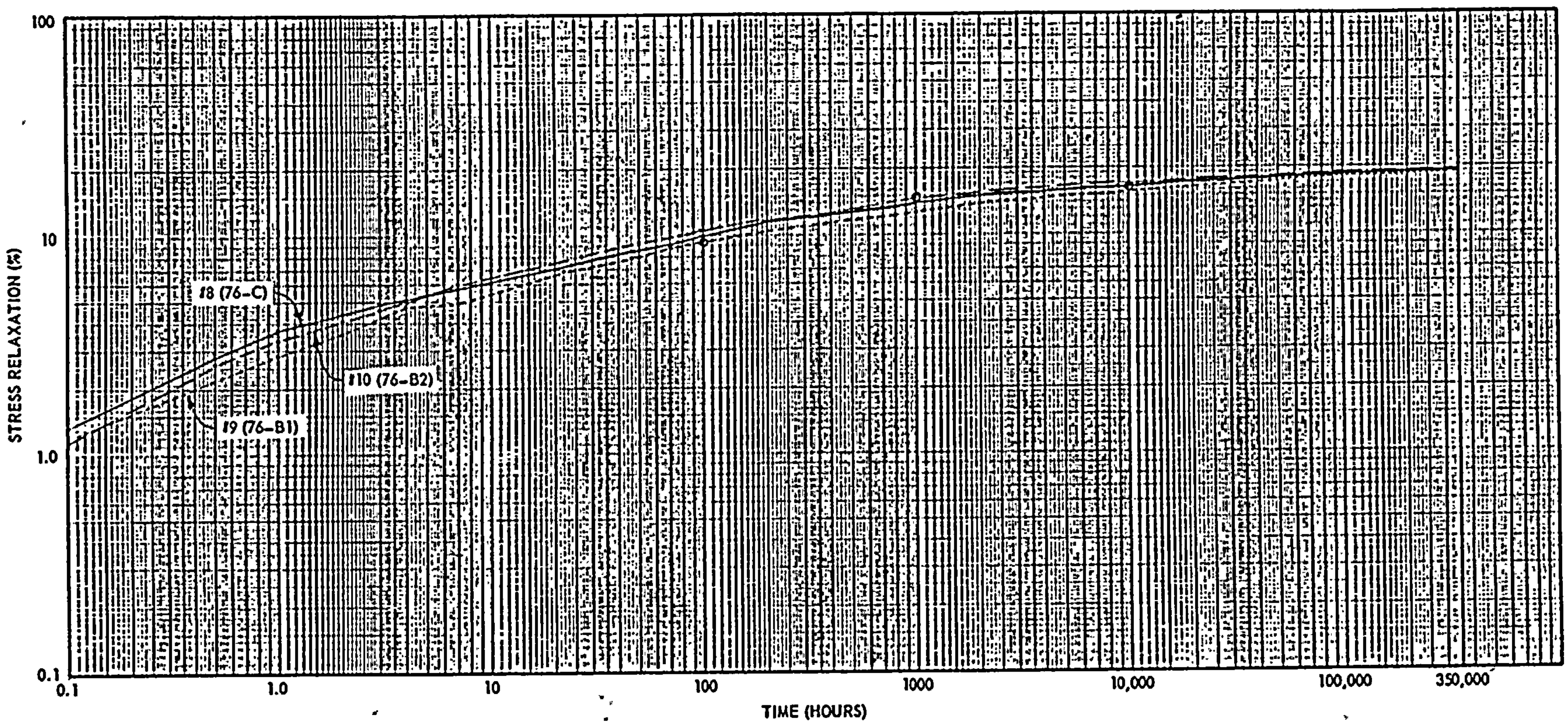


FIGURE 1-H BASE STRESS RELAXATION FOR WIRES #8, #9, AND #10

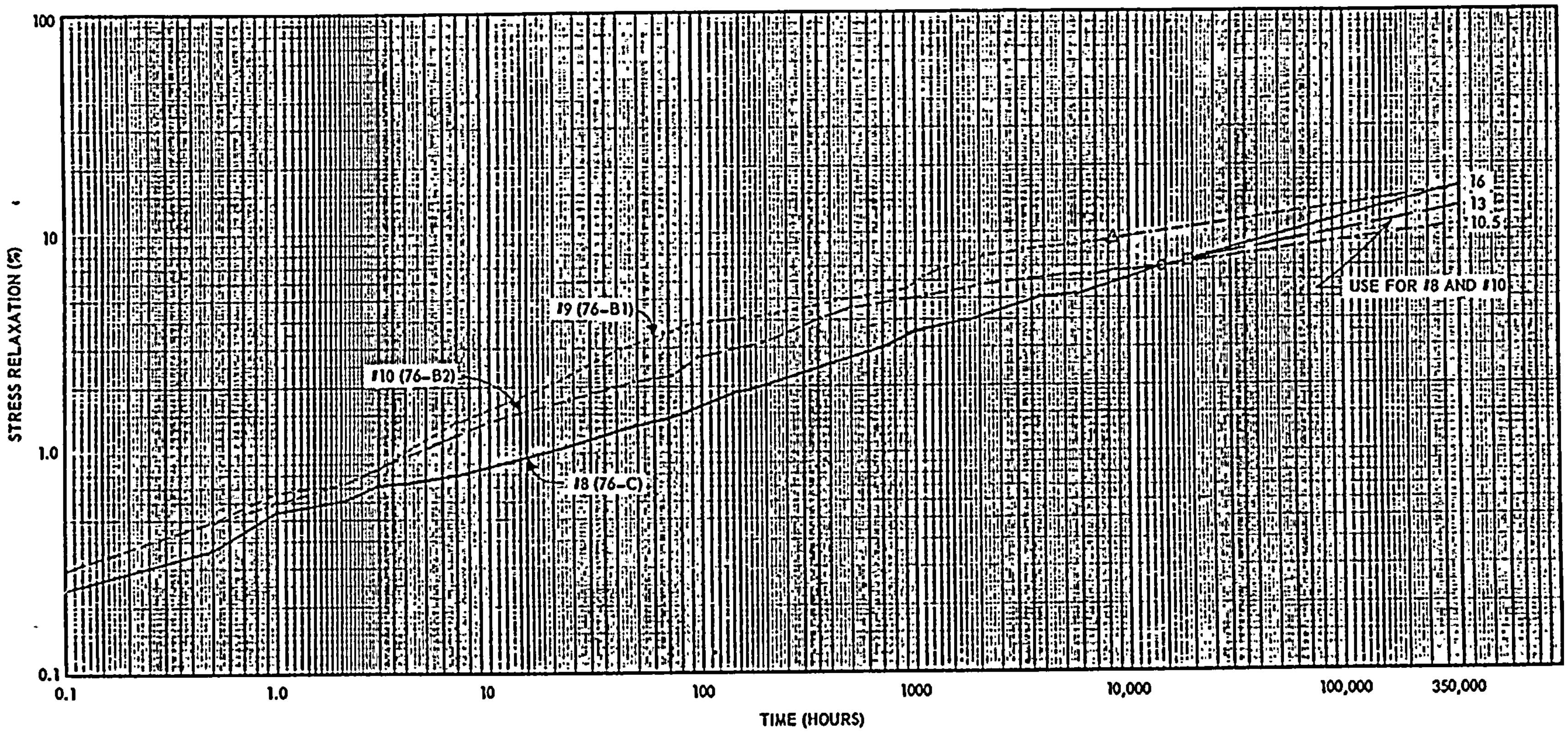


FIGURE 1-1 RETENSIONED STRESS RELAXATION FOR WIRES #8, #9, AND #10

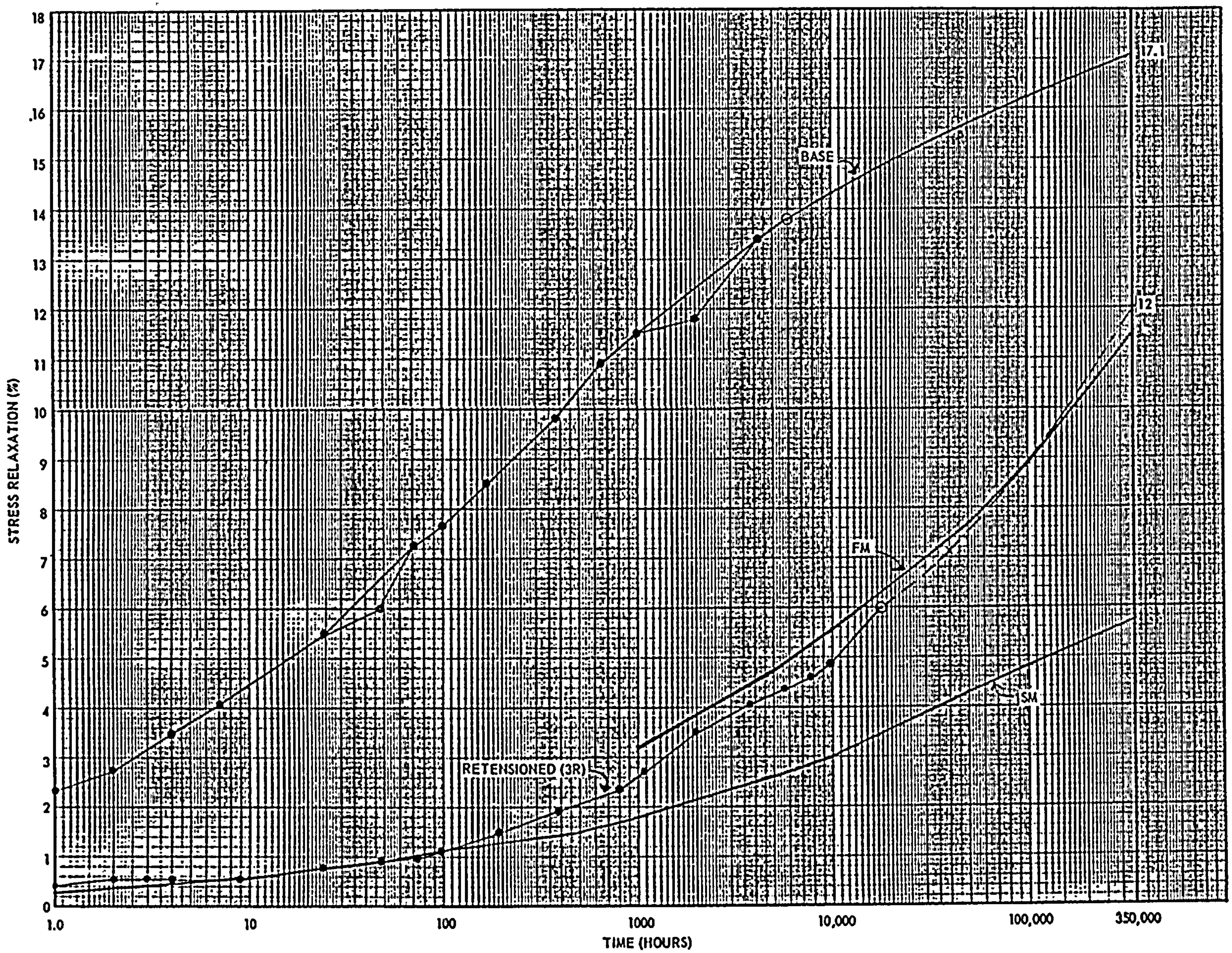


FIGURE 2–A BASE AND RETENSIONED STRESS RELAXATION FOR WIRE #3 (51–B)

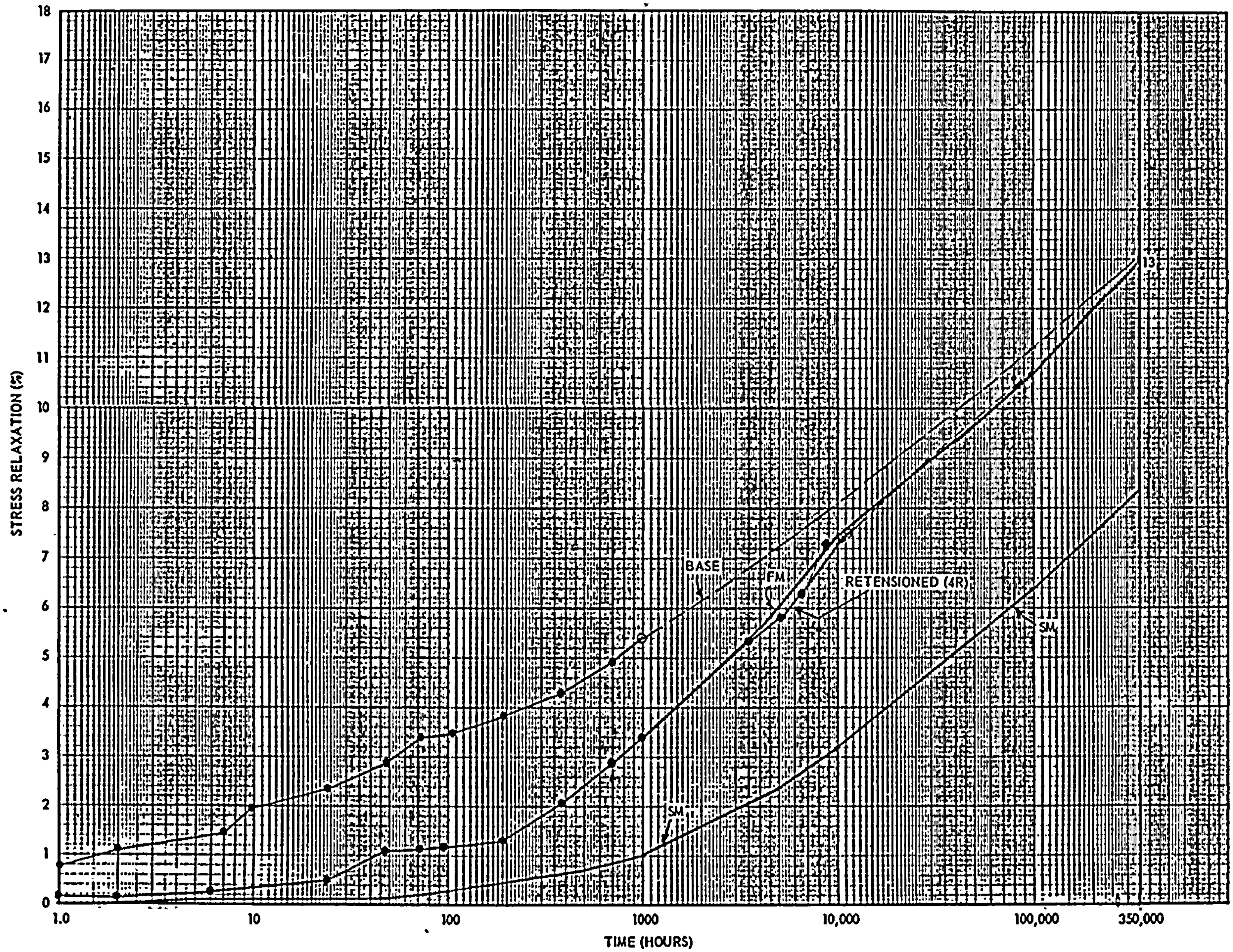


FIGURE 2-B BASE AND RETENSIONED STRESS RELAXATION FOR WIRE #4 (51-C)

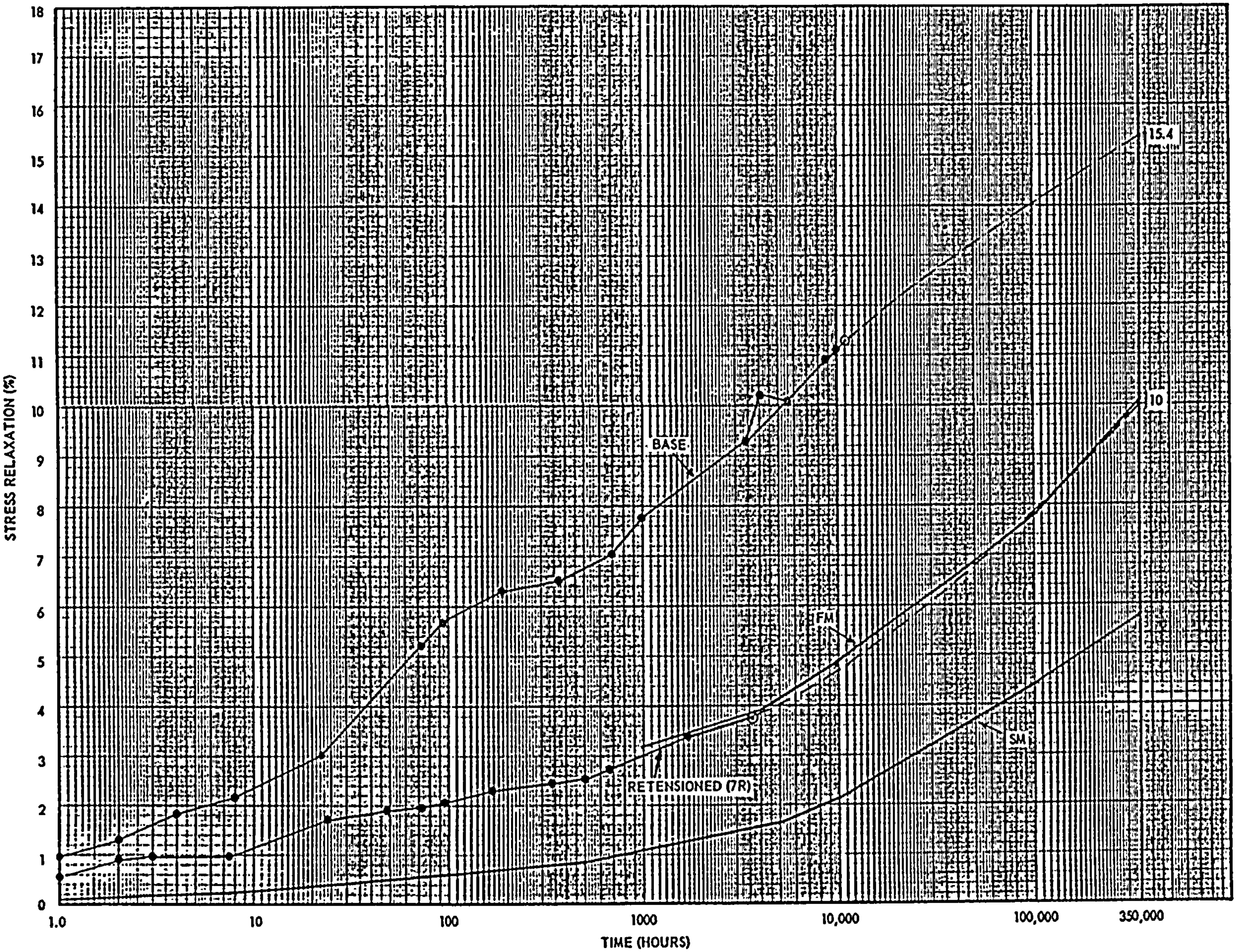


FIGURE 2-C BASE AND RETENSIONED STRESS RELAXATION FOR WIRE #7 (76-B)

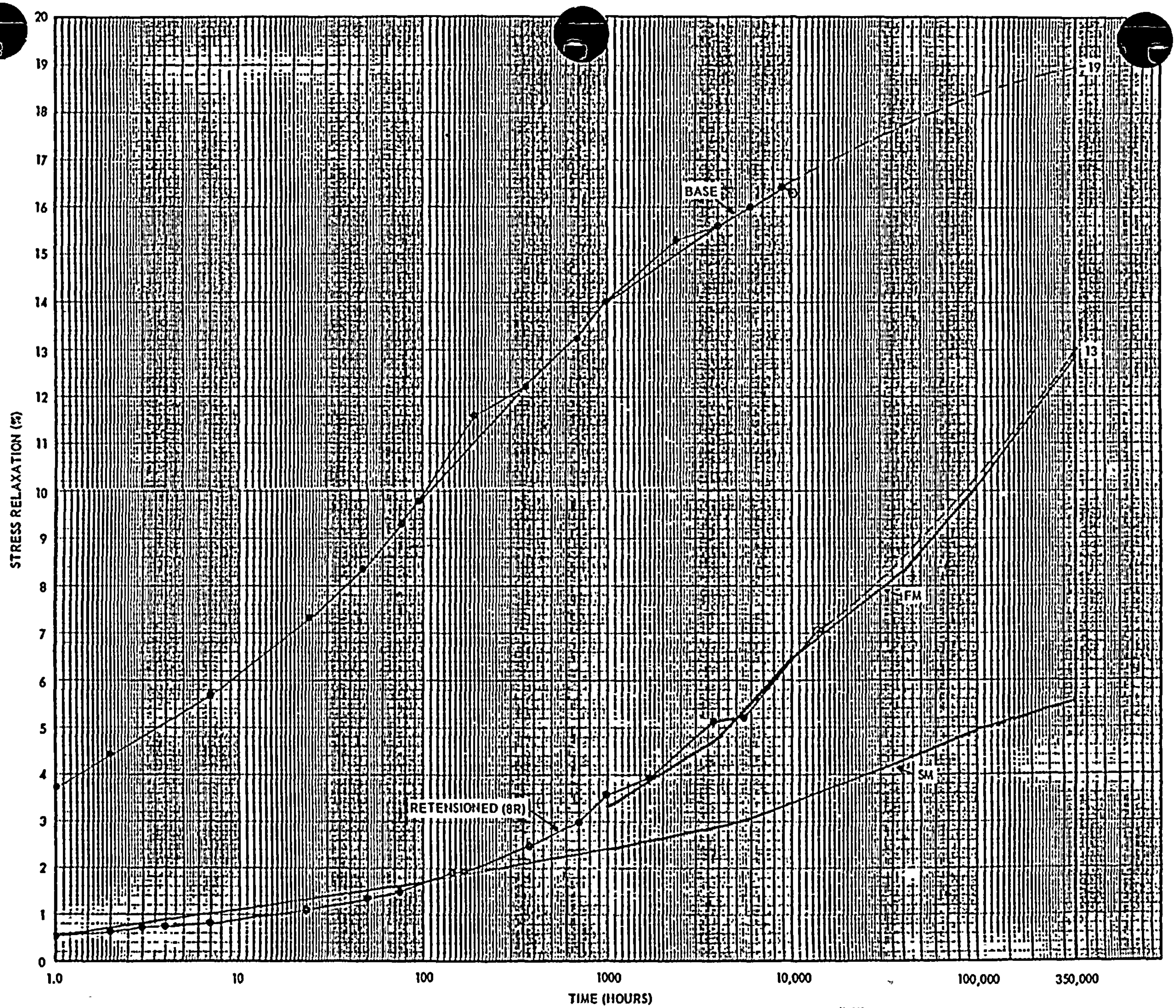


FIGURE 2-D BASE AND RETENSIONED STRESS RELAXATION FOR WIRE #8 (76-C)

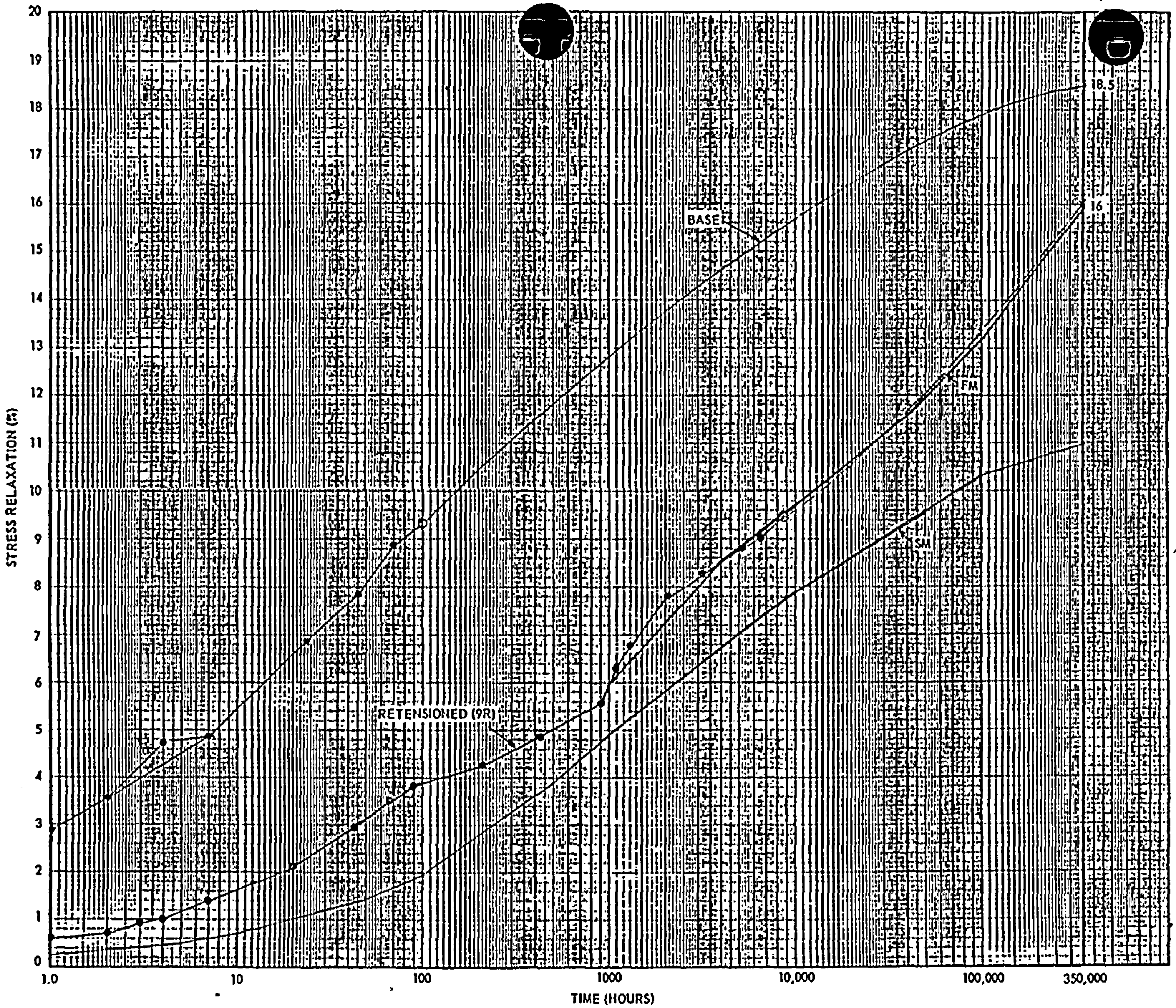


FIGURE 2-E BASE AND RETENSIONED STRESS RELAXATION FOR WIRE #9 (76-B1)

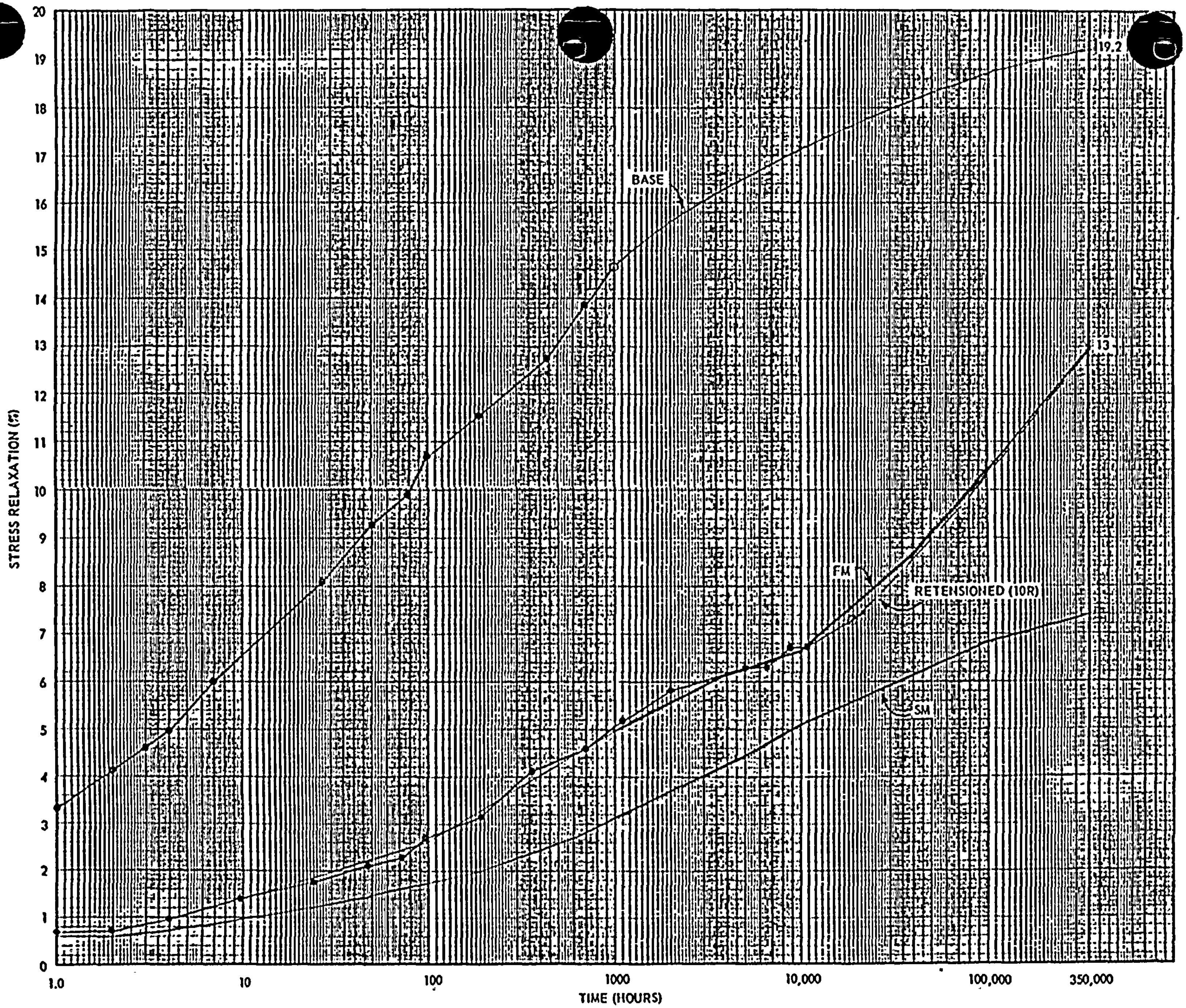


FIGURE 2–F BASE AND RETENSIONED STRESS RELAXATION FOR WIRE #10 (76–B2)

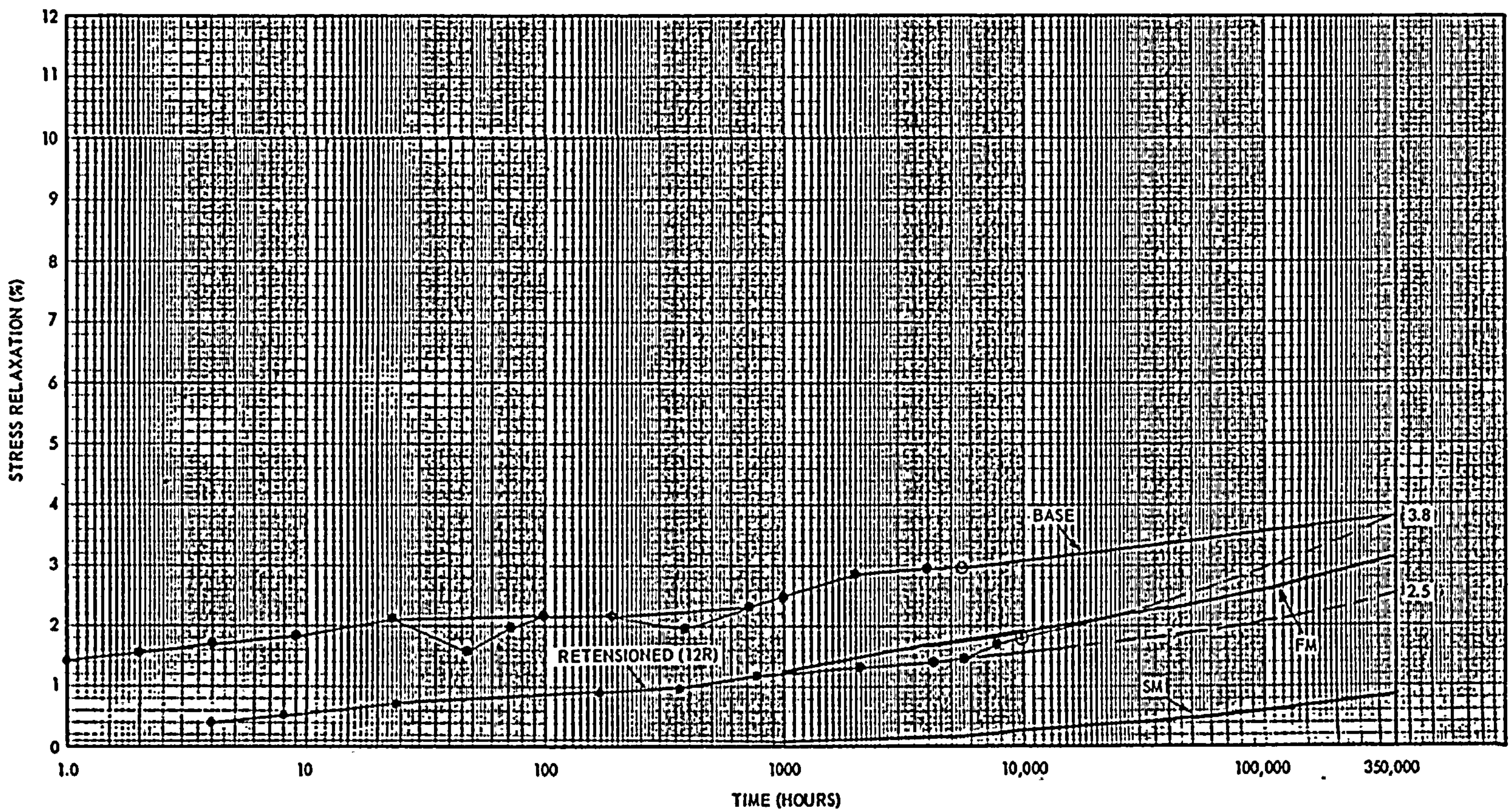


FIGURE 2-G BASE AND RETENSIONED STRESS RELAXATION FOR WIRE #12 (150-C2)

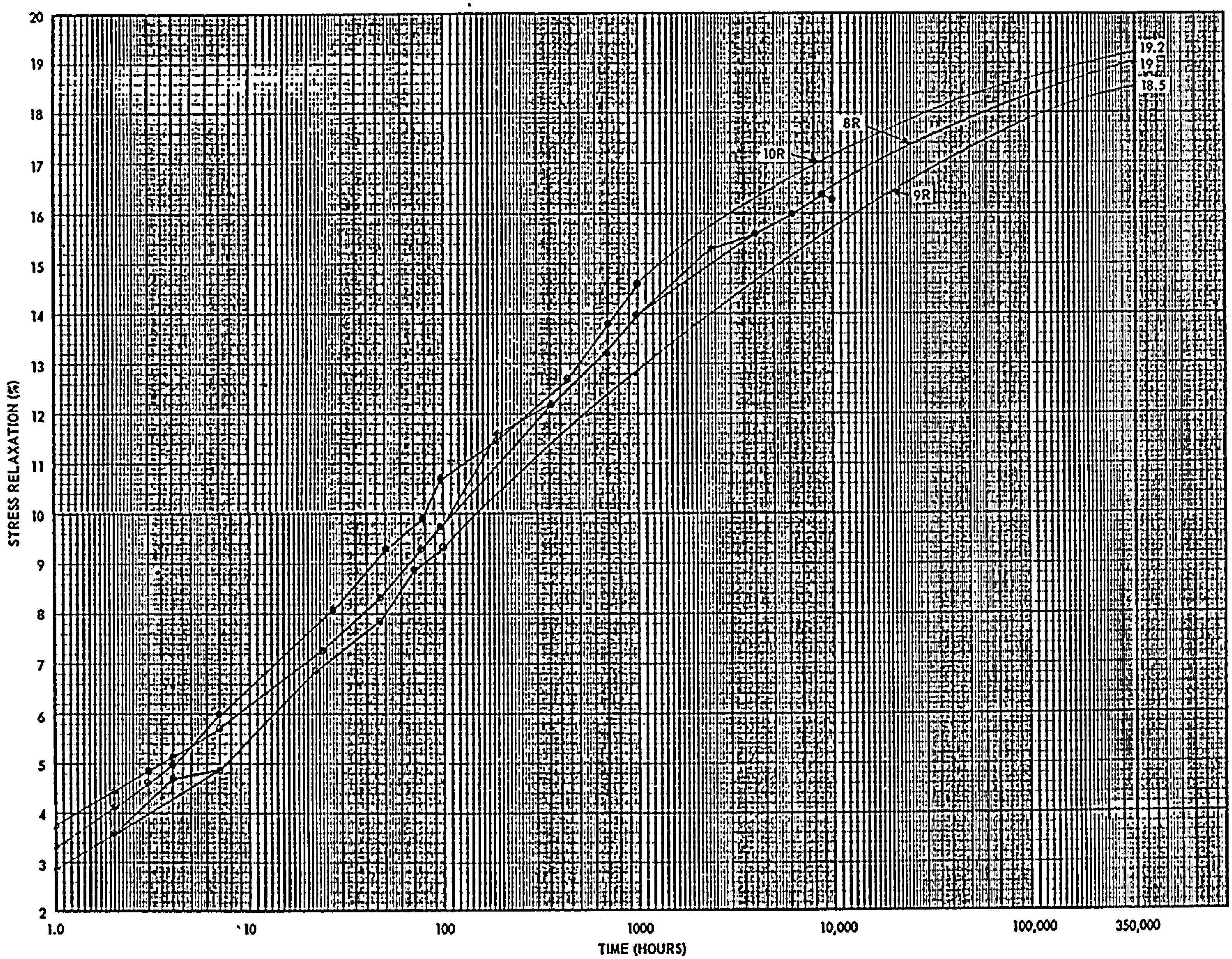


FIGURE 2-H BASE STRESS RELAXATION FOR WIRES #8, #9, AND #10

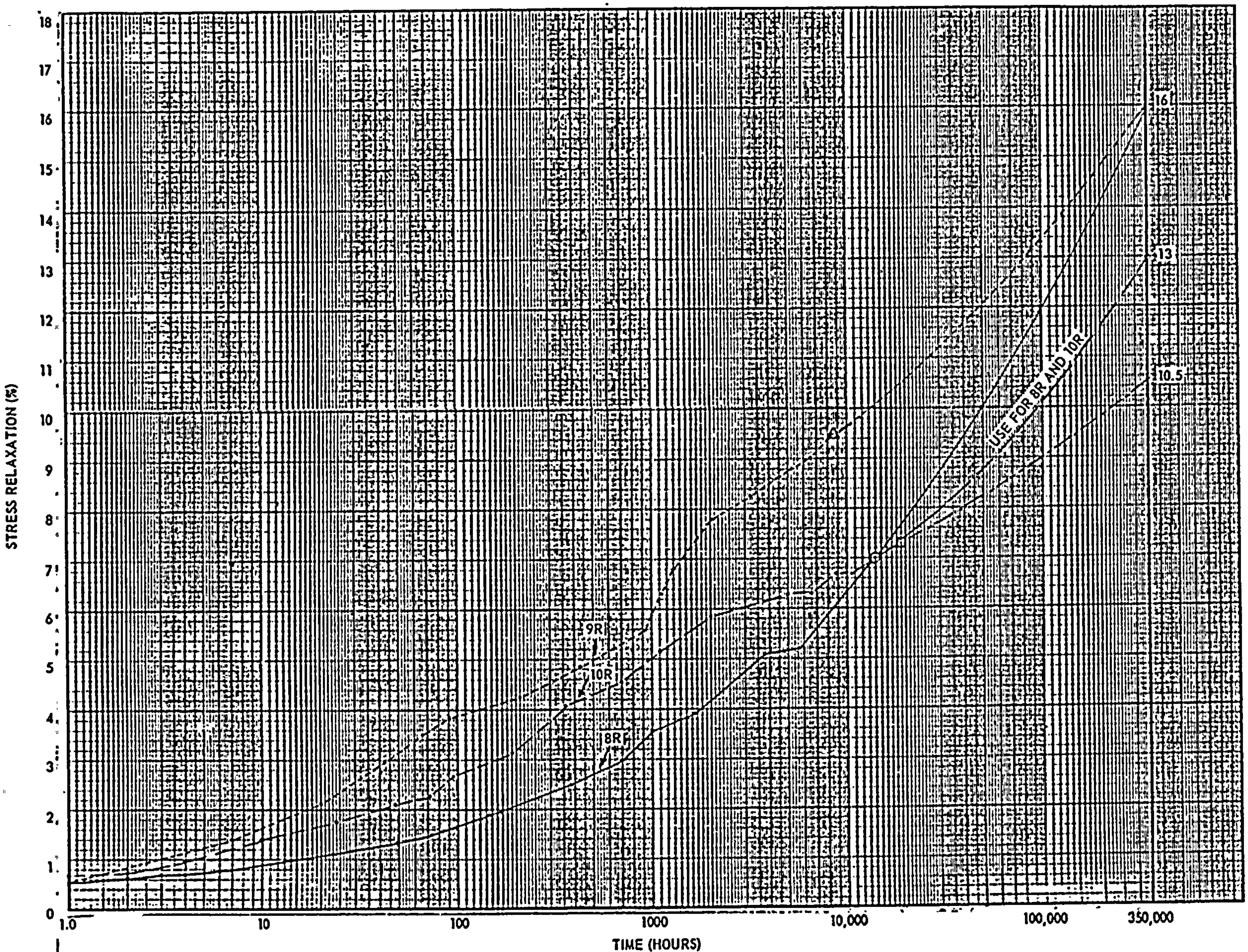


FIGURE 2-1 RETENSIONED STRESS RELAXATION FOR WIRES #8, #9, AND #10

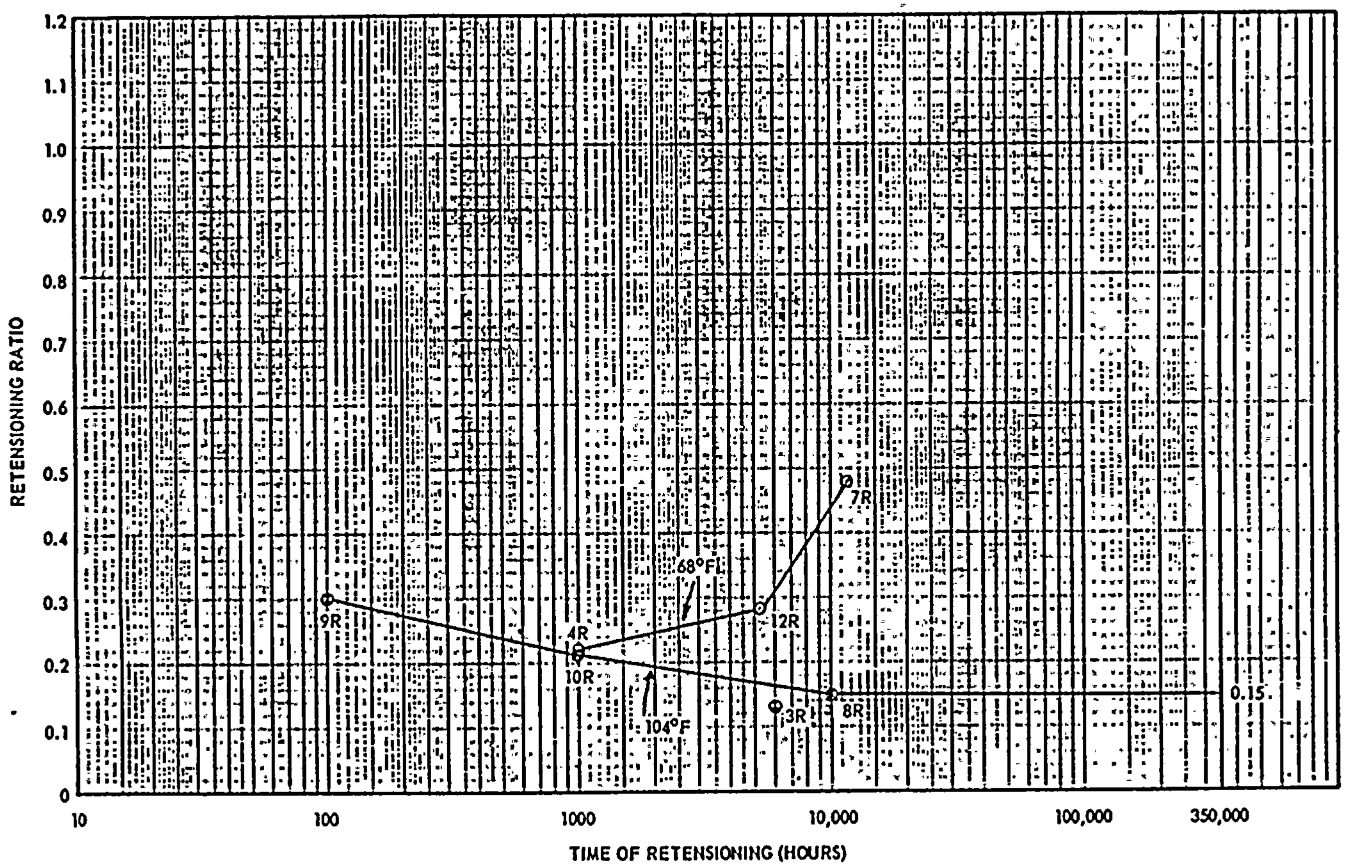


FIGURE 3-A RETENSIONING RATIO AT 10 HOURS AFTER RETENSIONING

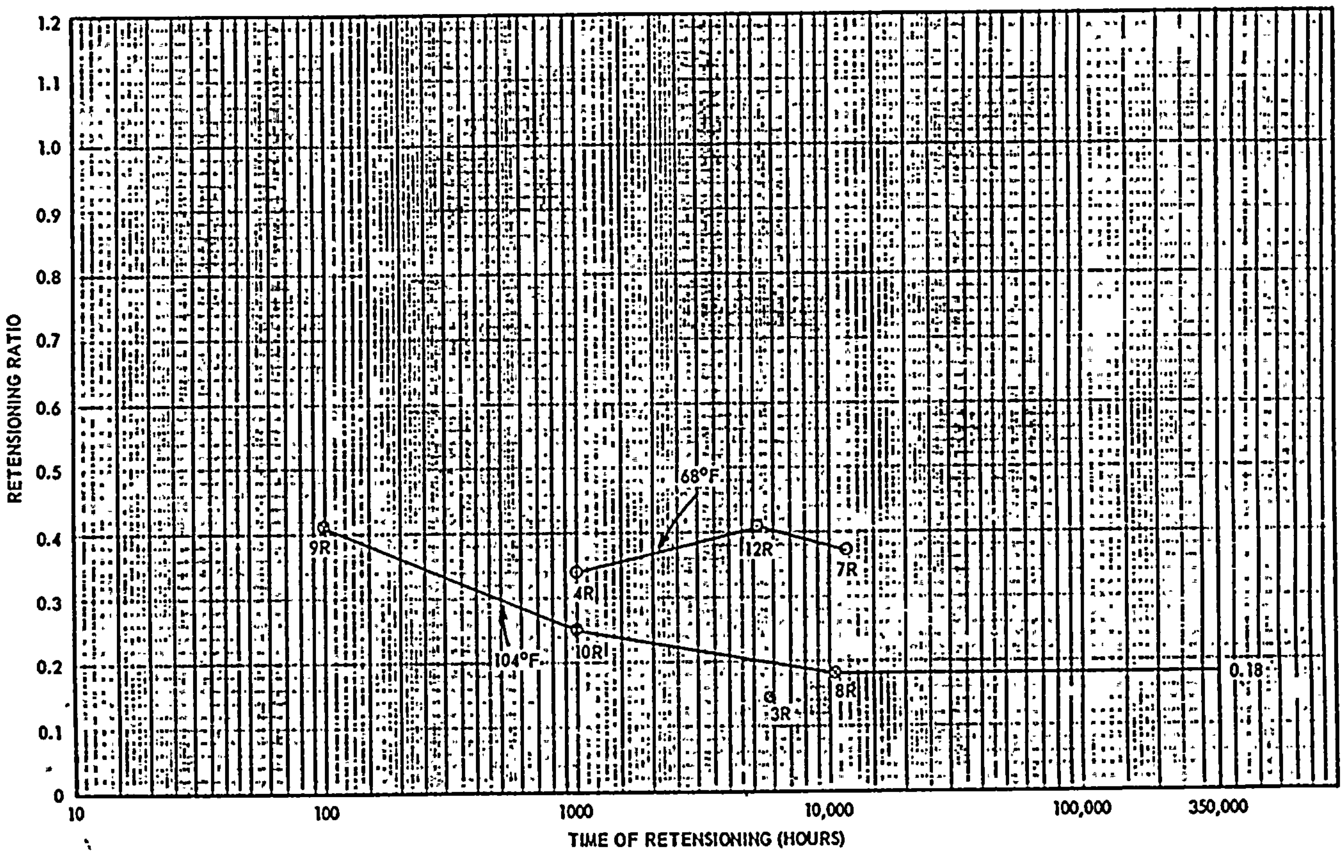


FIGURE 3-B RETENSIONING RATIO AT 100 HOURS AFTER RETENSIONING

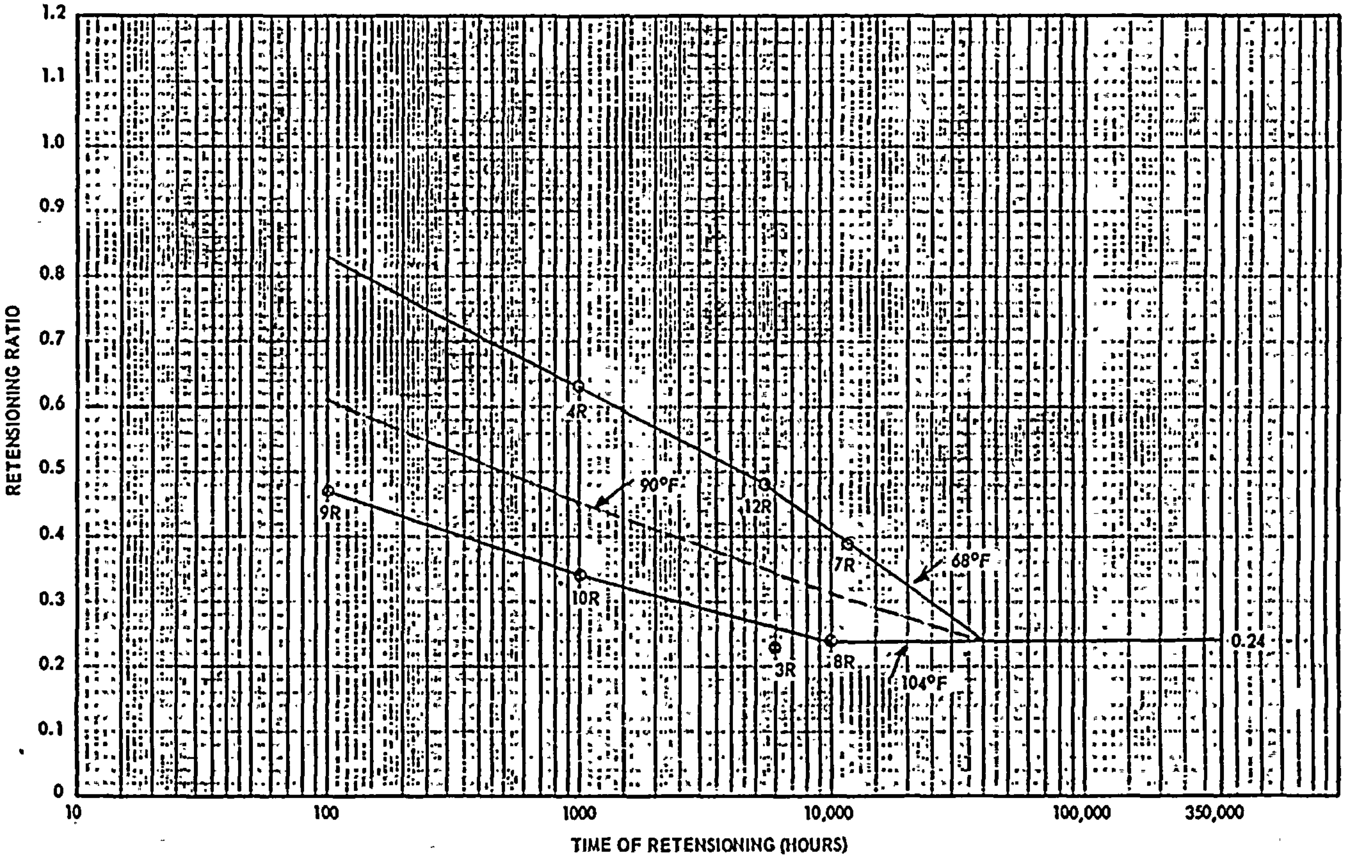


FIGURE 3-C RETENSIONING RATIO AT 1000 HOURS AFTER RETENSIONING

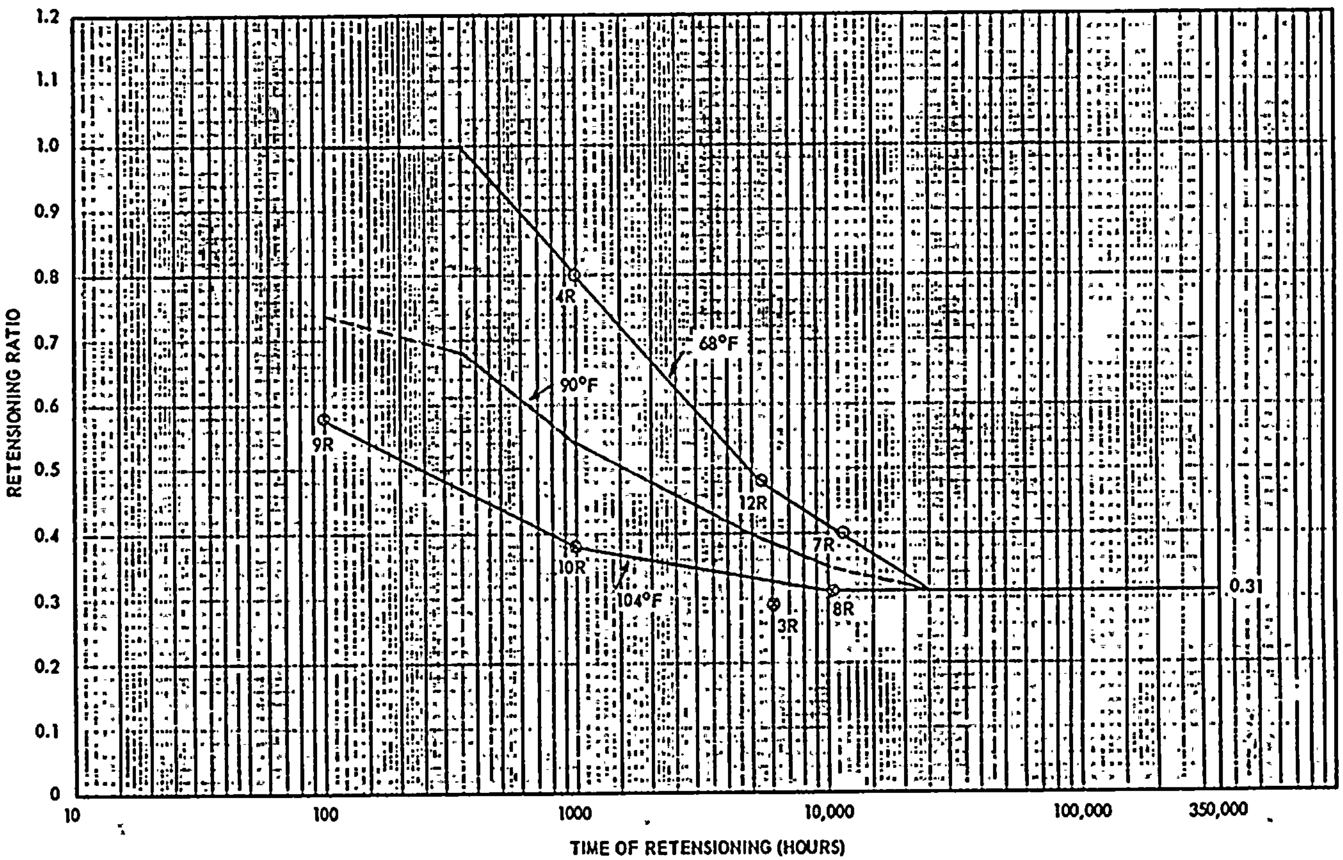


FIGURE 3-D RETENSIONING RATIO AT 4000 HOURS AFTER RETENSIONING

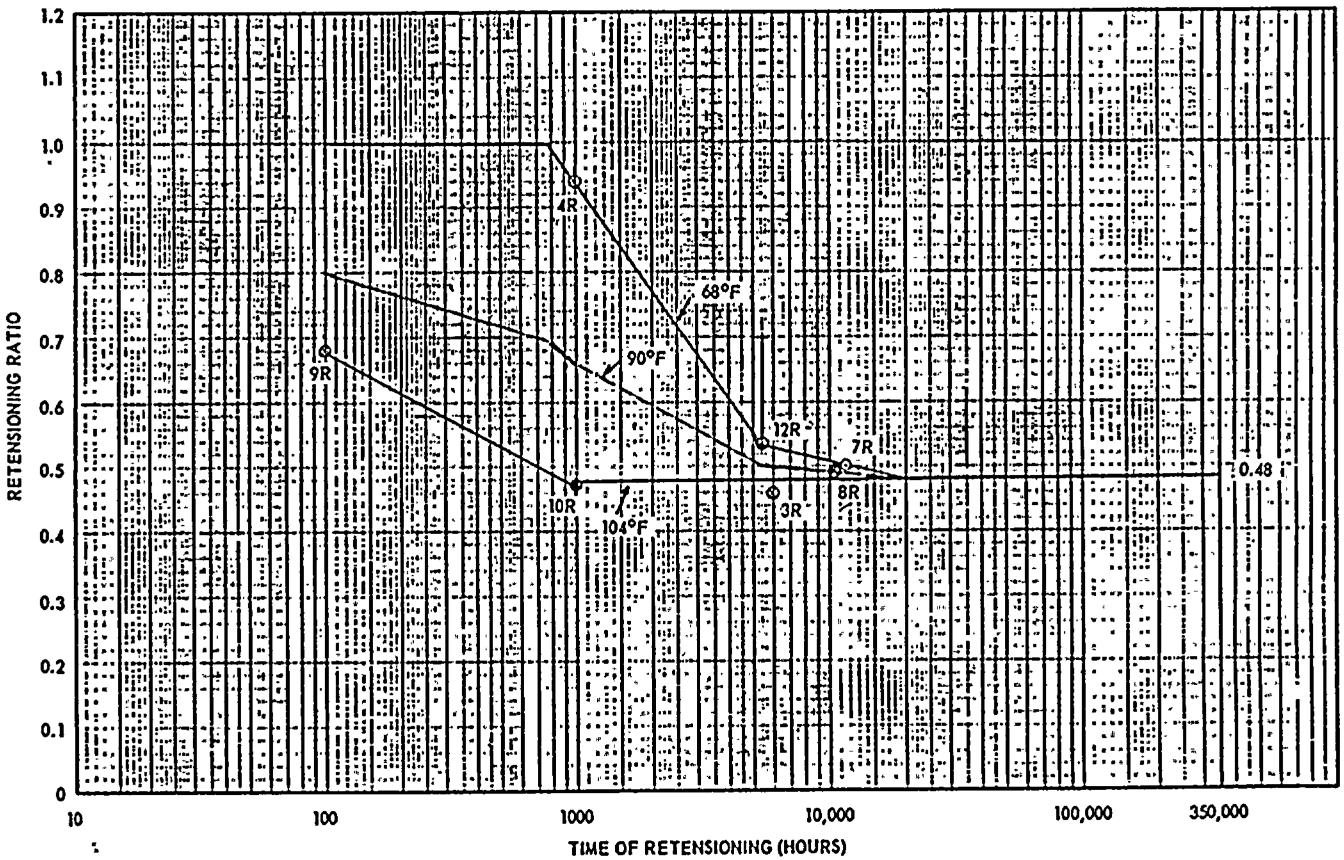


FIGURE 3-F RETENSIONING RATIO AT 40,000 HOURS AFTER RETENSIONING

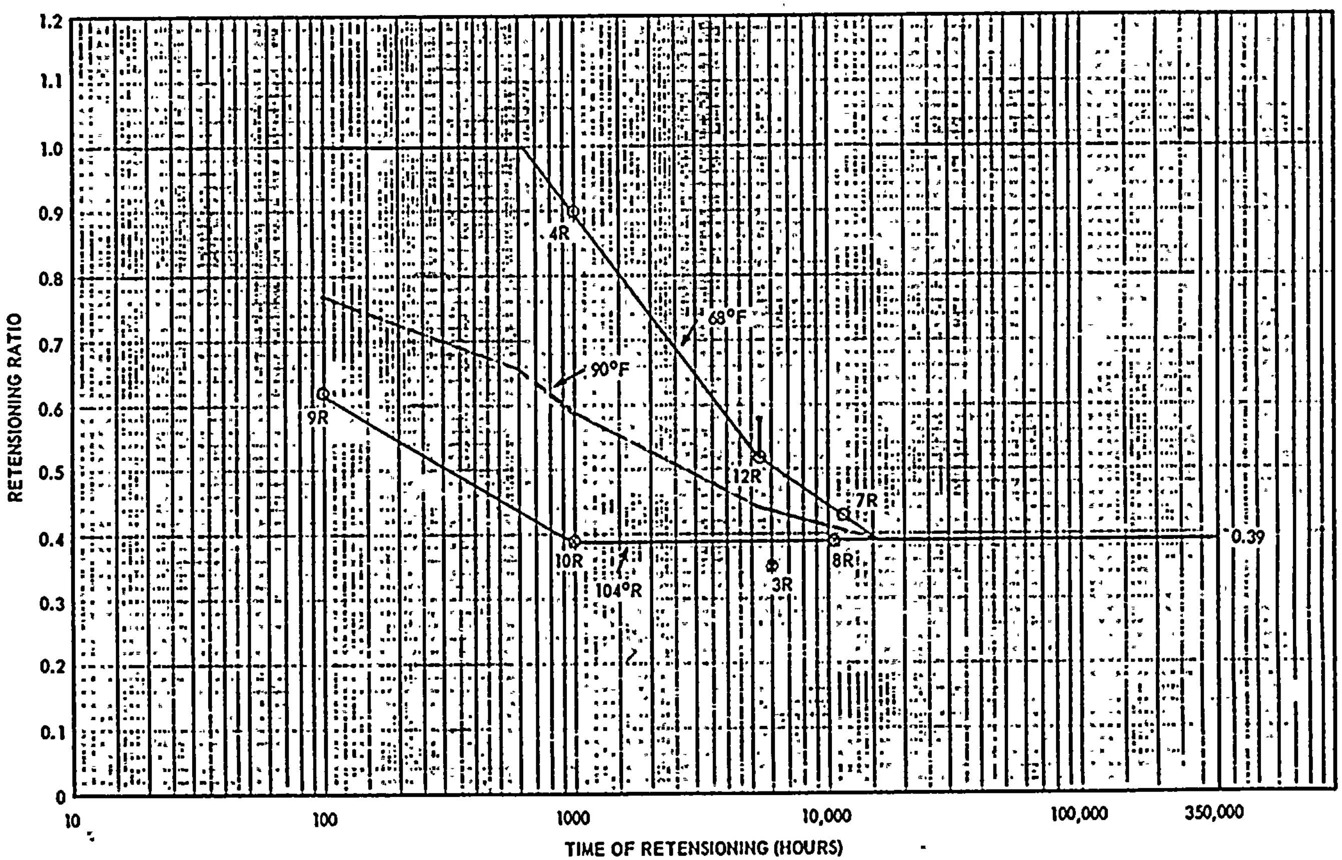


FIGURE 3-E RETENSIONING RATIO AT 10,000 HOURS AFTER RETENSIONING

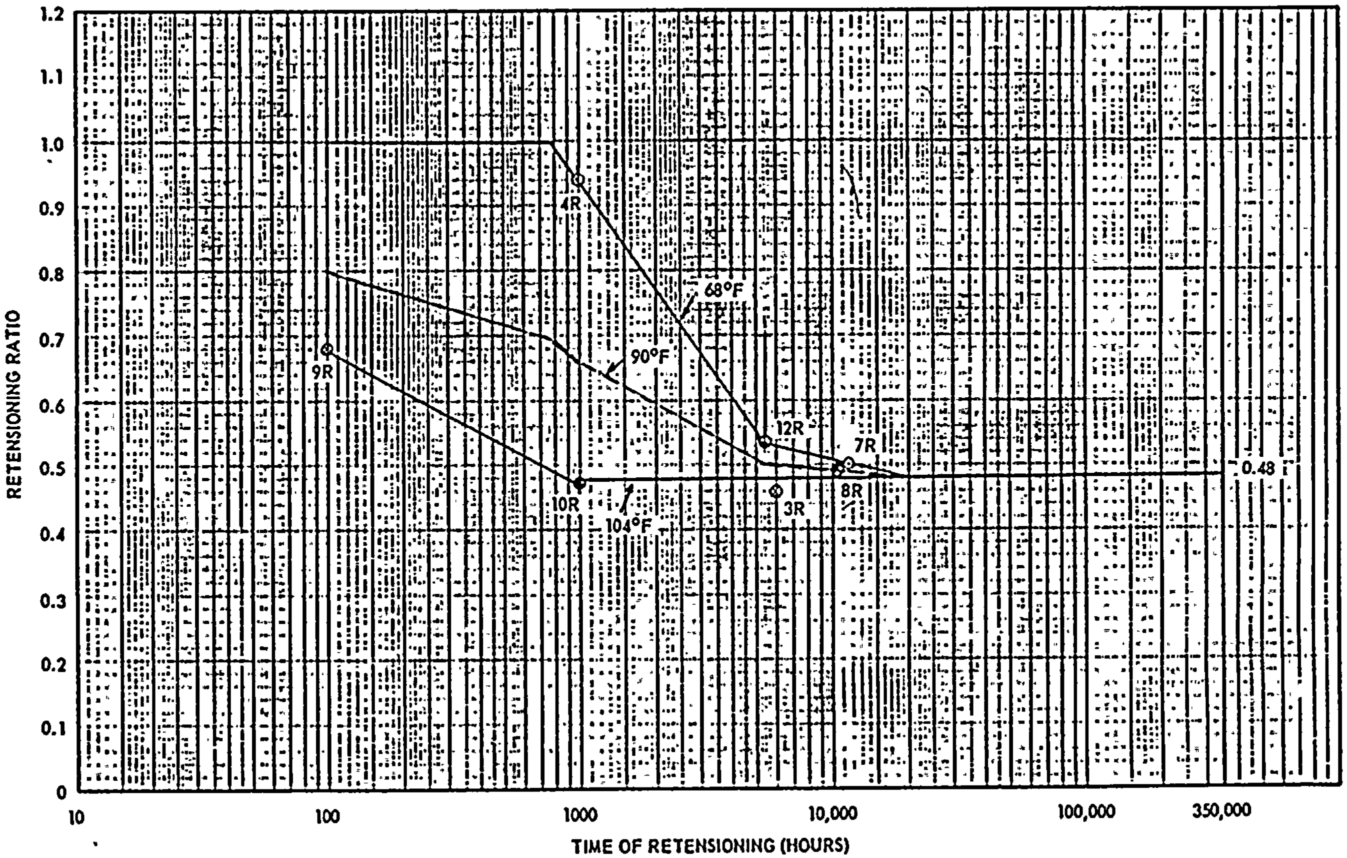


FIGURE 3-F RETENSIONING RATIO AT 40,000 HOURS AFTER RETENSIONING

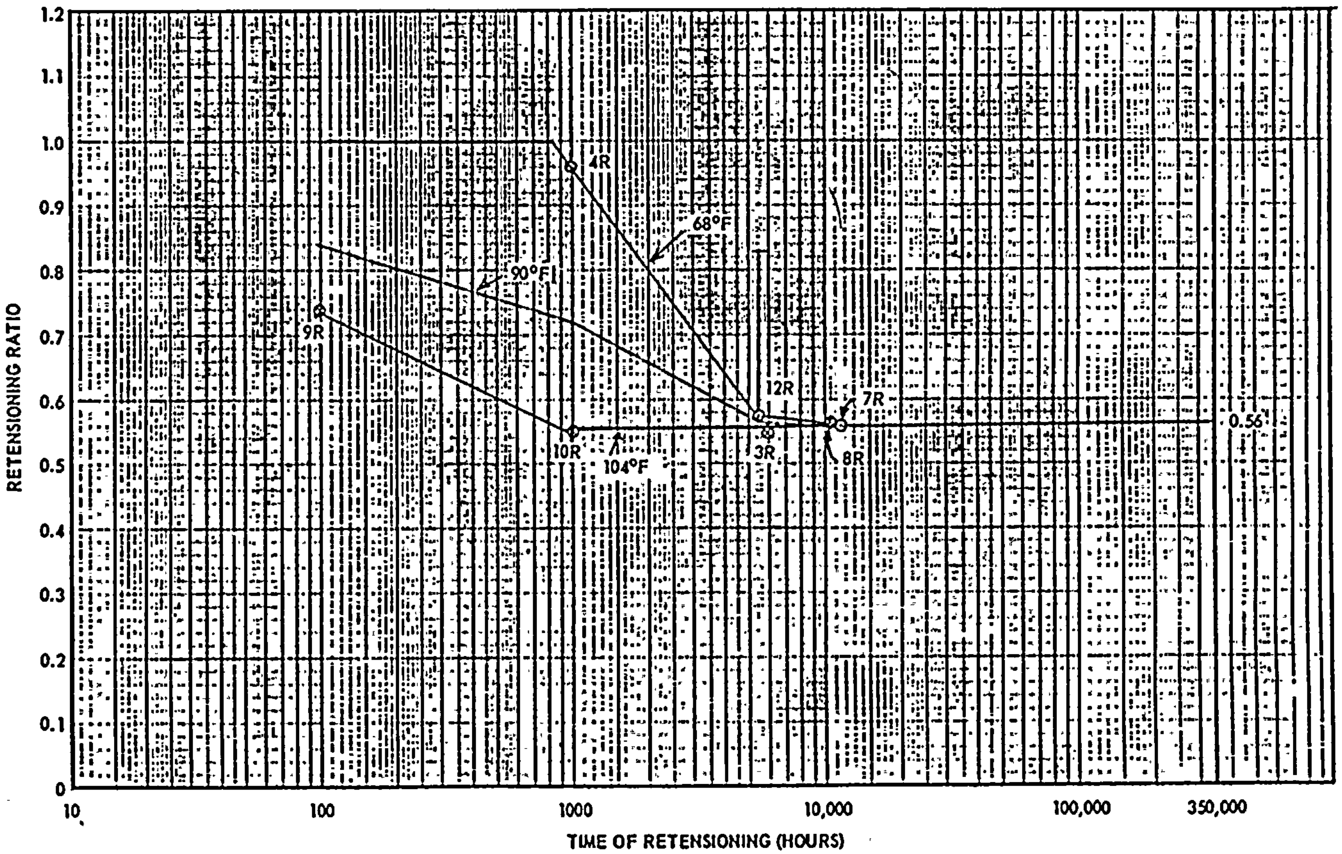


FIGURE 3–G RETENSIONING RATIO AT 100,000 HOURS AFTER RETENSIONING

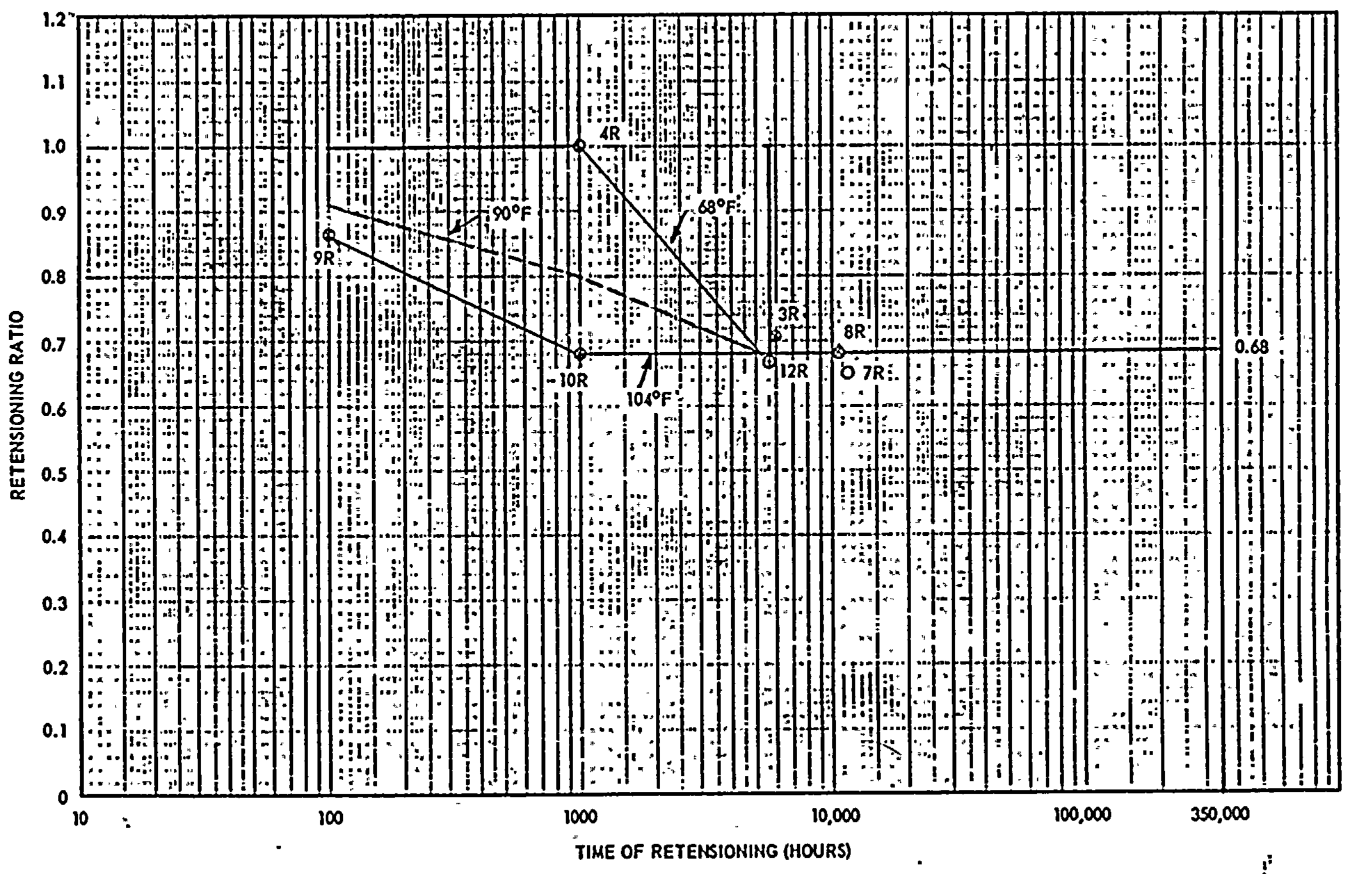


FIGURE 3-H RETENSIONING RATIO AT 350,000 HOURS AFTER RETENSIONING

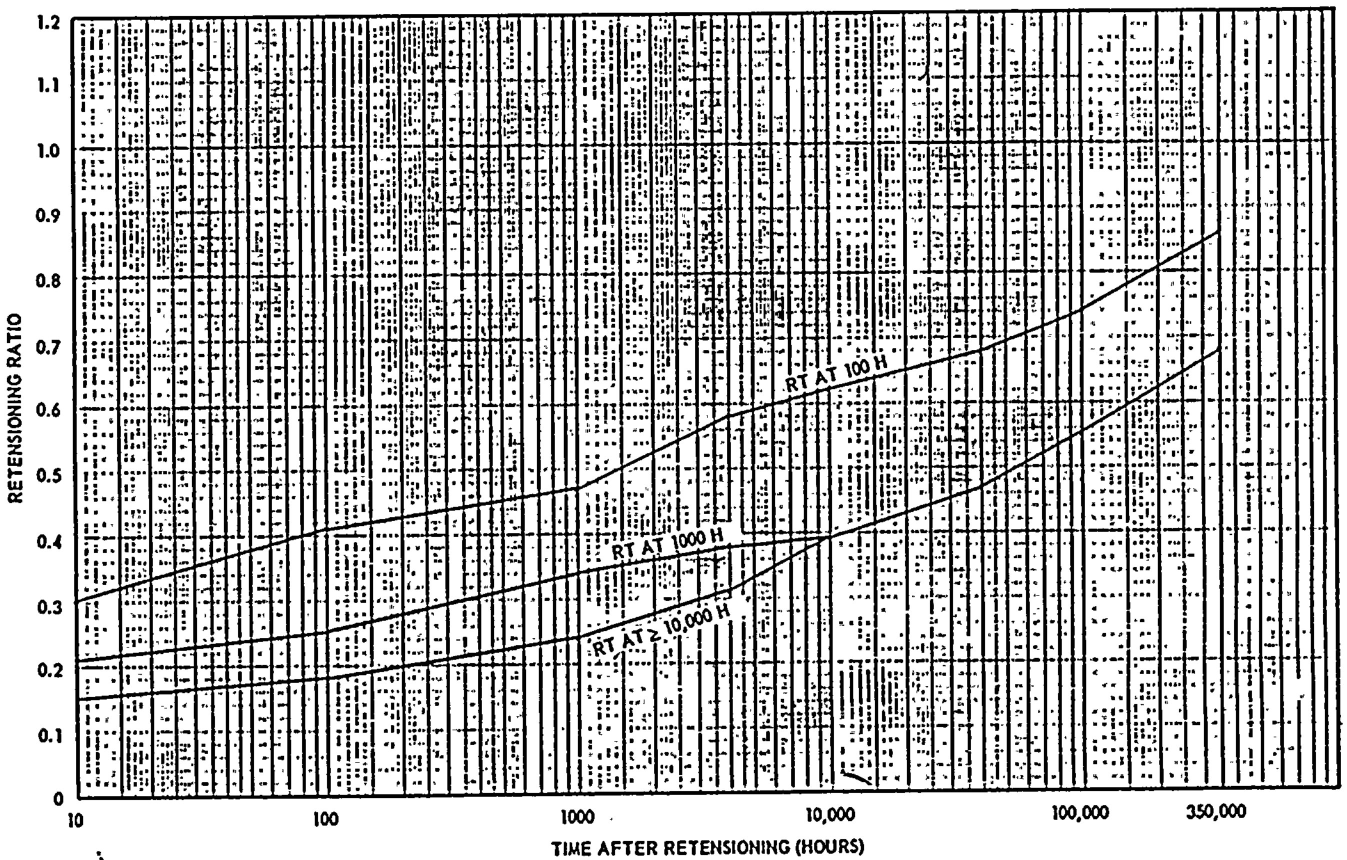


FIGURE 3-1 RETENSIONING RATIO FOR 104°F

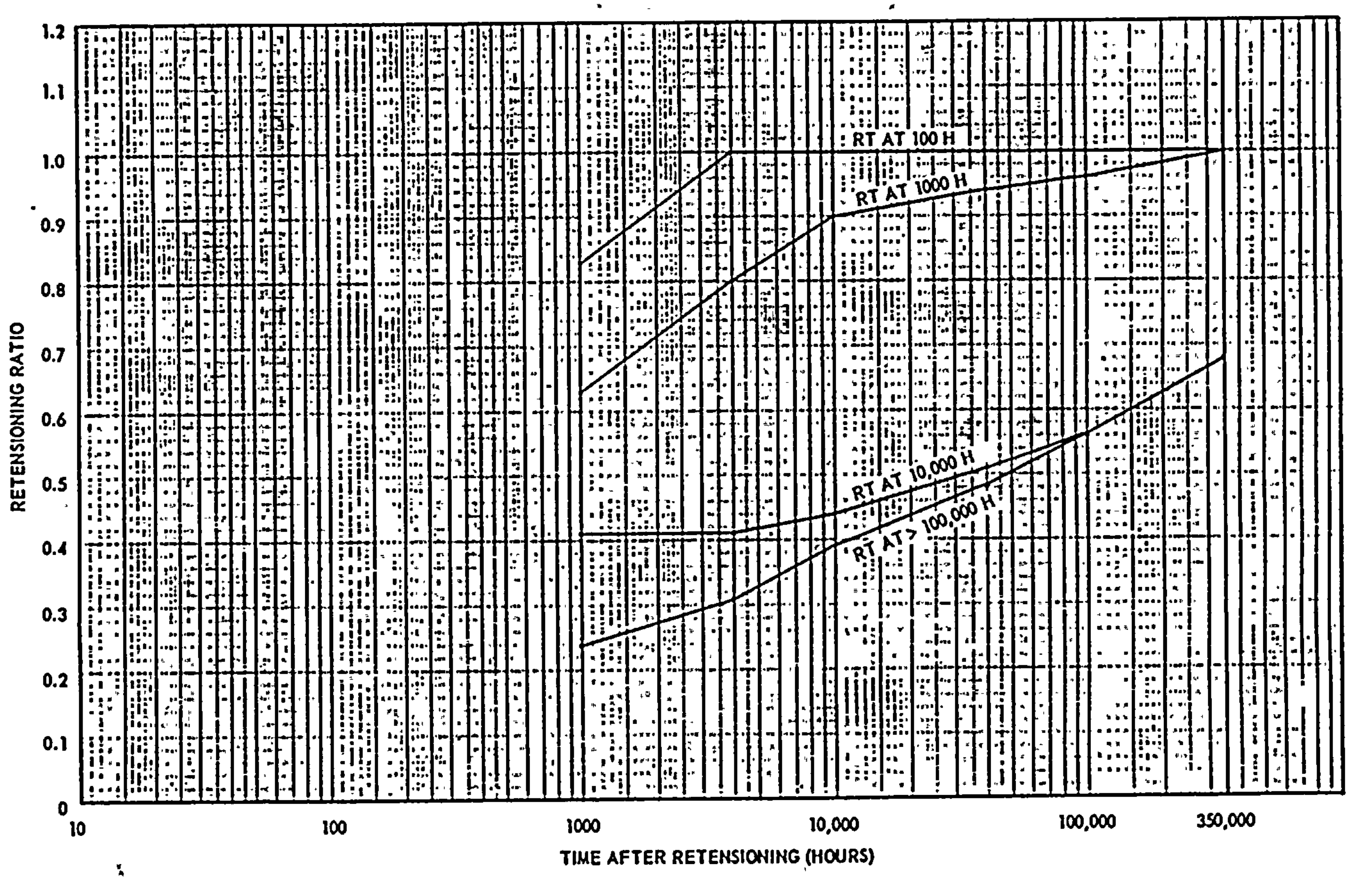


FIGURE 3-J RETENSIONING RATIO FOR 68°F

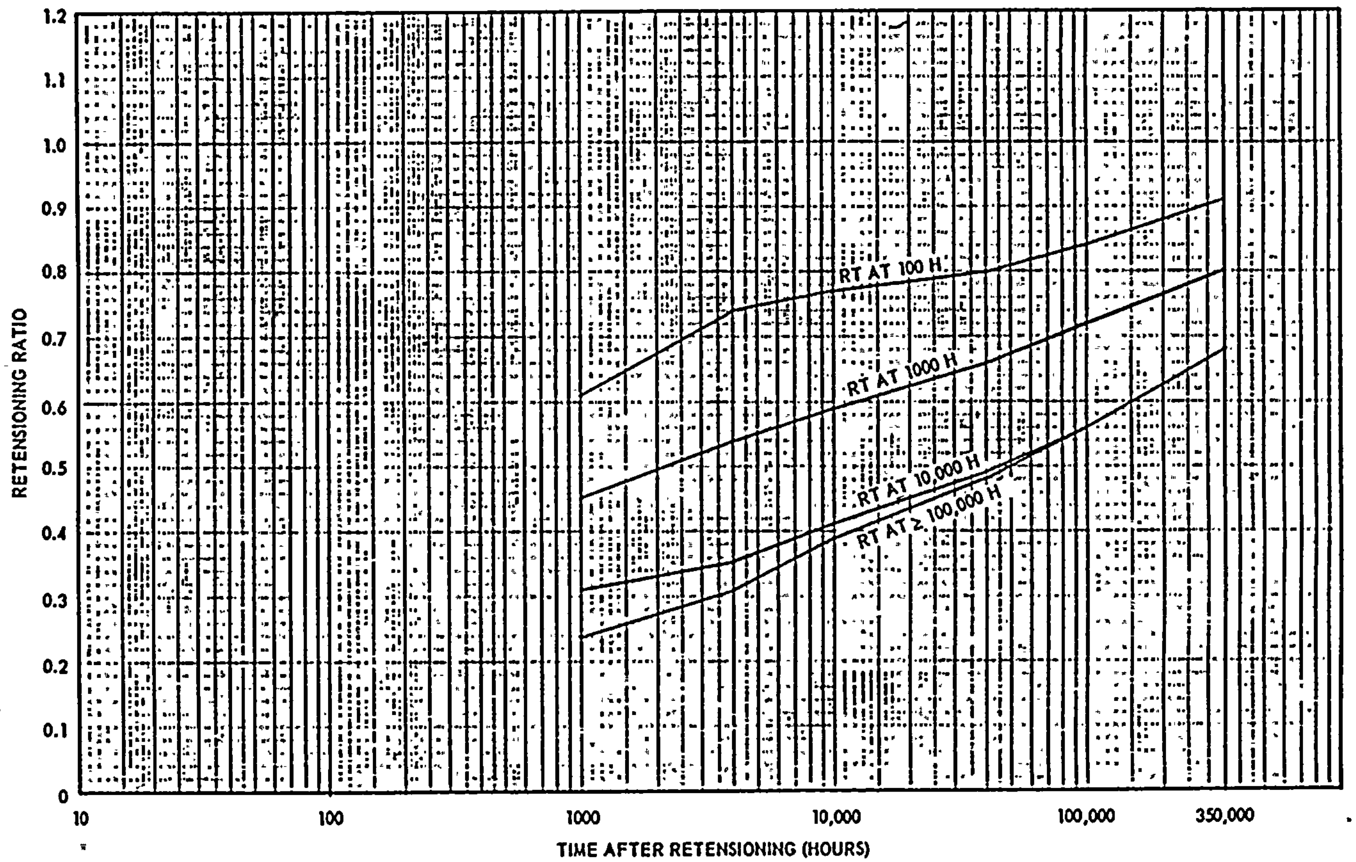


FIGURE 3-K RETENSIONING RATIO FOR 90°F

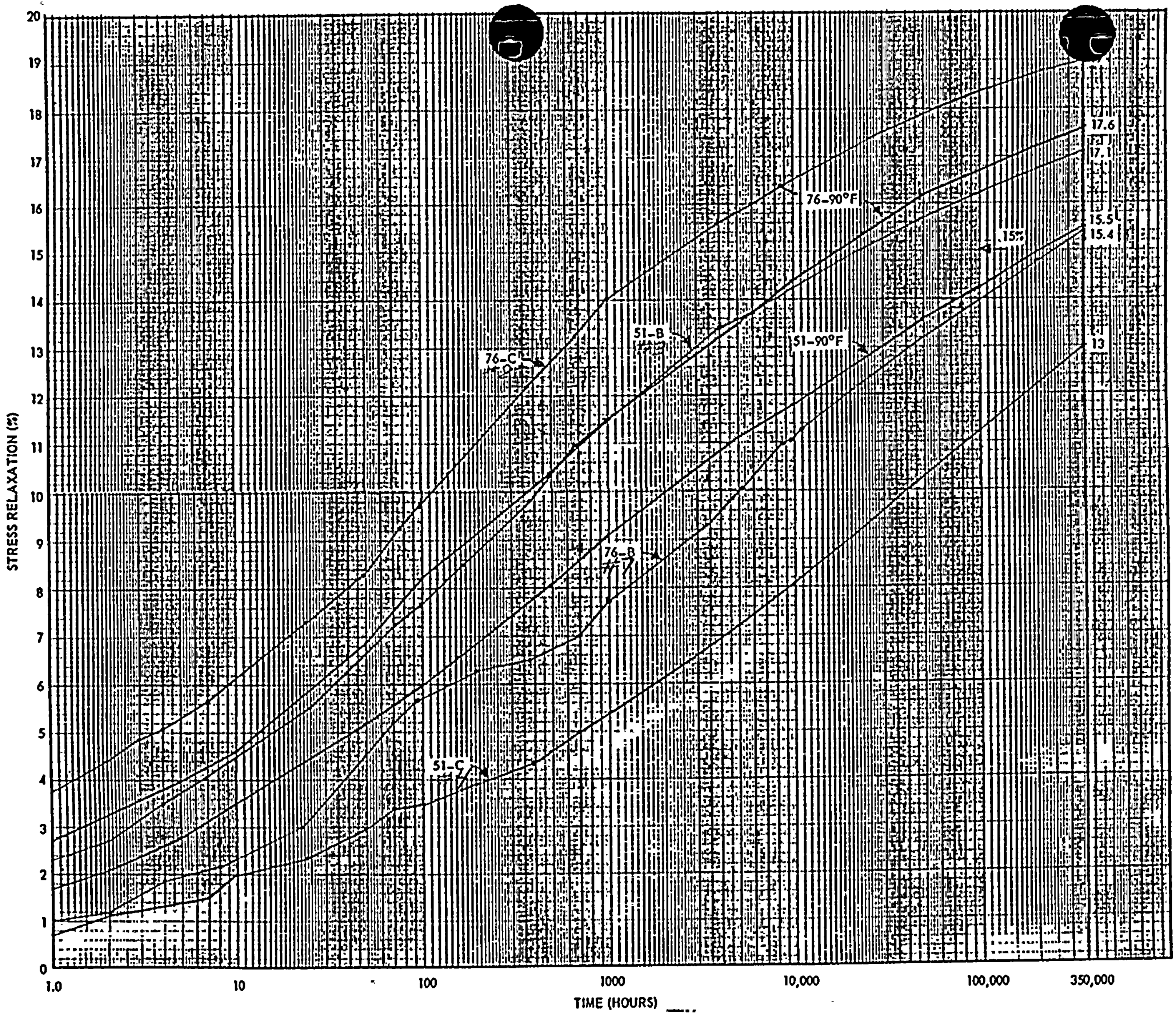


FIGURE 4 BASE RELAXATION FOR ACTUAL TENDONS

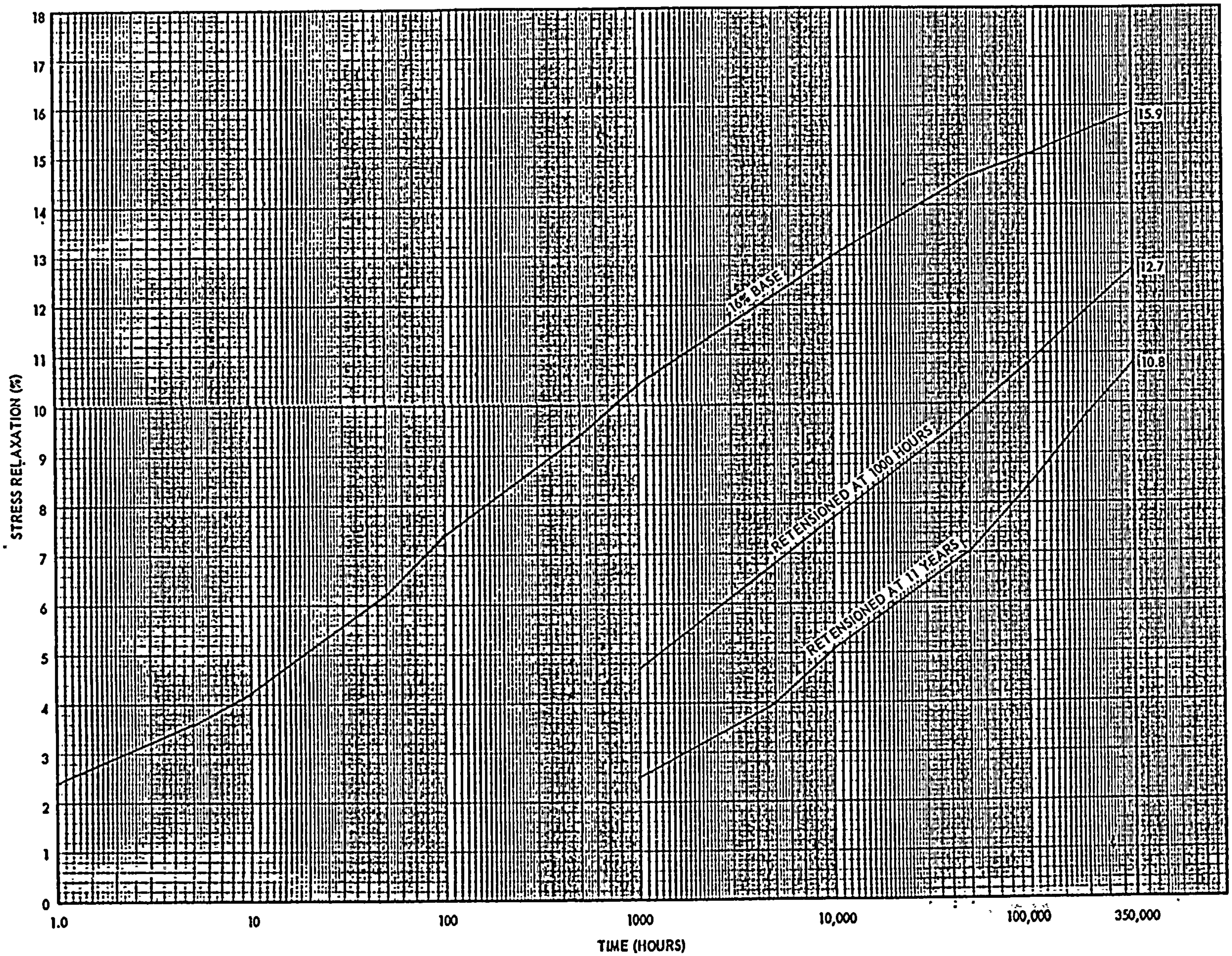
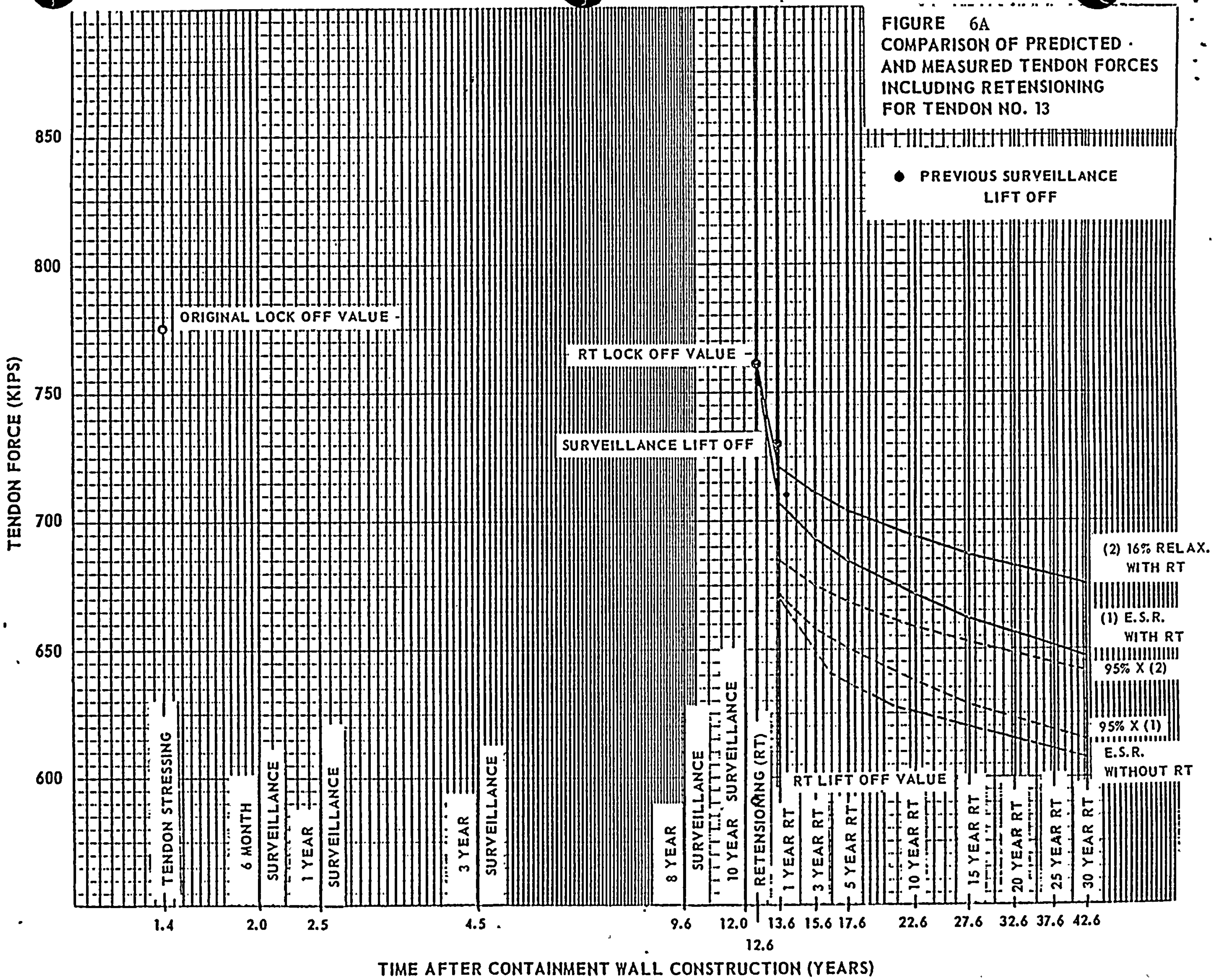


FIGURE 5 BASE AND RETENSIONED RELAXATION FOR ACTUAL TENDONS

FIGURE 6A
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES INCLUDING RETENSIONING FOR TENDON NO. 13



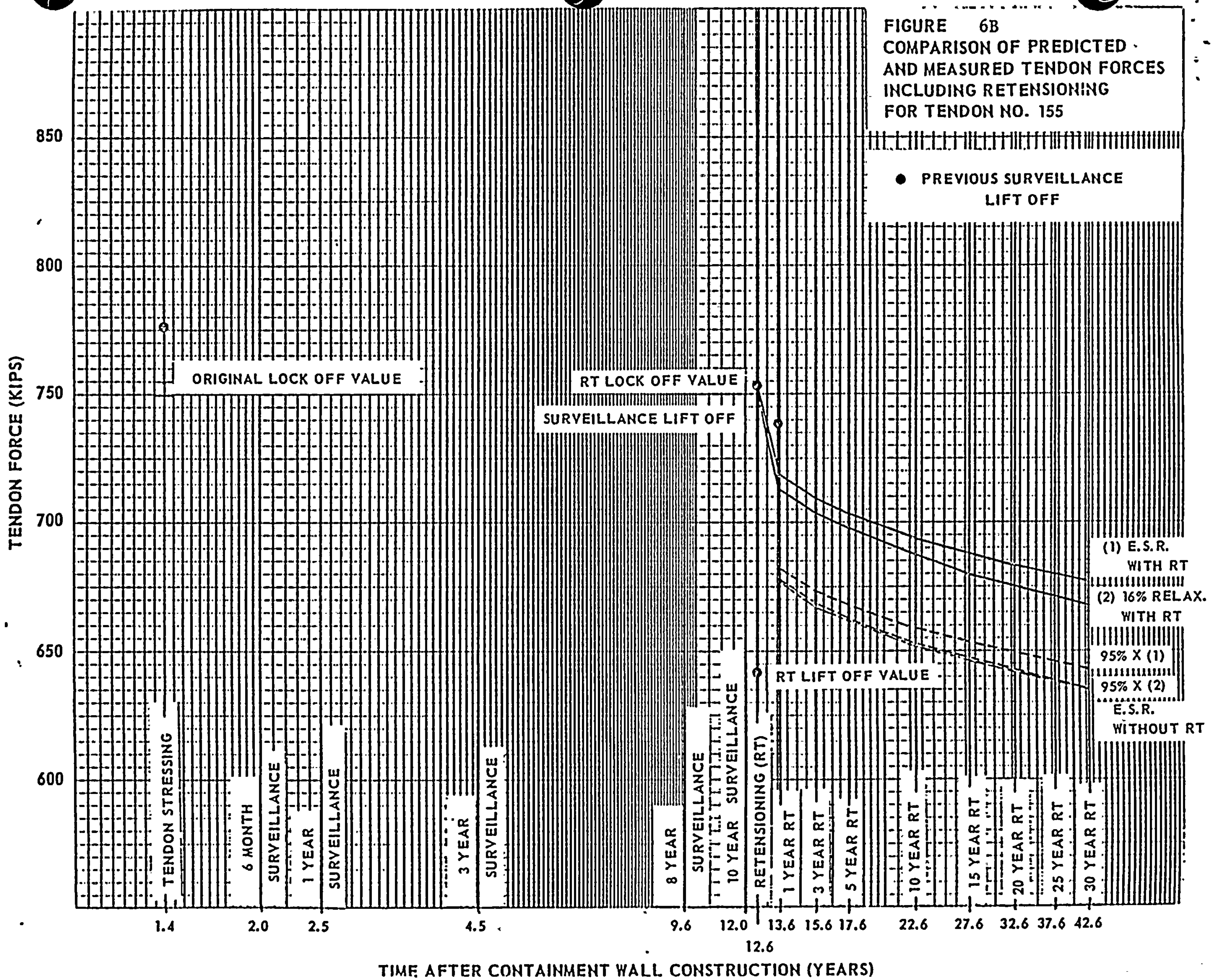


FIGURE 6B
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES INCLUDING RETENSIONING FOR TENDON NO. 155
PREVIOUS SURVEILLANCE LIFT OFF
TENDON FORCE (KIPS)
850
800
750
700
650
600
ORIGINAL LOCK OFF VALUE
RT LOCK OFF VALUE
SURVEILLANCE LIFT OFF
RT LIFT OFF VALUE
(1) E.S.R. WITH RT
(2) 16% RELAX. WITH RT
95% X (1)
95% X (2)
E.S.R. WITHOUT 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)

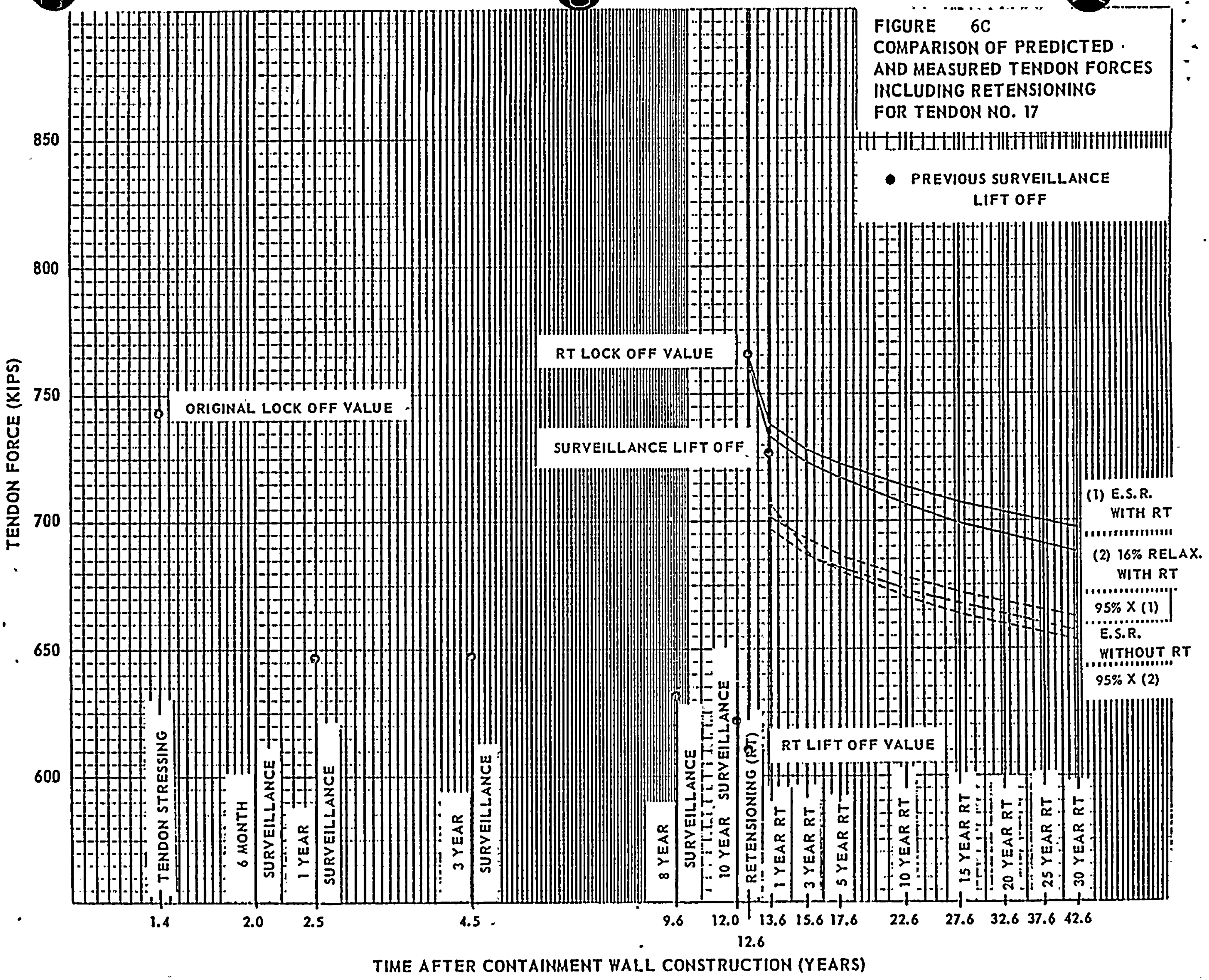


FIGURE 6C
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES INCLUDING RETENSIONING FOR TENDON NO. 17
● PREVIOUS SURVEILLANCE LIFT OFF
TENDON FORCE (KIPS)
850
800
750
700
650
600
ORIGINAL LOCK OFF VALUE
RT LOCK OFF VALUE
SURVEILLANCE LIFT OFF
RT LIFT OFF VALUE
(1) E.S.R. WITH RT
(2) 16% RELAX. WITH RT
95% X (1)
E.S.R. WITHOUT RT
95% X (2)
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)

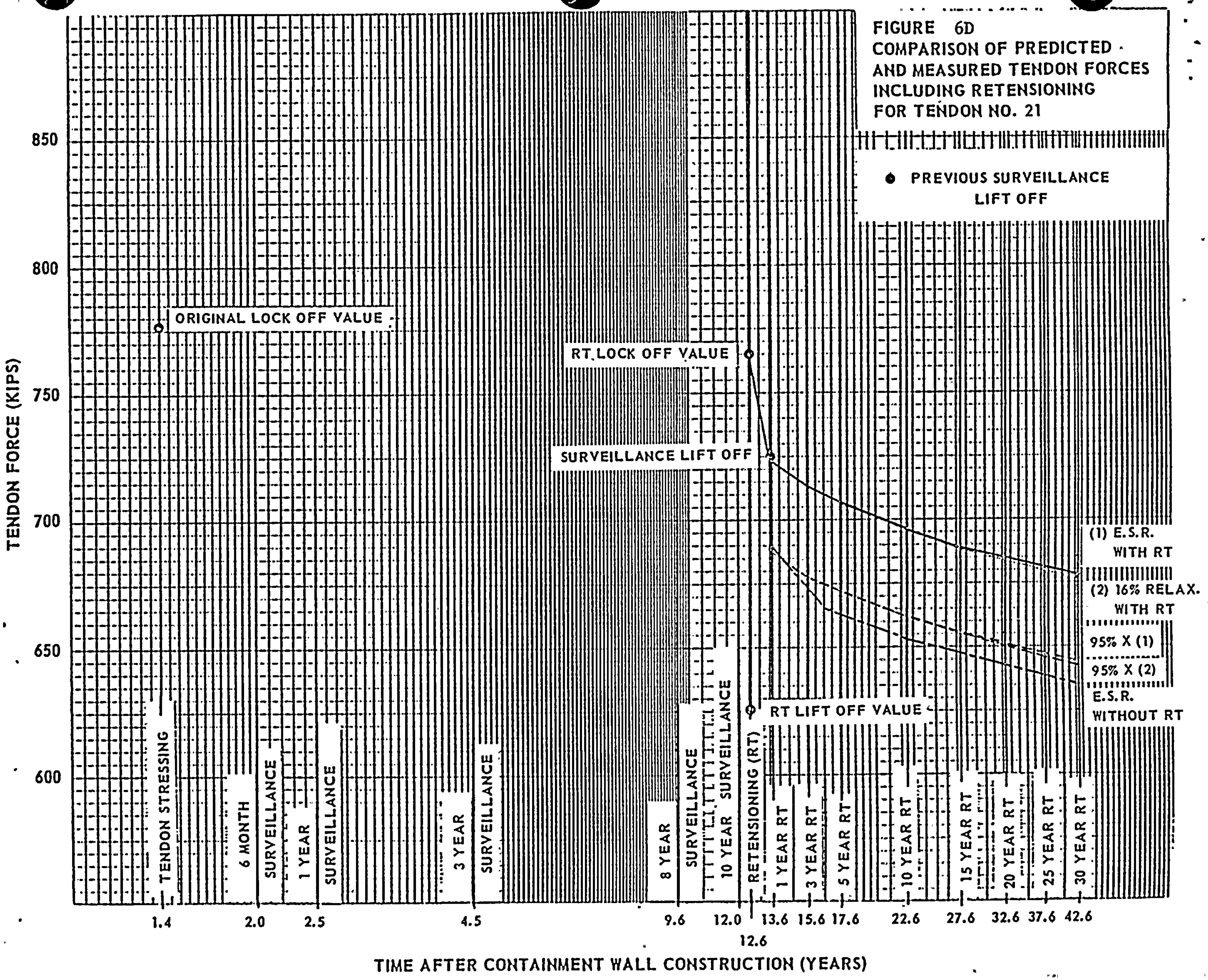


FIGURE 6D
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES INCLUDING RETENSIONING FOR TENDON NO. 21
PREVIOUS SURVEILLANCE LIFT OFF
TENDON FORCE (KIPS)
850
800
750
700
650
600
ORIGINAL LOCK OFF VALUE
RT LOCK OFF VALUE
SURVEILLANCE LIFT OFF
RT LIFT OFF VALUE
(1) E.S.R. WITH RT
(2) 16% RELAX. WITH RT
95% X (1)
95% X (2)
E.S.R. WITHOUT 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)

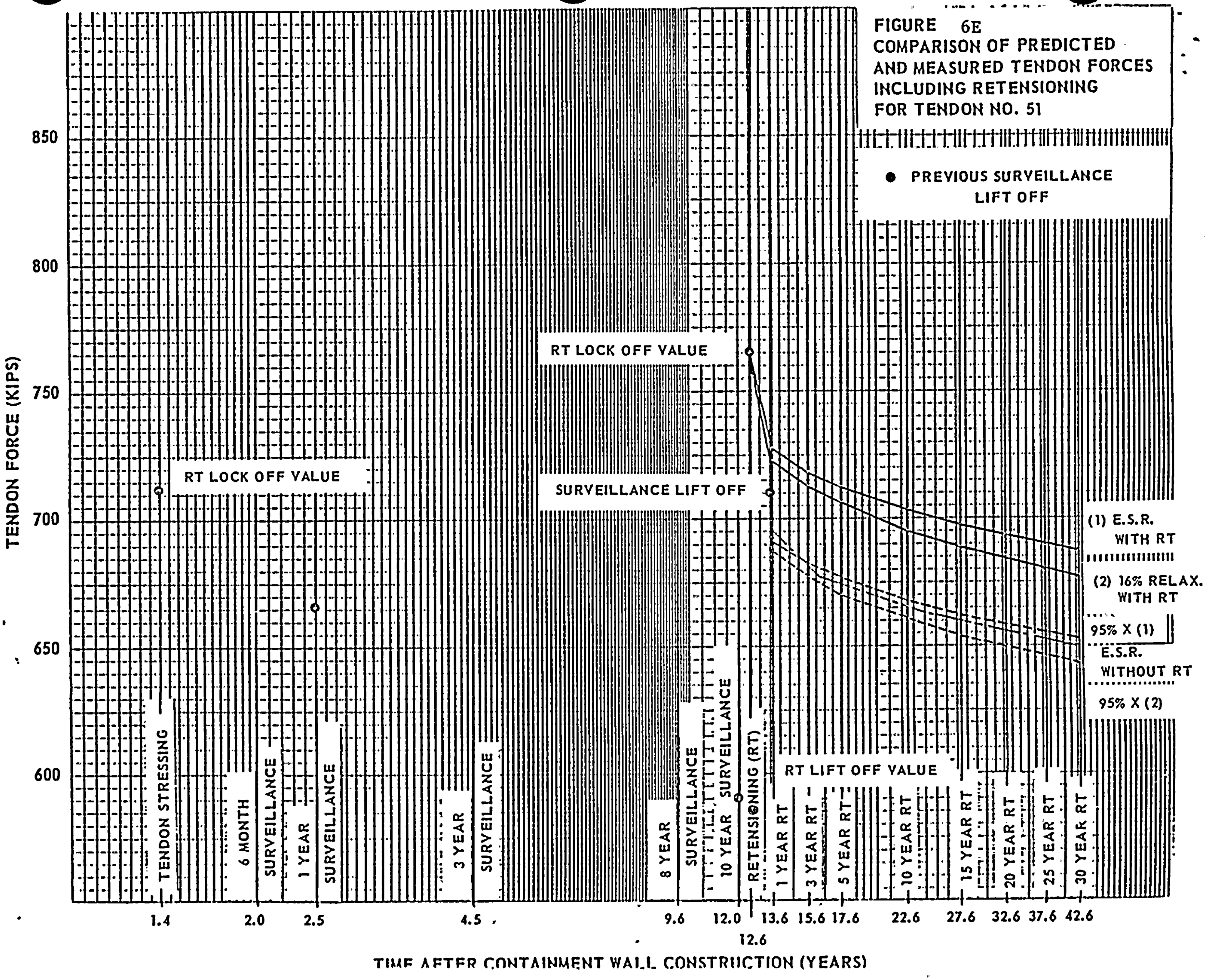


FIGURE 6E
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES INCLUDING RETENSIONING FOR TENDON NO. 51
● PREVIOUS SURVEILLANCE LIFT OFF
TENDON FORCE (KIPS)
850
800
750
700
650
600
RT LOCK OFF VALUE
RT LOCK OFF VALUE
SURVEILLANCE LIFT OFF
RT LIFT OFF VALUE
(1) E.S.R. WITH RT
(2) 16% RELAX. WITH RT
95% X (1)
E.S.R. WITHOUT RT
95% X (2)
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)

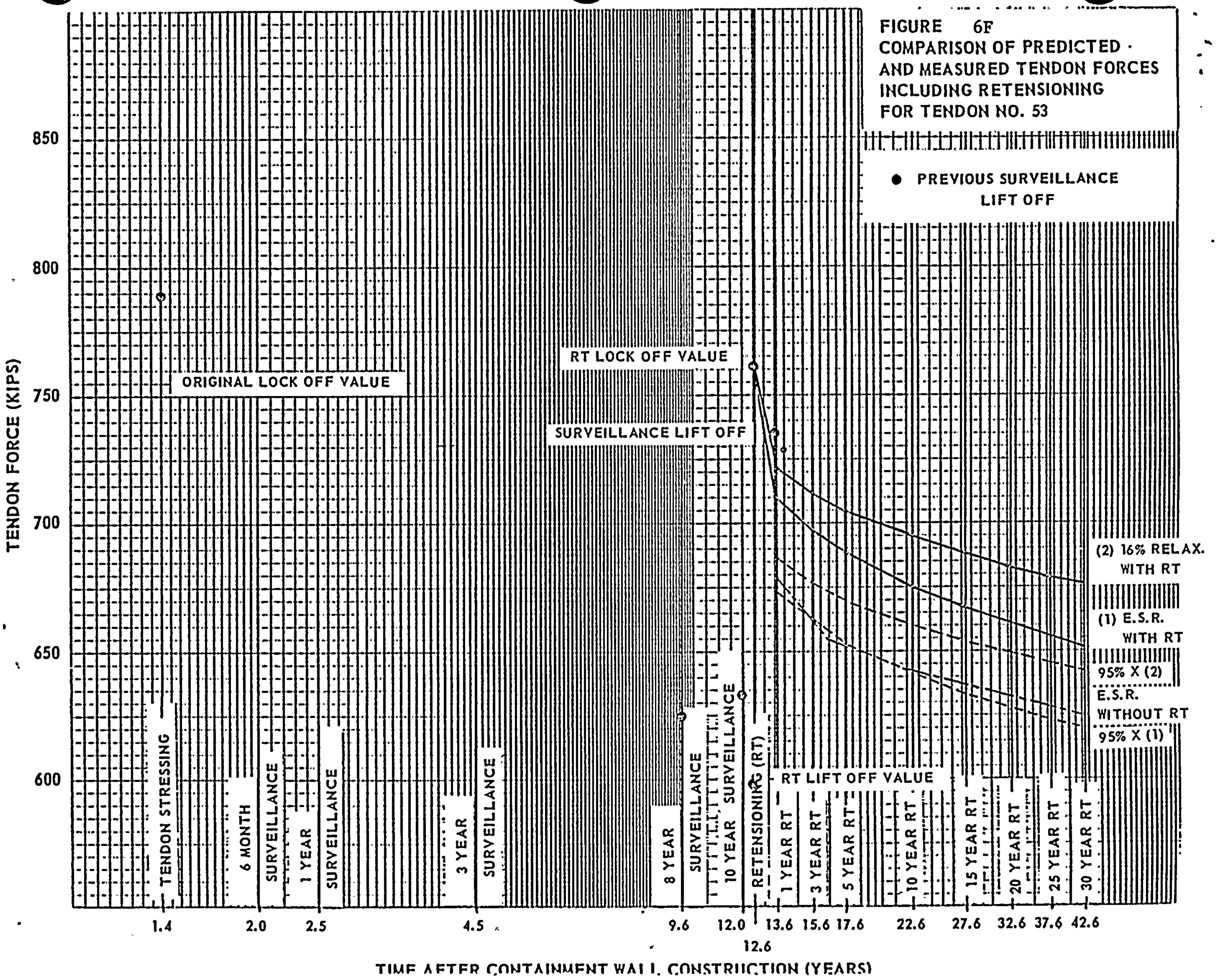


FIGURE 6F
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES INCLUDING RETENSIONING FOR TENDON NO. 53
● PREVIOUS SURVEILLANCE LIFT OFF
TENDON FORCE (KIPS)
850
800
750
700
650
600
ORIGINAL LOCK OFF VALUE
RT LOCK OFF VALUE
SURVEILLANCE LIFT OFF
(2) 16% RELAX. WITH RT
(1) E.S.R. WITH RT
95% X (2)
E.S.R. WITHOUT RT
95% X (1)
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)

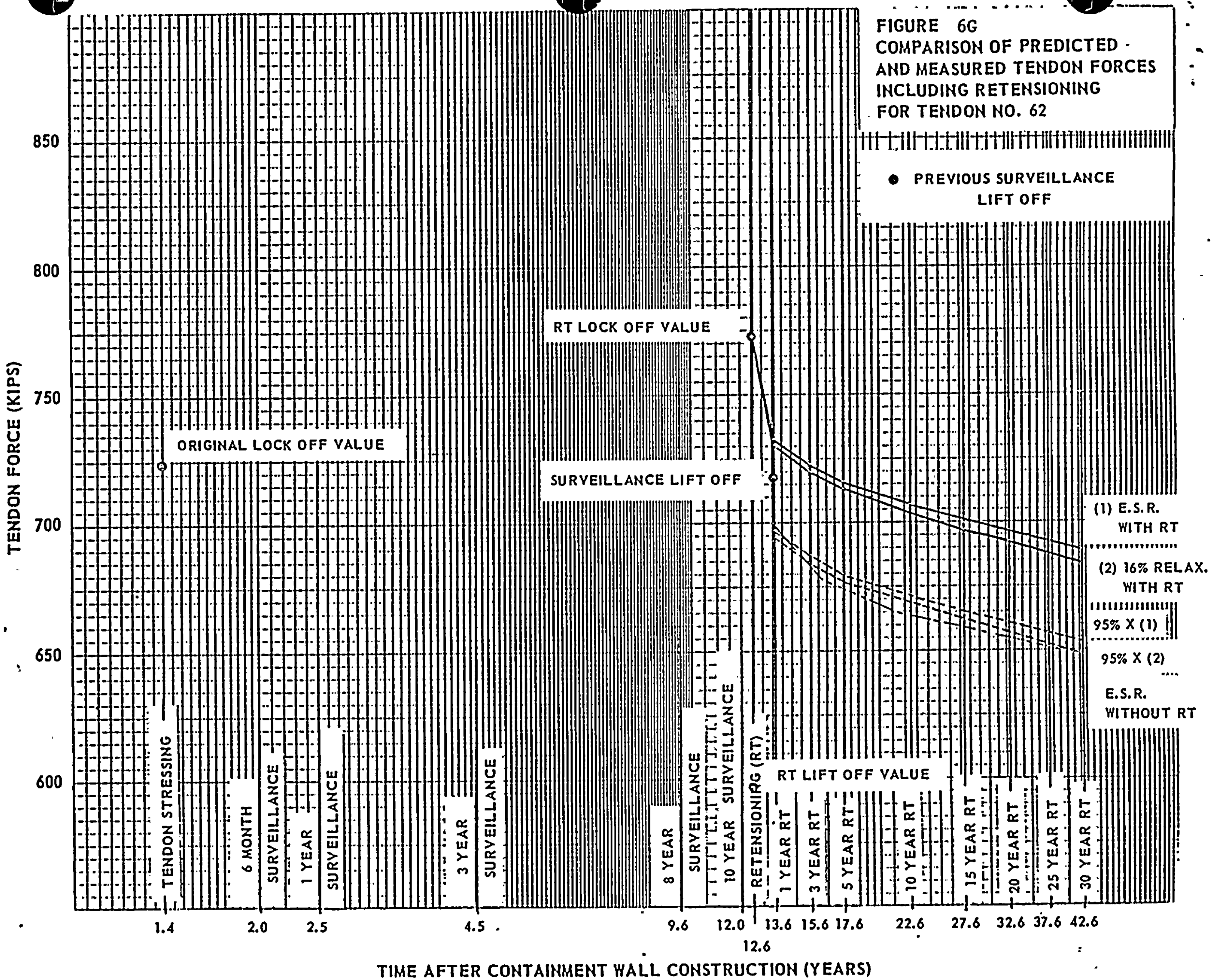


FIGURE 6G
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES INCLUDING RETENSIONING FOR TENDON NO. 62
PREVIOUS SURVEILLANCE LIFT OFF
TENDON FORCE (KIPS)
850
800
750
700
650
600
RT LOCK OFF VALUE
ORIGINAL LOCK OFF VALUE
SURVEILLANCE LIFT OFF
(1) E.S.R. WITH RT
(2) 16% RELAX. WITH RT
95% X (1)
95% X (2)
E.S.R. WITHOUT 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)

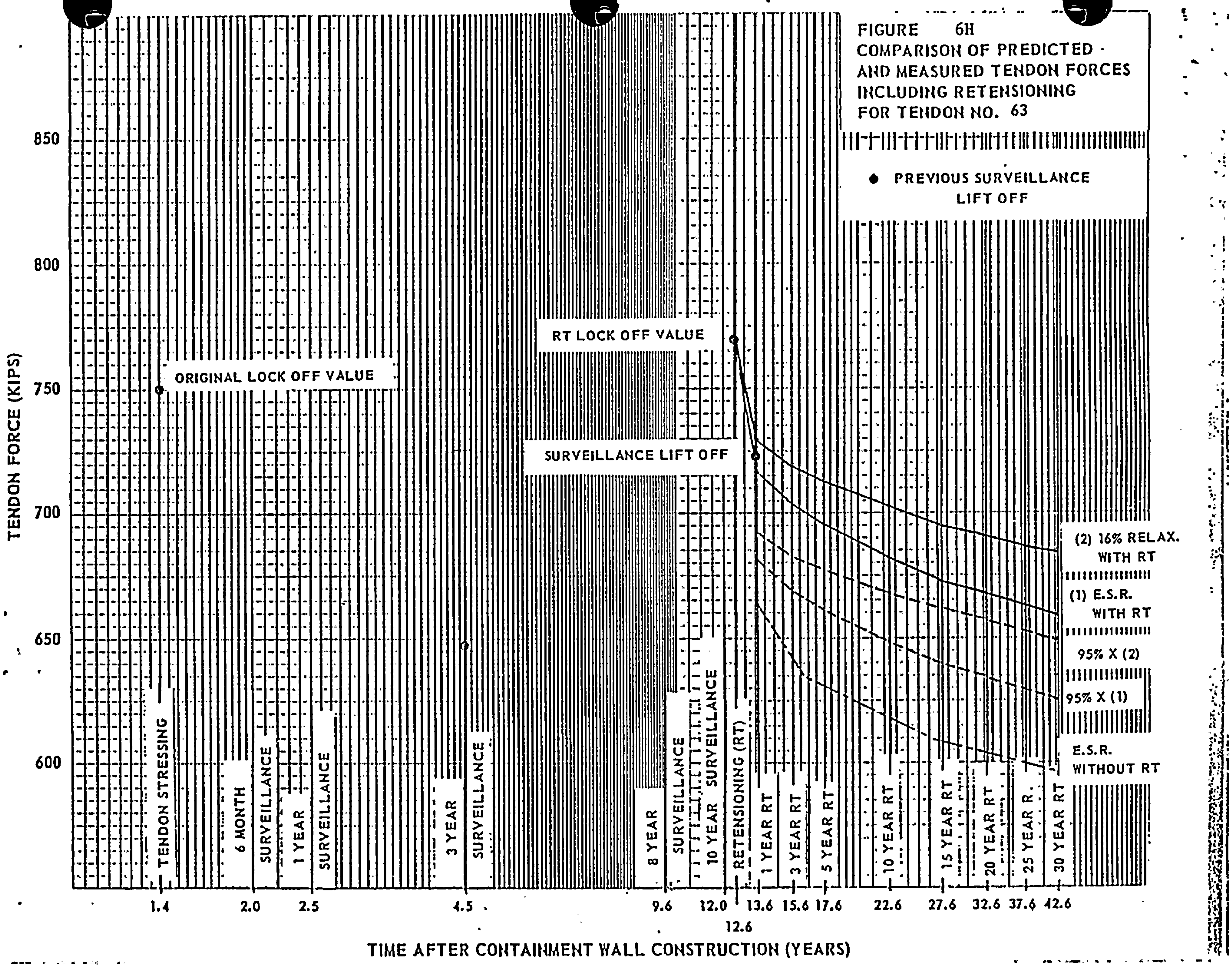


FIGURE 6H
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES INCLUDING RETENSIONING FOR TENDON NO. 63
● PREVIOUS SURVEILLANCE LIFT OFF
TENDON FORCE (KIPS)
850
800
750
700
650
600
RT LOCK OFF VALUE
ORIGINAL LOCK OFF VALUE
SURVEILLANCE LIFT OFF
(2) 16% RELAX. WITH RT
(1) E.S.R. WITH RT
95% X (2)
95% X (1)
E.S.R. WITHOUT 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 R.
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)

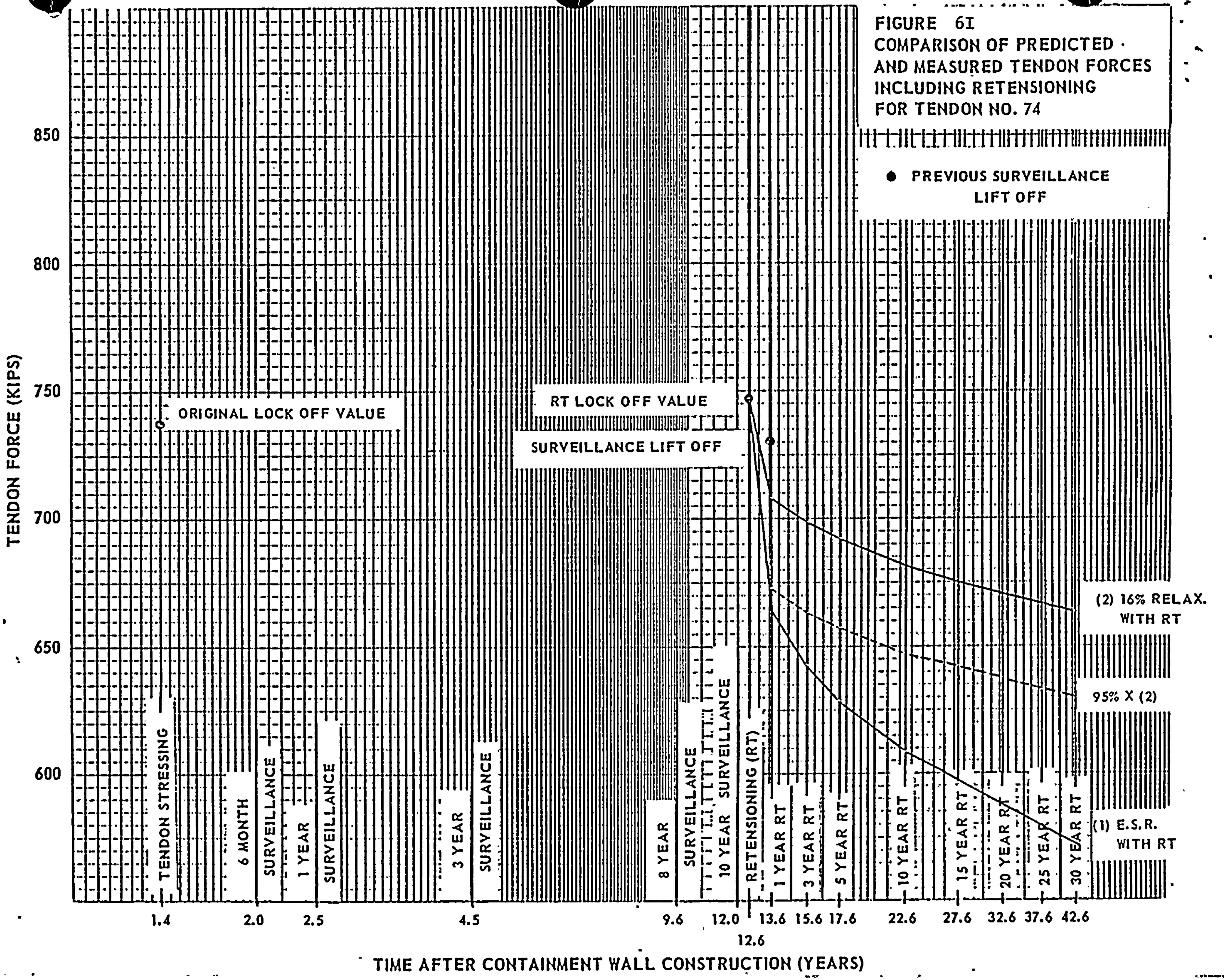


FIGURE 6I
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES INCLUDING RETENSIONING FOR TENDON NO. 74

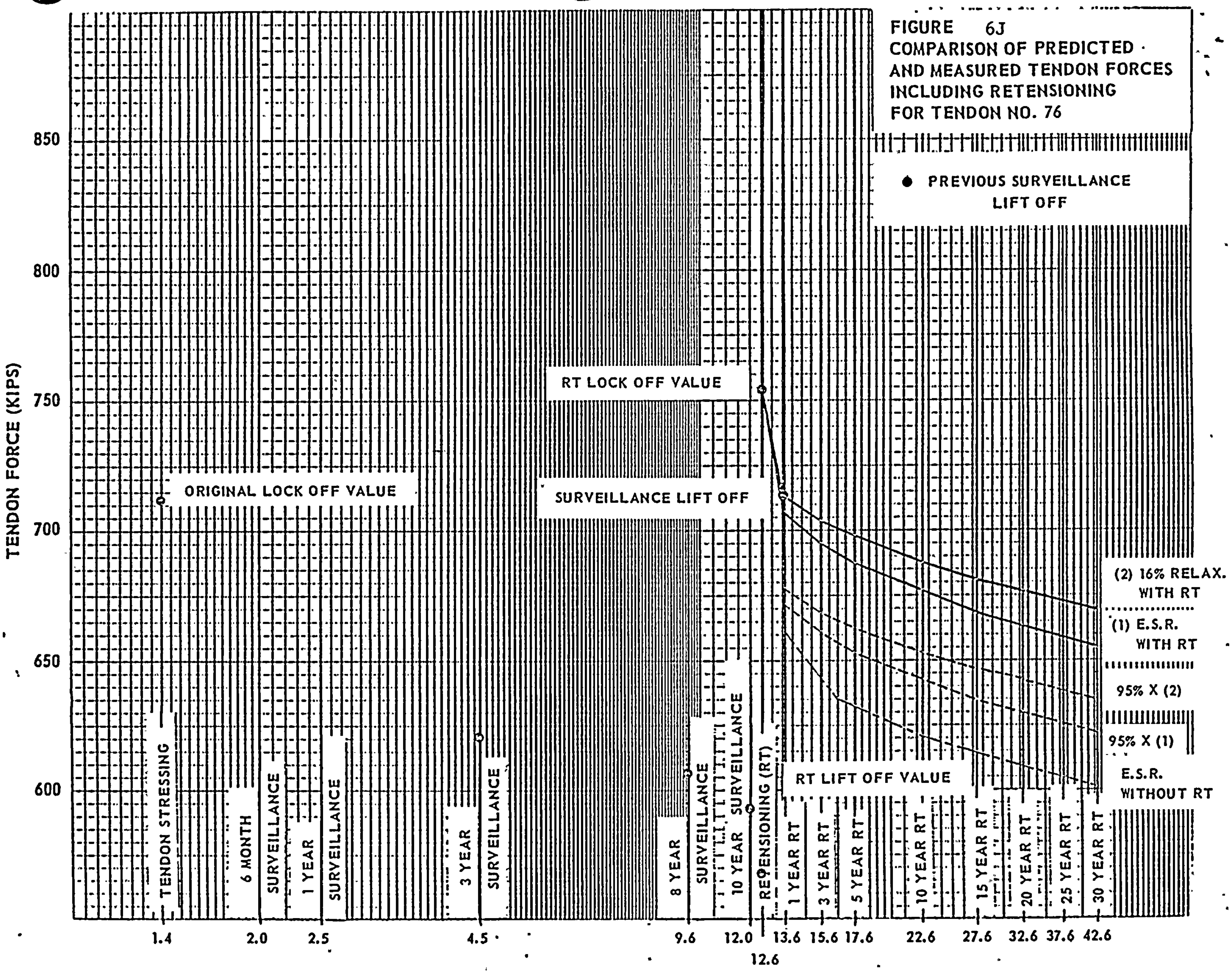


FIGURE 6J
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES INCLUDING RETENSIONING FOR TENDON NO. 76

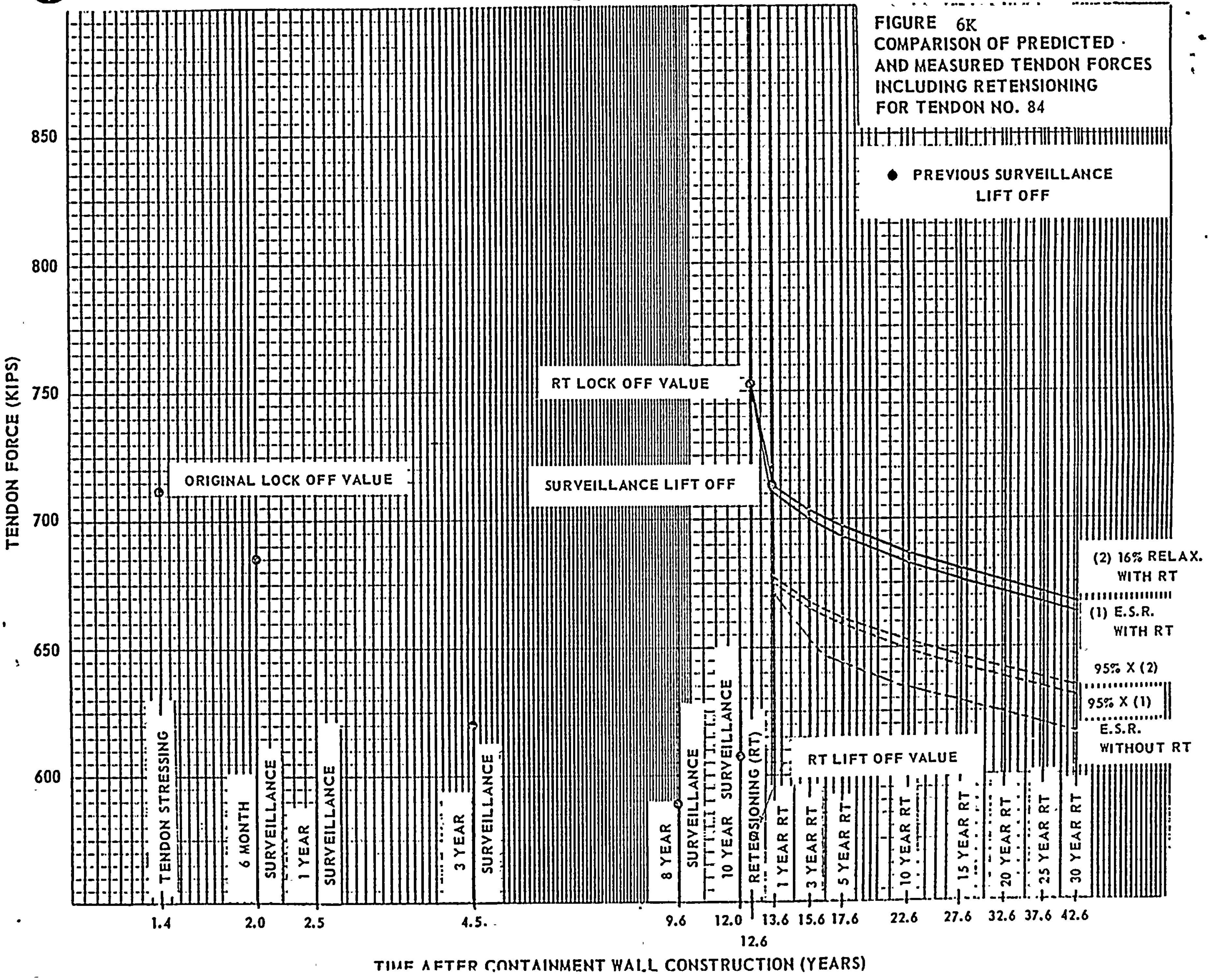


FIGURE 6K
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES INCLUDING RETENSIONING FOR TENDON NO. 84
PREVIOUS SURVEILLANCE LIFT OFF
TENDON FORCE (KIPS)
850
800
750
700
650
600
RT LOCK OFF VALUE
ORIGINAL LOCK OFF VALUE
SURVEILLANCE LIFT OFF
(2) 16% RELAX. WITH RT
(1) E.S.R. WITH RT
95% X (2)
95% X (1)
E.S.R. WITHOUT 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)

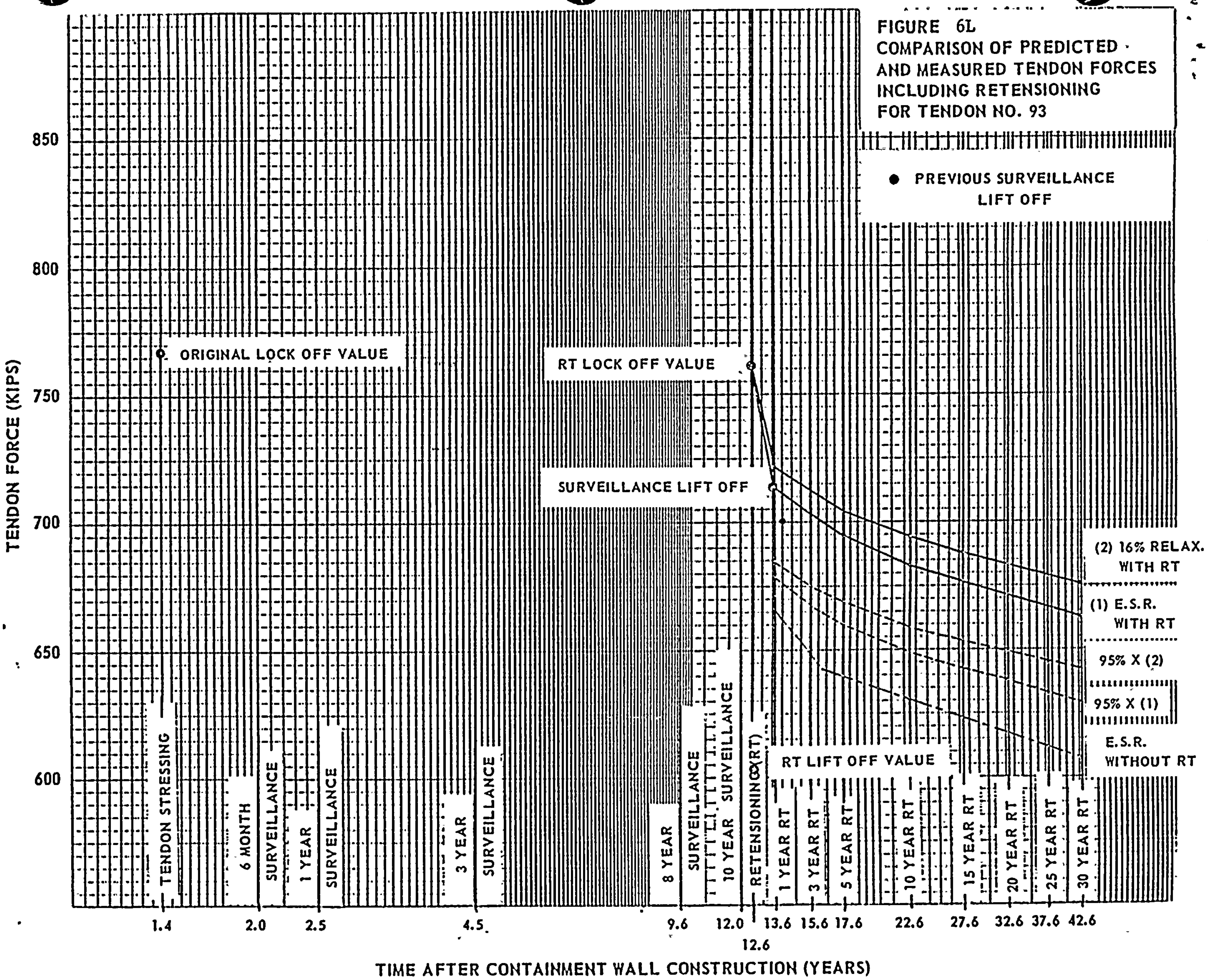
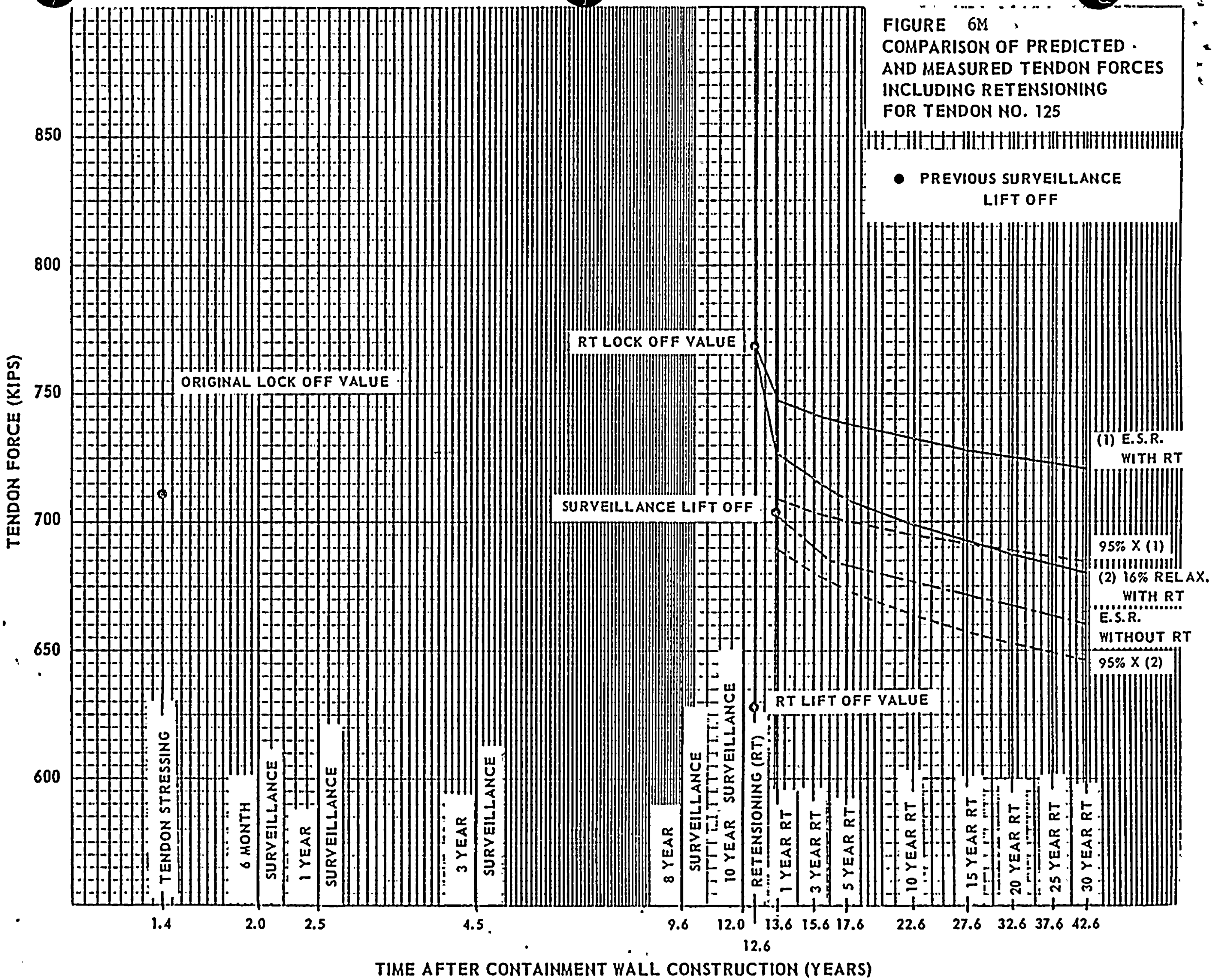


FIGURE 6L
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES INCLUDING RETENSIONING FOR TENDON NO. 93
● PREVIOUS SURVEILLANCE LIFT OFF
ORIGINAL LOCK OFF VALUE
RT LOCK OFF VALUE
SURVEILLANCE LIFT OFF
RT LIFT OFF VALUE
(2) 16% RELAX. WITH RT
(1) E.S.R. WITH RT
95% X (2)
95% X (1)
E.S.R. WITHOUT RT
TENDON FORCE (KIPS)
850
800
750
700
650
600
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 6M
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES INCLUDING RETENSIONING FOR TENDON NO. 125



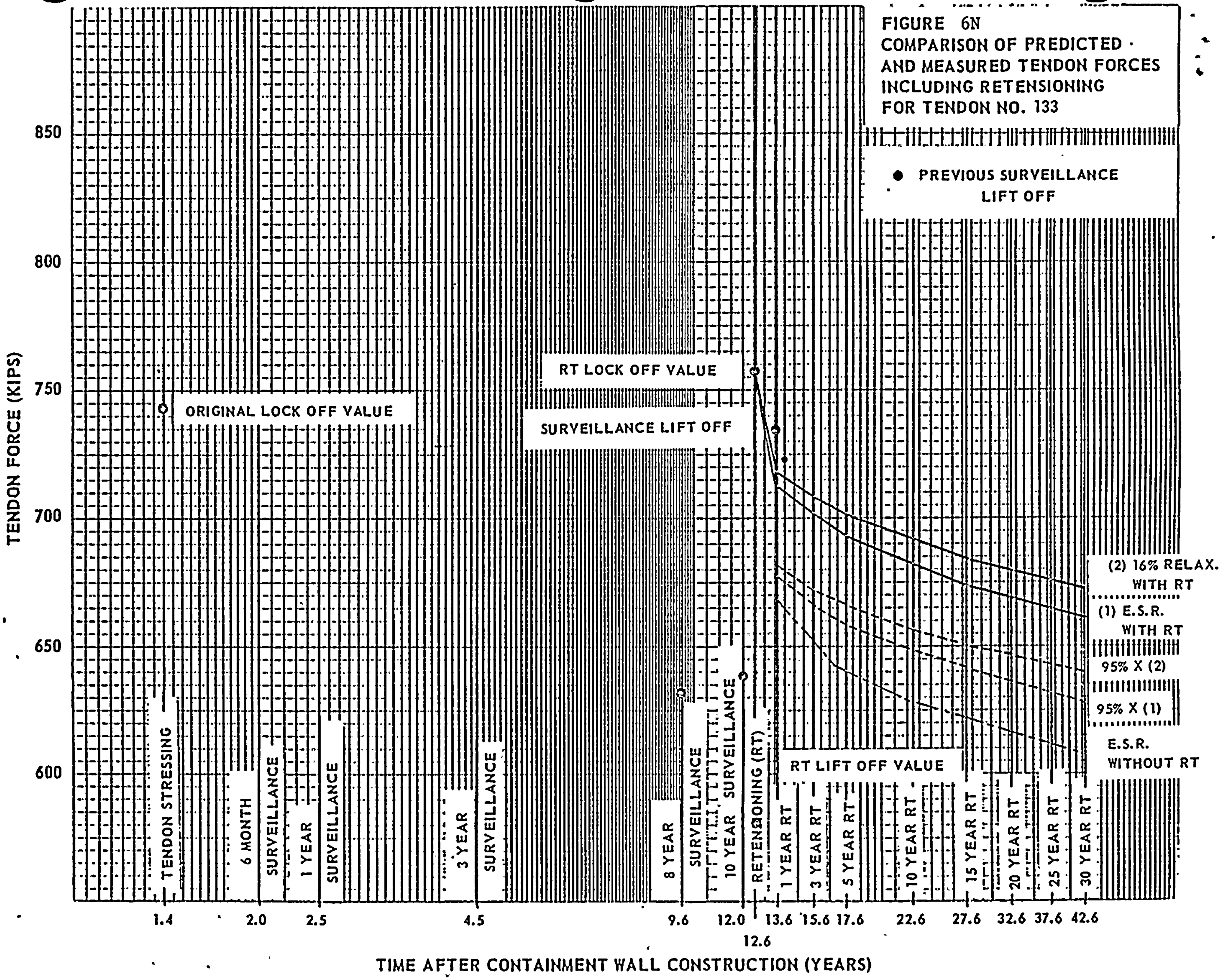


FIGURE 6N
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES INCLUDING RETENSIONING FOR TENDON NO. 133
PREVIOUS SURVEILLANCE LIFT OFF
TENDON FORCE (KIPS)
850
800
750
700
650
600
ORIGINAL LOCK OFF VALUE
RT LOCK OFF VALUE
SURVEILLANCE LIFT OFF
RT LIFT OFF VALUE
(2) 16% RELAX. WITH RT
(1) E.S.R. WITH RT
95% X (2)
95% X (1)
E.S.R. WITHOUT 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)

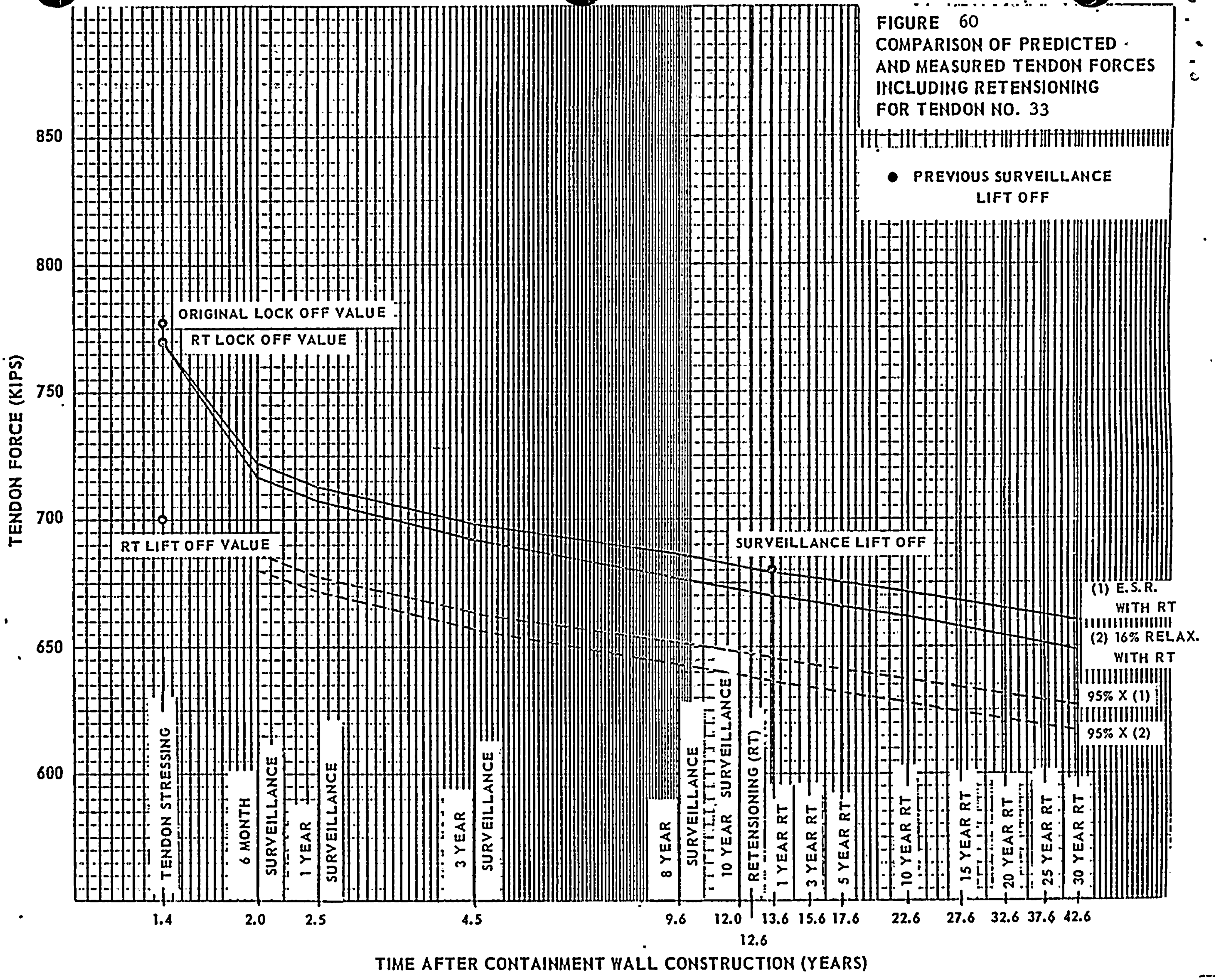


FIGURE 60
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES INCLUDING RETENSIONING FOR TENDON NO. 33
● PREVIOUS SURVEILLANCE LIFT OFF
TENDON FORCE (KIPS)
850
800
750
700
650
600
ORIGINAL LOCK OFF VALUE
RT LOCK OFF VALUE
RT LIFT OFF VALUE
SURVEILLANCE LIFT OFF
(1) E.S.R. WITH RT
(2) 16% RELAX. WITH RT
95% X (1)
95% X (2)
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)

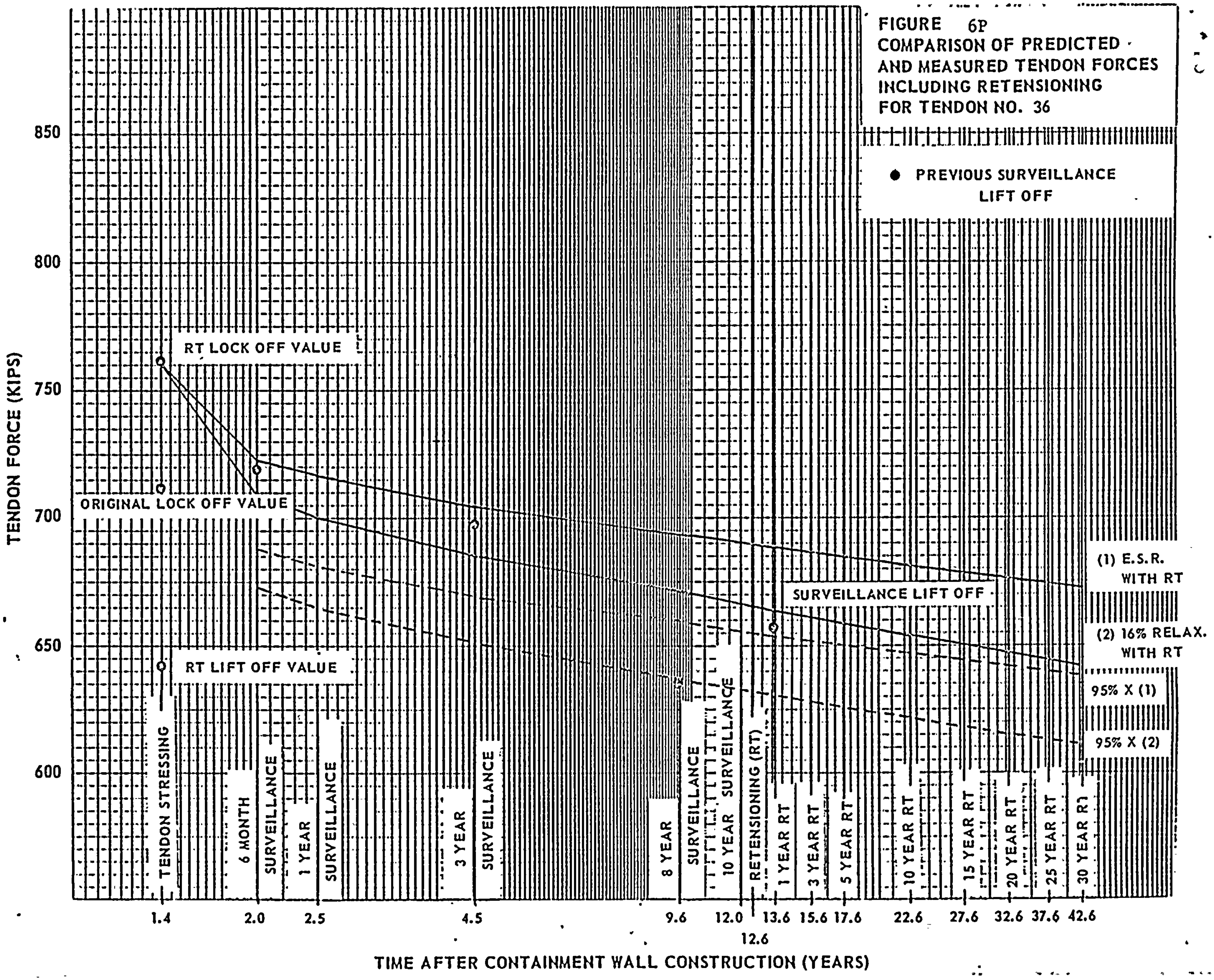


FIGURE 6P
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES INCLUDING RETENSIONING FOR TENDON NO. 36
● PREVIOUS SURVEILLANCE LIFT OFF
TENDON FORCE (KIPS)
850
800
750
700
650
600
RT LOCK OFF VALUE
ORIGINAL LOCK OFF VALUE
RT LIFT OFF VALUE
SURVEILLANCE LIFT OFF
(1) E.S.R. WITH RT
(2) 16% RELAX. WITH RT
95% X (1)
95% X (2)
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)

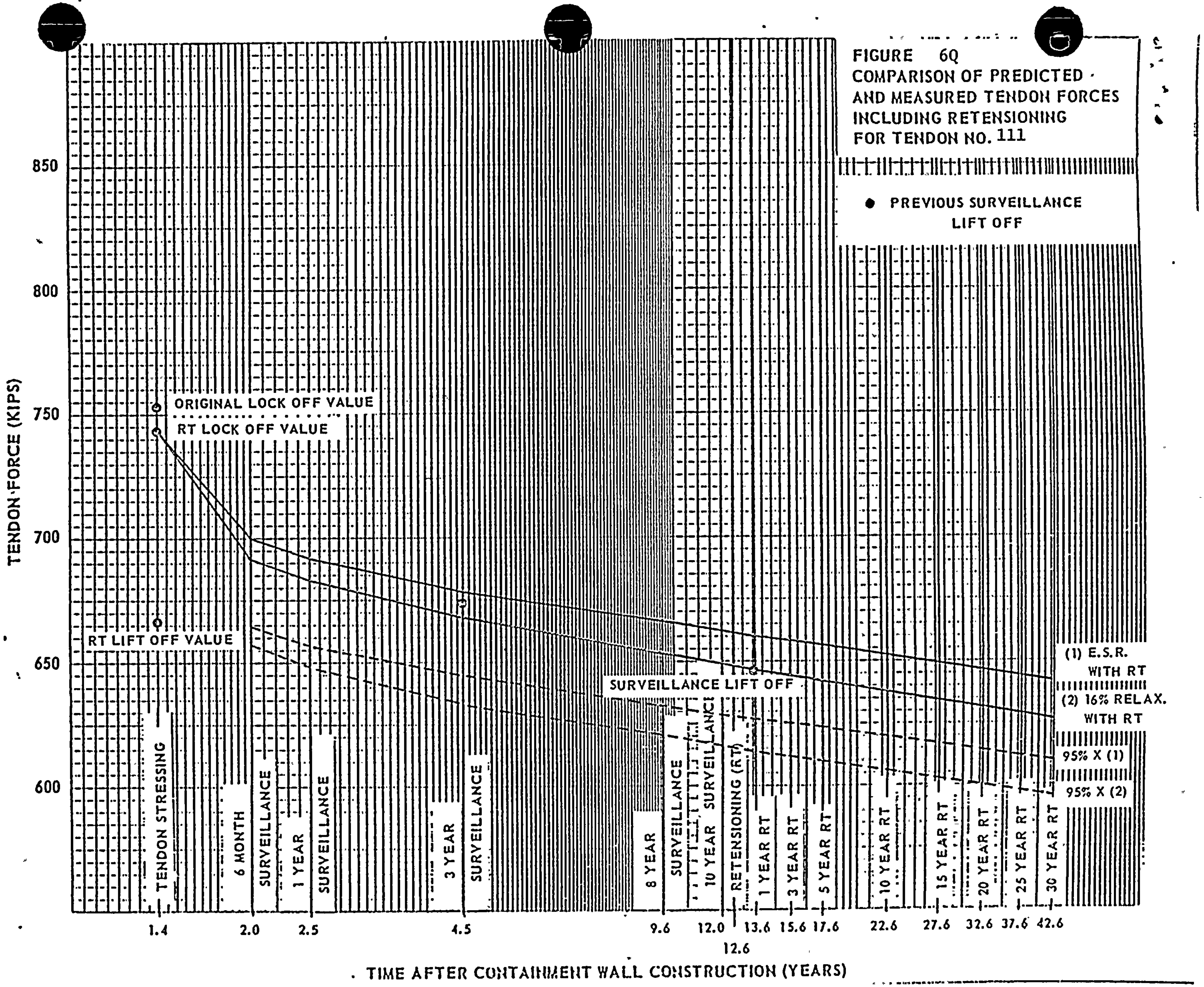


FIGURE 6Q
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES INCLUDING RETENSIONING FOR TENDON NO. 111
● PREVIOUS SURVEILLANCE LIFT OFF
850
800
750
700
650
600
TENDON FORCE (KIPS)
ORIGINAL LOCK OFF VALUE
RT LOCK OFF VALUE
RT LIFT OFF VALUE
SURVEILLANCE LIFT OFF
(1) E.S.R. WITH RT
(2) 16% RELAX. WITH RT
95% X (1)
95% X (2)
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)

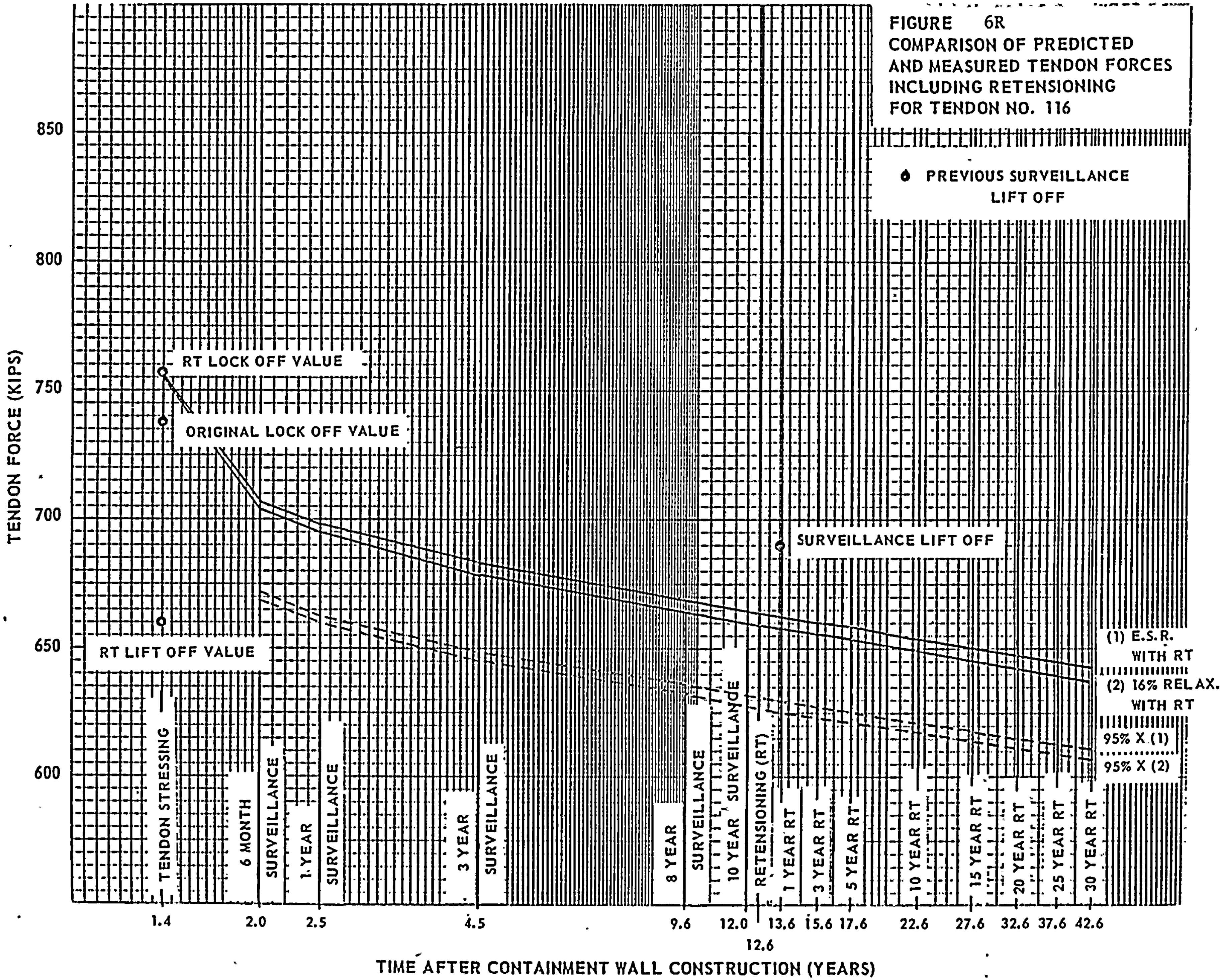


FIGURE 6R
COMPARISON OF PREDICTED AND MEASURED TENDON FORCES INCLUDING RETENSIONING FOR TENDON NO. 116
PREVIOUS SURVEILLANCE LIFT OFF
RT LOCK OFF VALUE
ORIGINAL LOCK OFF VALUE
SURVEILLANCE LIFT OFF
RT LIFT OFF VALUE
(1) E.S.R. WITH RT
(2) 16% RELAX. WITH RT
95% X (1)
95% X (2)
TENDON FORCE (KIPS)
850
800
750
700
650
600
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)

APPENDIX A

STRESS RELAXATION TEST REPORT

Lehigh University

RELAXATION TESTS ON 1/4" PRESTRESSING WIRE

BY

ROGER G. SLUTTER

Fritz Engineering Laboratory

REPORT NO. 200.79.100.5

200.79.100.5

LEHIGH UNIVERSITY
Bethlehem, Pennsylvania 18015
Telephone 215 861-3515

Fritz Engineering Laboratory
Building 13

January 21, 1982

Mr. Ken Murray
Gilbert Associates, Inc.
P. O. Box 1498
Reading, PA 19603

Dear Mr. Murray:

Enclosed is a report on the relaxation tests that we have been doing on 1/4" wire. We put this report together because the testing is substantially completed. We are still continuing all of the wire under load and the 104° F temperature is being maintained in one cabinet.

Please let us know if you need additional copies of the report.

Sincerely yours,

Roger G. Slutter

RGS/df

Enclosure

RELAXATION TESTS ON 1/4" PRESTRESSING WIRE

INTRODUCTION

In March of 1980 relaxation tests were started in Fritz Engineering Laboratory on 1/4" diameter prestressing wire received from the Robert E. Ginna Nuclear Power Station of Rochester Electric and Gas Company. The wire samples were obtained from the tendon surveillance wires in the plant and were ASTM A421 type BA wire (240 ksi UTS).

The relaxation tests were conducted under conditions and procedures meeting ASTM A328-78 specifications in controlled environment cabinets originally constructed for conducting similar tests on 1/2" diameter 7-wire prestressing strands. Fourteen wires were included in the testing program. Tests were conducted at temperatures of 68° and 104° F with initial tension of 0.70 UTS and 0.75 UTS. Some tests were conducted for 10,000 hours while others were under load for a longer period of time. Modifications to a conventional relaxation test procedure were made to simulate loading history of actual tendons in the Ginna Nuclear Power Plant. Guidance for the program was provided by Mr. Jim Fulton and Mr. Ken Murray of Gilbert Associates.

TEST SPECIMENS

Specimen identification numbers were assigned to wire specimens prior to their arrival at Fritz Engineering Laboratory. All of the wires supplied were used in testing except specimen No. 2, which was badly bent in several places along the length. Several other wires were bent at one point along the length. These kinks probably were the result of difficulty in removing the wire from the tendons. In order to determine the effect of these kinks on relaxation, two tests were run for approximately 100 hours in a testing machine at room temperature. A short piece of specimen No. 6 was straight while a similar length of specimen No. 12 was tested with a kink in the center of the gage length of 20 inches. These tests demonstrated that a kink somewhere in the 10 foot gage length in the relaxation tests would have only a negligible effect on the results.

In cutting the specimens down to fit in our cabinets, it was possible to eliminate kinks in several specimens. In the final tests only Specimen Nos. 8 and 15AB had plastically deformed wire within the 10 foot gage length. The deformation in Specimen No. 8 was a large radius bend of approximately 10 feet and 15AB had a kink in the gage length. Specimen Nos. 1, 3 and 5 had jaw marks on the wire but it was possible to keep these outside the gage length by properly selecting the specimen length for testing. In the 68° F cabinet the length of wire under test was 21 feet and in the elevated temperature cabinet the length was 16 feet. The original length as shipped was

approximately 22 feet. Table 1 provides a list of test specimens. Specimen No. 2 is not included since it was never tested.

TESTING PROCEDURE

The cabinets for relaxation tests were constructed of plywood with insulation on the inside surface and windows for access to instrumentation. The 68^{o} cabinet was equipped with an air conditioning system and the two cabinets for elevated temperature were provided with heating mats and cicrulating fans.

Each wire was placed in a separate frame consisting of two angles 5" x 3-1/2" x 3/8" with spacers and 3/4" thick bearing plates at each end. Wires were held at each end using chucks for 1/2" diameter 7-wire strand with one jaw removed. These chucks were tested in a testing machine prior to use to be sure that they would not slip with time under load. The frames were stored on steel racks so that each frame was free to expand and contract independent of the others. Chucks which ancored the wires were centered on the center of gravity of the pair of angles with the wire between the angles.

Each specimen had a 10 foot gage length near midspan. At each end of the gage length steel clamps were attached to the wire and to a gage length rod supported on rollers resting on top of the pair of angles. Figure 1 shows the dial gage mounted on one end of the rod with plunger bearing on the bracket at one end of the 10 foot gage length. This photograph was taken through the window in the cabinet located near the jacking end of the wire. The dial gage is

graduated in mils and enables the 10 foot gage length to be set within ± 0.000002 in/in. The brackets were attached to the wire by bolting spring loaded plates on each side of the wire.

Loads were read by a 20 kip BLH load cell incorporated in the pulling rod of a 30 ton hydraulic ram. This loading assembly is shown in Fig. 2. A threaded lug attaches to each chuck and is engaged by a pulling yoke attached to the load cell. The hydraulic ram is a center hole ram and load is applied by a pull rod connected to the load cell and passing through the ram. The BLH load cell was carefully calibrated on one of our testing machines to read the load directly in pounds.

During initial tensioning of each specimen the initial load for the relaxation test was applied in five equal increments over a period of five minutes. When the exact load was reached at the end of five minutes, the dial gage on the 10 foot gage length was read. Thereafter, all loads were read at the same dial reading. Thus any slip of the grips would not affect the test results although no slip of grips was observed. In order to hold the correct load in each wire when the jacking assembly was removed, shims were carefully fitted between the chuck and bearing plate by trial and error until the dial gage read essentially the same as the specified reading for measuring the load. The correct shims could be found so that the dial reading was within ± 0.002 inch of the load reading value.

During the first 24 hours the load was held by the hydraulic ram with the load cell under load. After the 24 hour reading the shims

were fitted and the jacking assembly was removed for use on other specimens. Since the load cell was not under load it was possible to check zero settings and check the calibration of the load cell at any time. The zero load setting was checked each day that readings were taken.

The procedure for taking readings after the first 24 hours was to install the jacking assembly in position by means of a hand operated fork lift. Load was applied until shims could be removed. The gage length was adjusted to the correct value and the load cell was read. Tension was then increased until shims could be replaced and the jacking load was released. It was necessary to overload approximately 225 lbs. or approximately 2% of UTS for each reading. This overload was applied for approximately one minute for each reading. The effect of this overloading for readings is considered to be negligible in view of the small magnitude and short duration. The advantage of this procedure is that it minimizes the time that the load cell is loaded and thus eliminates problems related to stability of the load cell.

Temperature was maintained within $\pm 1^\circ$ F in the cabinet at 104° F and within $\pm 2^\circ$ F in the 68° F cabinet. The heating control was more precise than the air conditioning control depending on the ambient temperature. It was not necessary for the temperature to be so exact but experience has shown that the wire and angles do not change length at the same rate during a temperature change. Therefore, the temperatures were held very exact to eliminate the possibility that readings might be taken while the temperature was changing. It was

found that a rapid change of temperature could produce an error of 12 lbs. per ^{o}F in the load.

All data was kept in a date book with the following being recorded each time readings were taken.

Date
Watch Time
Time from Start of Test
Dial Gage Reading (always constant)
Load
Temperature
% Load of Load

Since relaxation data is plotted on a log scale for time, the readings were taken at time intervals that would be properly spaced on a log scale. Table 2 gives a tentative minimum schedule for taking readings. Constraints of working hours, weekends, and holidays resulted in the readings being taken at slightly different times for each specimen. However, for the first week of each test the schedule was carefully followed.

TEST RESULTS

As data was accumulated the pattern of the curves became obvious and additional test plans were evolved through discussions between Fritz Engineering Lab and Gilbert personnel. Since these additional tests complicate the interpretation of the test curves, an outline of the entire program as completed is given in Table 3. Only specimens 1, 6 and 11 were allowed to remain as initially tensioned.

For all other specimens there was an adjustment of tension or temperature to simulate the load history of the tendons.

Specimen Nos. 5 and 15AB were unique in that they were installed in the unused side of the 104° F cabinet with no heaters and the window open. Due to heating in the opposite side of the cabinet it was necessary to begin these tests at 80° F instead of 68° F. Temperature was increased to 104° F after 1000 hours to simulate the effect of a vessel being put into operation. After 8640 additional hours the wires were returned to 80° F or below so that the effect of this temperature change could be observed.

Specimen No. 13 exhibited very low losses compared to all other specimens. This specimen was released after 13,270 hours and allowed to set at no load for a week. It was then retensioned to the original load to observe the results. All other specimens were retensioned without unloading.

The data from all tests are plotted in Figs. 3 through 11 in the form of percent loss of load as ordinate and time in hours as abscissa. A log scale was used for both percent loss and time because of the advantage offered in checking each new data point as it was obtained. The specimens are grouped for convenience in comparing different wires under comparable conditions of loading or temperature.

Figures 7, 8 and 10 show comparison of the retensioned curve and the original relaxation curve for Specimen Nos. 7, 9 and 13. Retension curves for other specimens are shown on the same graph with

the family of original curves. The curves showing the effect of temperature change are given for Specimen Nos. 5 and 15AB in Fig. 11. The effect of returning the wires to a temperature of 80° F can not be plotted in Fig. 11 because of the time scale. In a period of 800 hours following the temperature reduction there was no change in load in the wires.

SUMMARY AND CONCLUSIONS

The wire under test was expected to exhibit a loss of 15% at 40 years. This is based on room temperatures. Projections to 40 years from our results for wires at room temperature indicate that Specimen No. 4 would reach 13%, Specimen No. 7 would reach 15%, Specimen No. 12 would reach 5% and Specimen No. 15AB10 would reach 7.5%. However, the tests conducted at 104° F are probably more indicative of loss to be expected in actual tendons. The 40 year prediction for 104° F specimens is that Specimen No. 3 would reach 15%, Specimen No. 5 would reach 16%, Specimen No. 8 would reach 20%, and Specimen No. 13 would reach 9.5%. Specimen No. 13 does not seem to be typical and the average projected 40 year loss would appear to exceed 18% at 40 years.

The effect of retensioning of the wires at any time from 1000 hours to 11,600 hours was considerable and would appear to reduce the loss to approximately a 12% level or lower depending on the time at which retensioning was performed. Retensioning at 100 hours on Specimen No. 9 was not conclusive in that the loss of the retensioned projects to approximately 14.5% in 40 years.

Other conclusions from analysis of this data are:

1. Tensioning to 0.75 UTS initially should not be done because losses are very high and the actual wire tension becomes lower than for wires tensioned to only 0.70 UTS after a period of time.
2. Temperature increases that occur at some time after wires are tensioned have a significant effect and essentially shift the amount of loss to the curve for the higher temperature.
3. The variation in the rleaxation rate among wires is significant, but an increase in temperature significantly increases the relaxation rate in all wires.
4. A temporary overstress of 6% for short durations which occur in tendon surveillance checks does not significantly affect relaxation loss.
5. A drop in temperature appears to produce a delay in the relaxation rate. More data would be necessary to substantiate this conclusion.

The testing program is continuing in that none of the wires have been unloaded. The 104^{o} F. temperature is being maintained constant, but the other wires are being held under load at whatever the room temperature is.

TABLE 1 TEST SPECIMENS

Specimen No.	Tendon No.	Position from Top of Tendon (ft.)	Initial Test Temperature (^oF)
1	51	0 - 23	104
3	51	46 - 69	104
4	51	69 - 91.33	68
5	51	91.33 - 114.33	80
6	76	0 - 23	104
7	76	23 - 46	68
8	76	46 - 69	104
9	76	69 - 91.67	104
10	76	91.67 - 114.67	104
11	150	0 - 23	104
12	150	23 - 46	68
13	150	46 - 69	104
15AB	150	91.67 - 114.67	80
15AB10	150	69 - 91.67	68

TABLE 2 READING INTERVALS FOR RELAXATION READINGS

Reading	Time from Start of Test	Reading	Time from Start of Test
1	2 min.	11	4 days
2	6 min.	12	8 days
3	30 min.	13	16 days
4	1 hr.	14	29 days
5	2 hrs.	15	6 weeks
6	4 hrs.	16	12 weeks
7	7 hrs.	17	24 weeks
8	20 hrs.	18	12 months
9	40 hrs.	19	21 months
10	70 hrs.	20	28 months

TABLE 3 DESCRIPTION OF TESTS

Specimen No.	Initial Test Temperature (°F)	Initial Tension (lbs.)	Description of Tests
1	104	8,840*	Continued relaxation test beyond 10,000 hrs. with no adjustments in load
3	104	8,250	Retensioned to original load after 6000 hrs.
4	68	8,240	Retensioned to original load after 1000 hrs.
5	80	8,240	Temperature was raised to 104° F after 1000 hrs. Temperature was reduced to 80° F after 8640 hrs. at 104° F
6	104	8,840	Continued relaxation test beyond 10,000 hrs. with no adjustments in load
7	68	8,240	Retensioned to original load after 11,600 hrs.
8	104	8,250	Retensioned to original load after 10,190 hrs.
9	104	8,240	Retensioned to original load after 100 hrs.
10	104	8,240	Retensioned to original load after 1000 hrs.
11	104	8,840	Continued relaxation test beyond 10,000 hrs. with no adjustments in load
12	68	8,240	Retensioned to original load after 5500 hrs.
13	104	8,240	Retensioned to original load after 13,270 hrs. Unloaded and retensioned after one week to original load
15AB	80	8,240	Temperature was raised to 104° F after 1000 hrs. Temperature was reduced to 80° F after 8640 hrs. at 104° F
15AB10	68	8,240	The effect of 6% overstress was studied after 10,000 hrs.

*8840 lbs. corresponds to 0.75 UTS and 8240 or 8250 corresponds to 0.70 UTS.

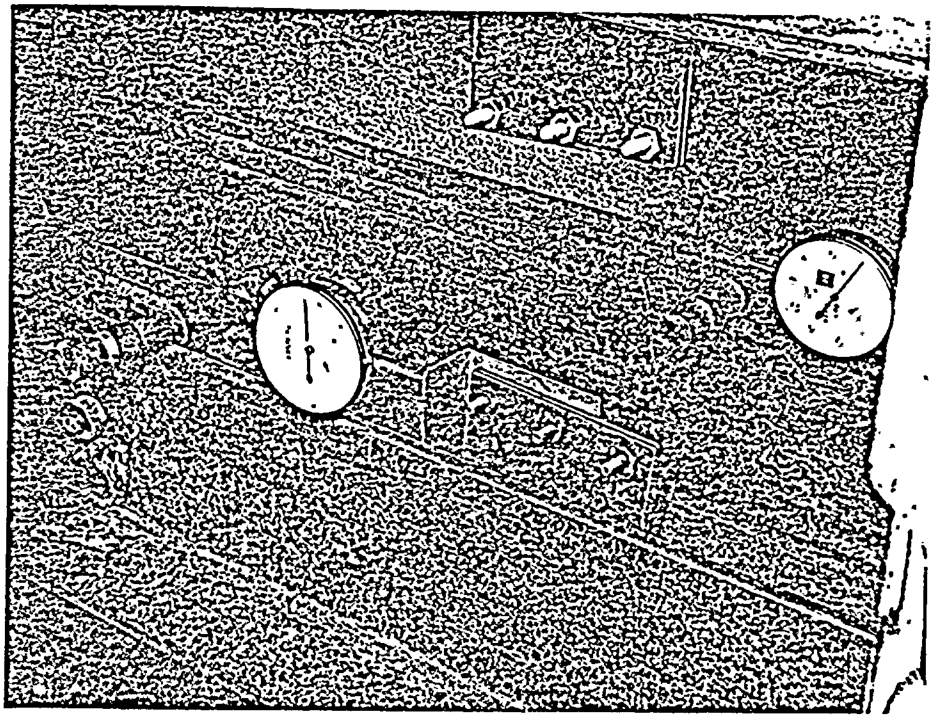


Fig. 1 Dial Gage and Gage Length Rod

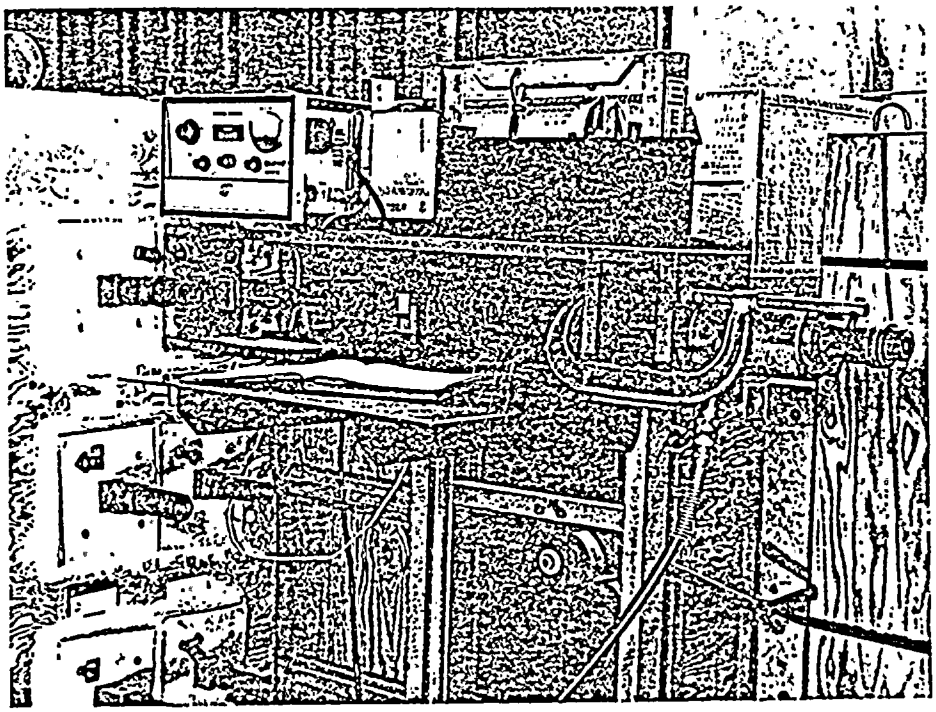


Fig. 2 Loading System for Tensioning and Checking Load

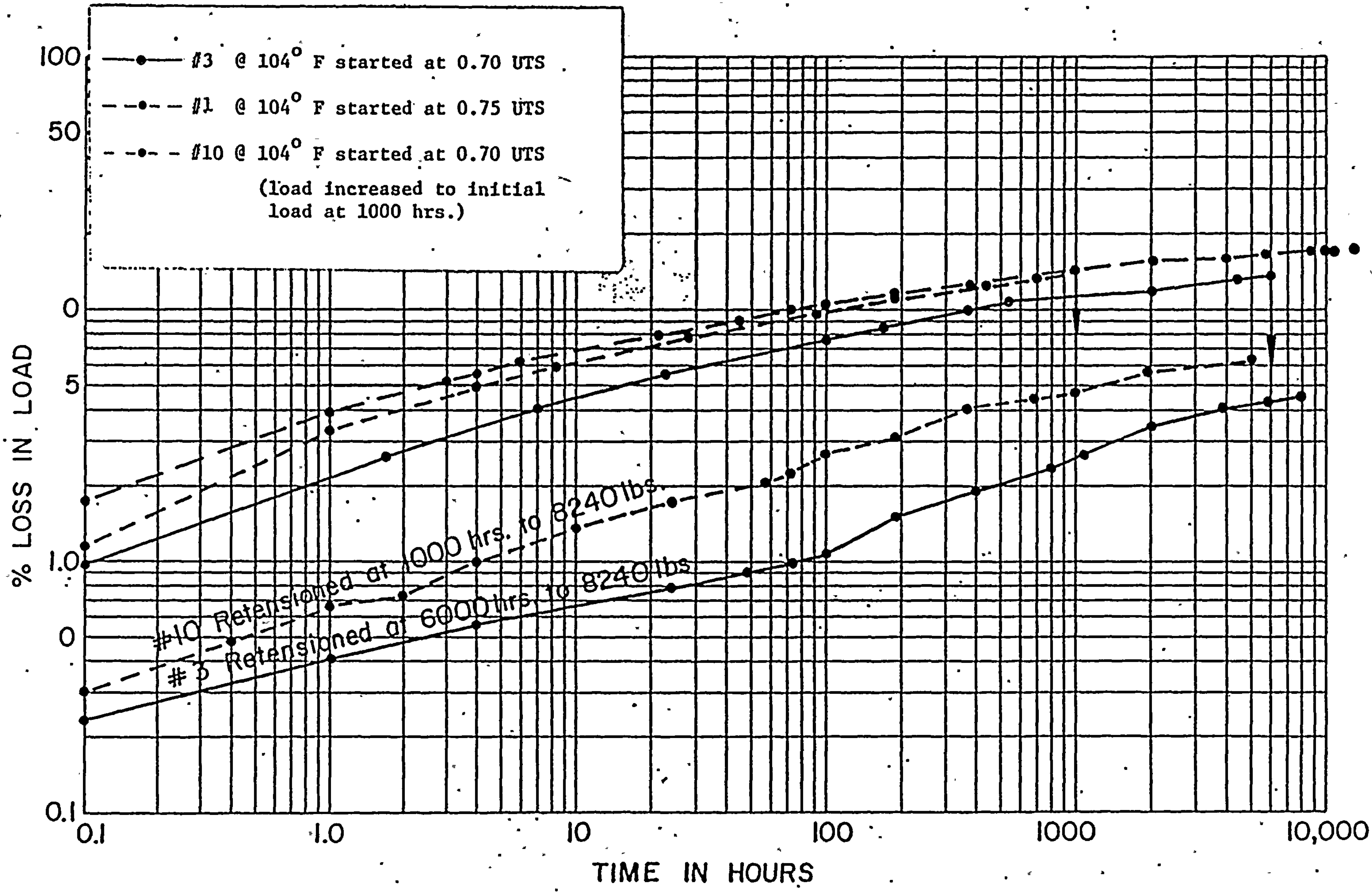
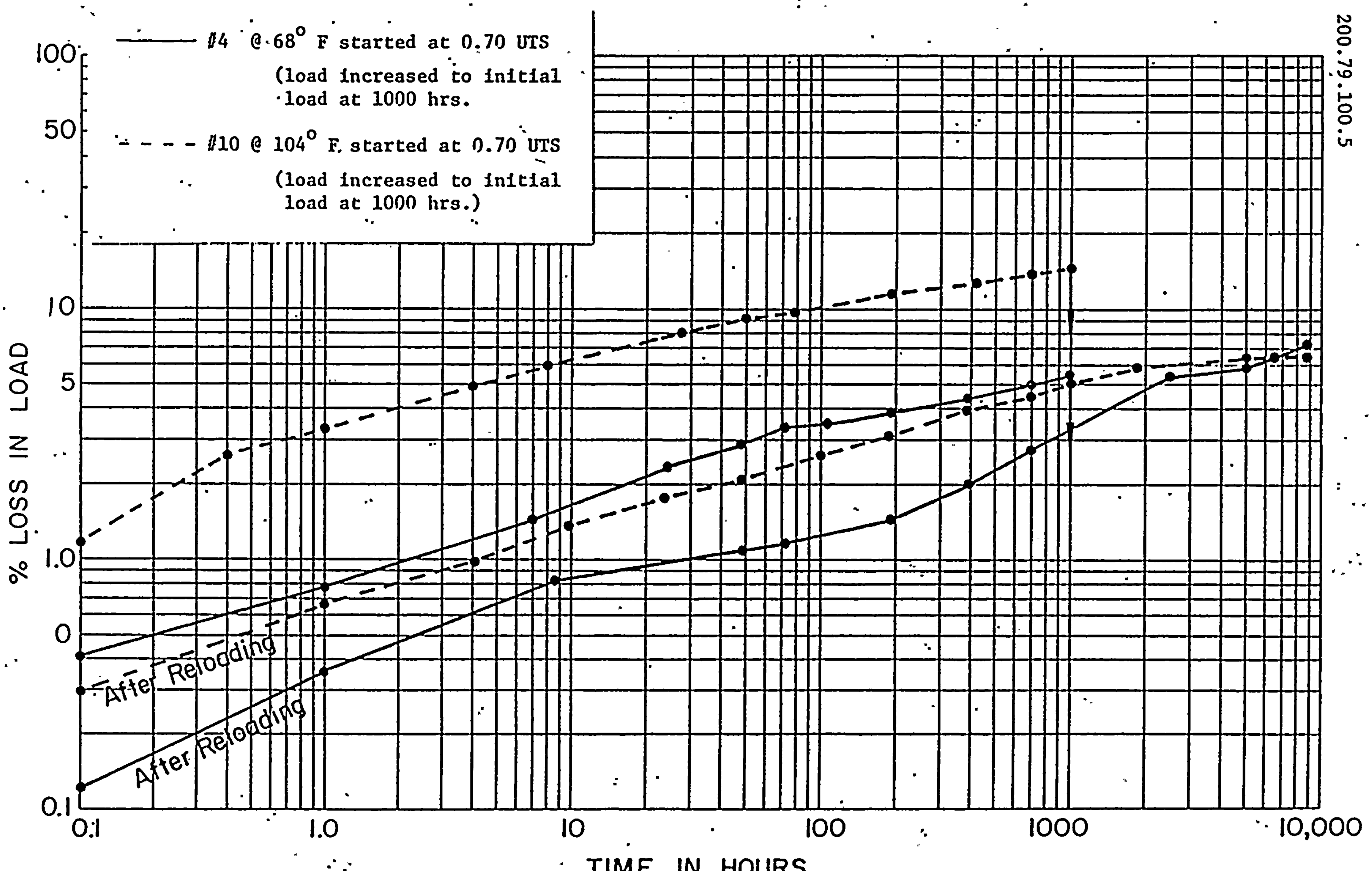


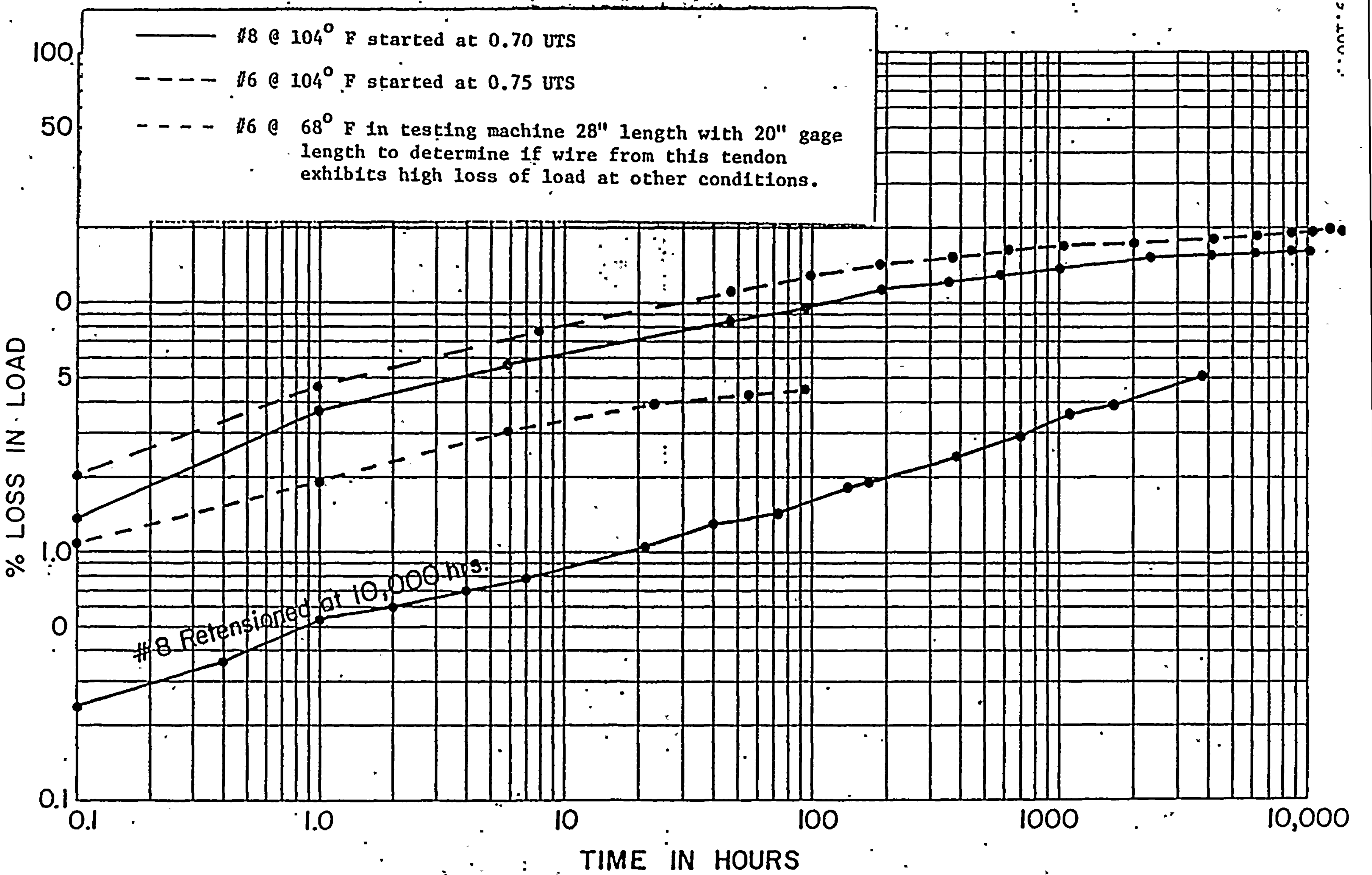
Fig. 3

200.79.100.5



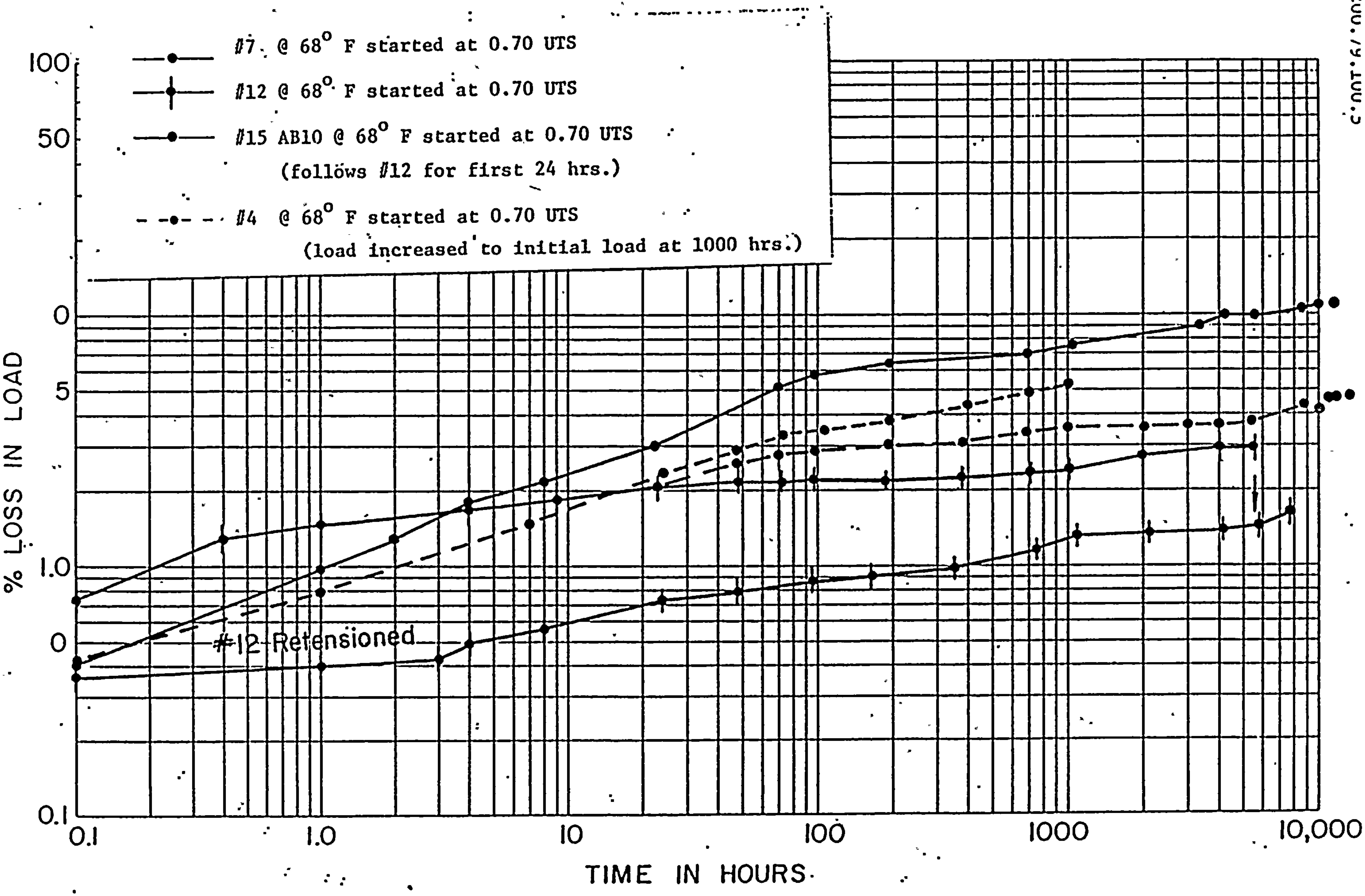
#4 @ 68° F started at 0.70 UTS
(load increased to initial load at 1000 hrs.
#10 @ 104° F started at 0.70 UTS
(load increased to initial load at 1000 hrs.)
100
50
10
5
1.0
0
0.1
% LOSS IN LOAD
After Reloading
After Reloading
0.1
1.0
10
100
1000
10,000
TIME IN HOURS
200.79.100.5

Fig. 4



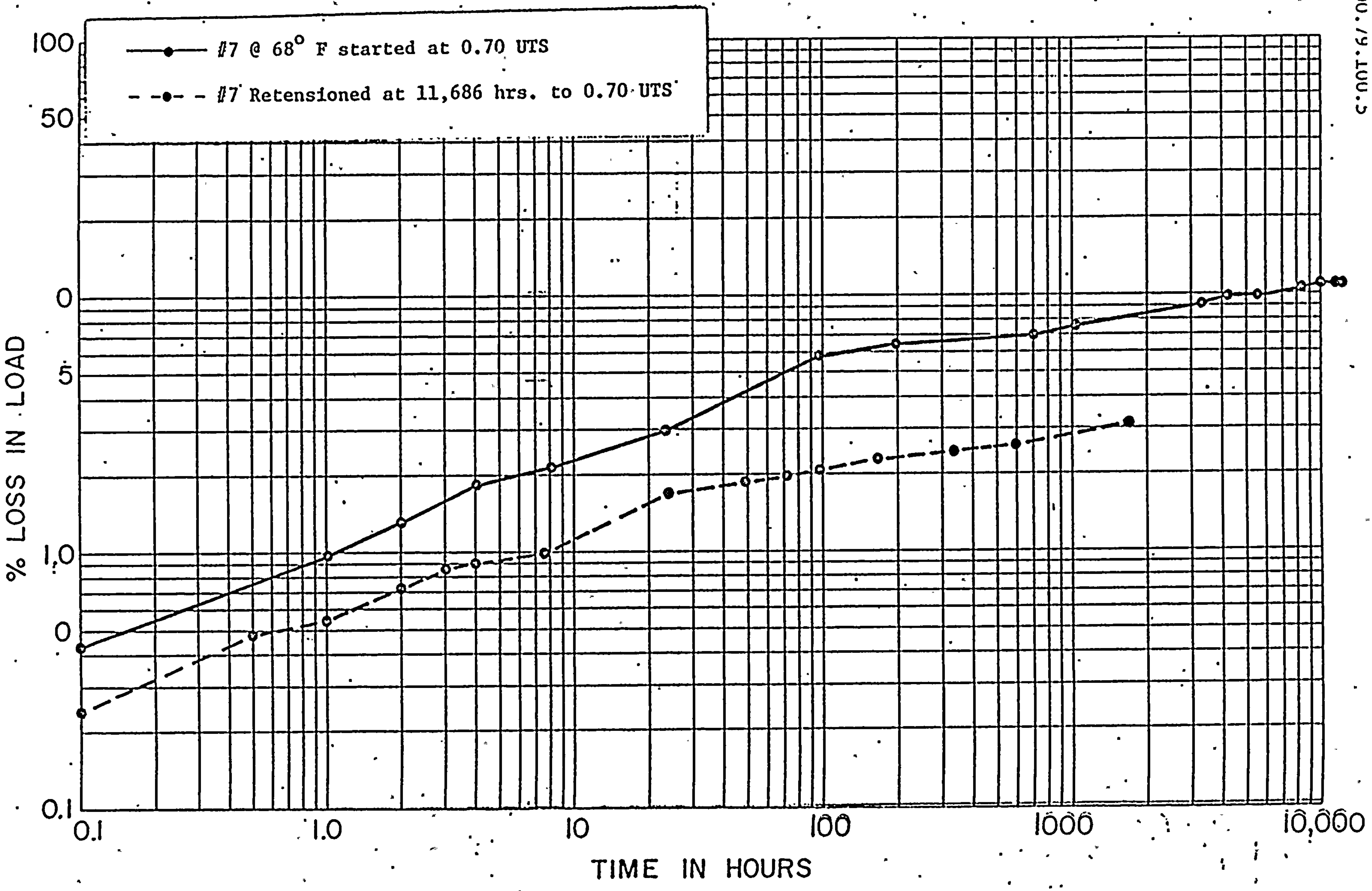
#8 @ 104° F started at 0.70 UTS
#6 @ 104° F started at 0.75 UTS
#6 @ 68° F in testing machine 28" length with 20" gage length to determine if wire from this tendon exhibits high loss of load at other conditions.
#8 Retensioned at 10,000 hrs.
% LOSS IN LOAD
100
50
0
5
1.0
0
0.1
0.1
1.0
10
100
1000
10,000
TIME IN HOURS

Fig. 5



#7 @ 68° F started at 0.70 UTS
#12 @ 68° F started at 0.70 UTS
#15 AB10 @ 68° F started at 0.70 UTS
(follows #12 for first 24 hrs.)
#4 @ 68° F started at 0.70 UTS
(load increased to initial load at 1000 hrs.)
#12 Retensioned
% LOSS IN LOAD
TIME IN HOURS

Fig. 6.



#7 @ 68° F started at 0.70 UTS
#7 Retensioned at 11,686 hrs. to 0.70 UTS
% LOSS IN LOAD
TIME IN HOURS
100
50
0
5
1.0
0
0.1
0.1
1.0
10
100
1000
10,000

Fig. 7

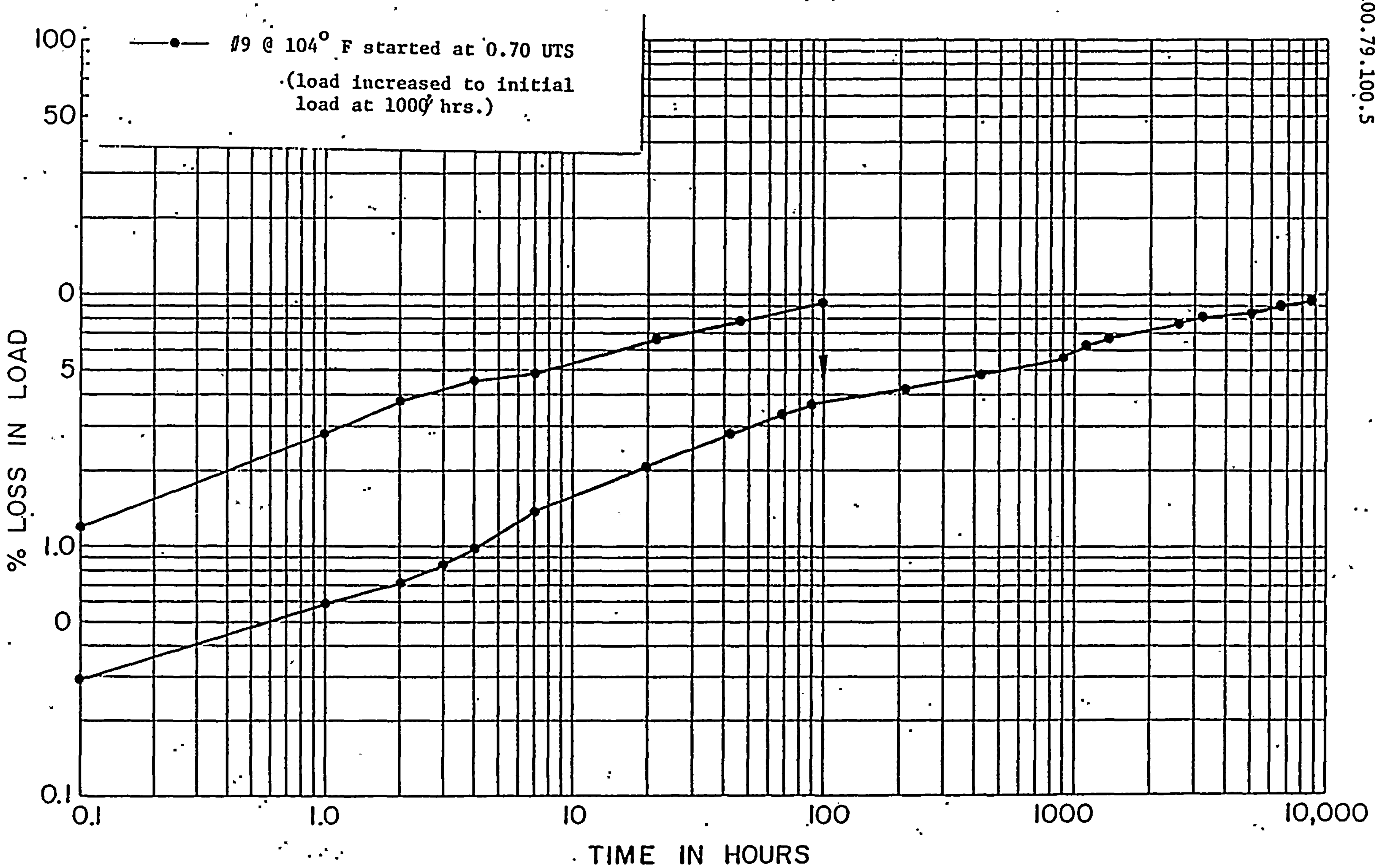
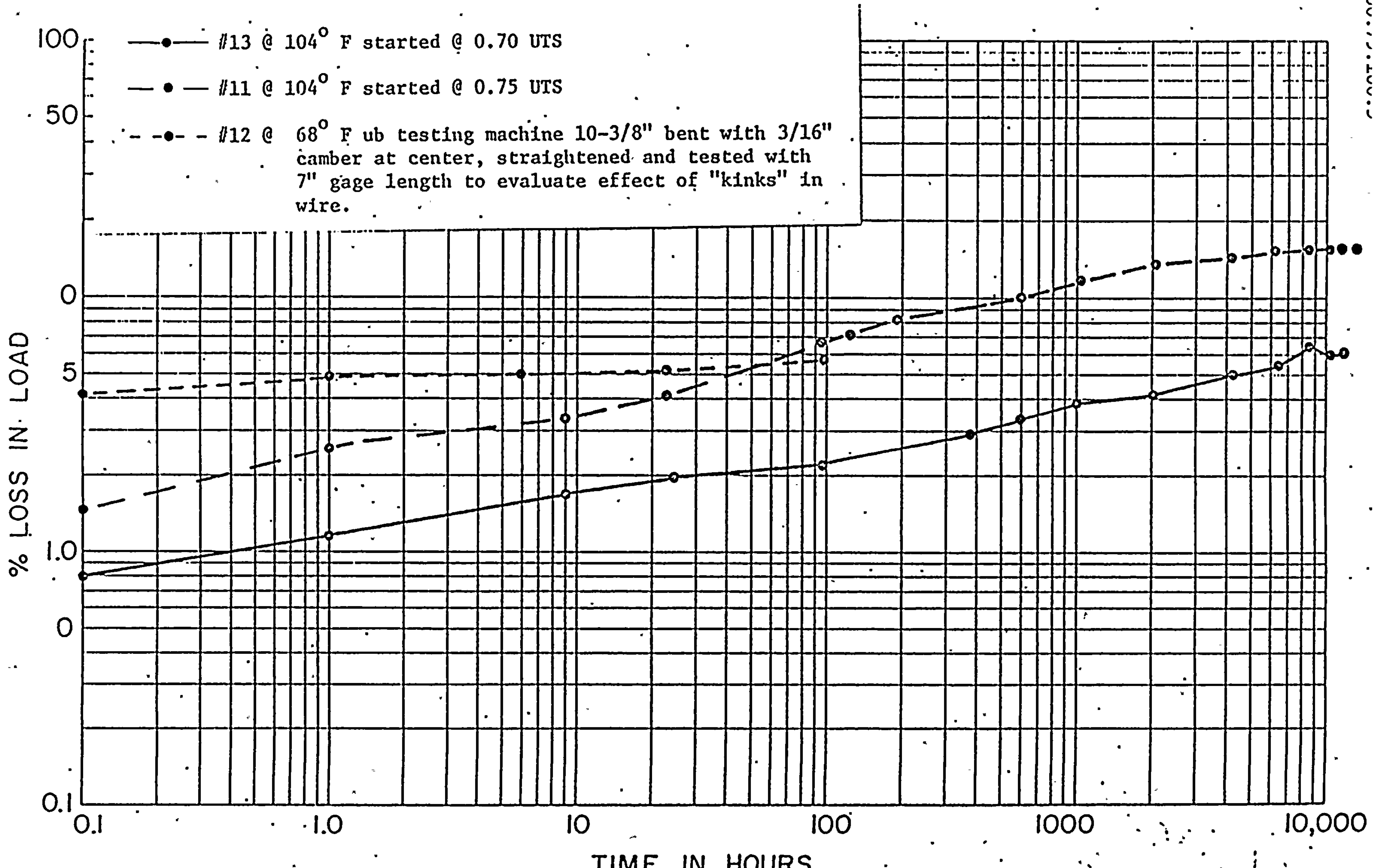

#9 @ 104° F started at 0.70 UTS
(load increased to initial load at 1000 hrs.)
100
50
0
5
1.0
0
0.1
0.1
1.0
10
100
1000
10,000
% LOSS IN LOAD
TIME IN HOURS

Fig. 8



#13 @ 104° F started @ 0.70 UTS
#11 @ 104° F started @ 0.75 UTS
#12 @ 68° F ub testing machine 10-3/8" bent with 3/16" camber at center, straightened and tested with 7" gage length to evaluate effect of "kinks" in wire.
100
50
0
5
1.0
0
0.1
% LOSS IN LOAD
0.1
1.0
10
100
1000
10,000
TIME IN HOURS

Fig. 9.

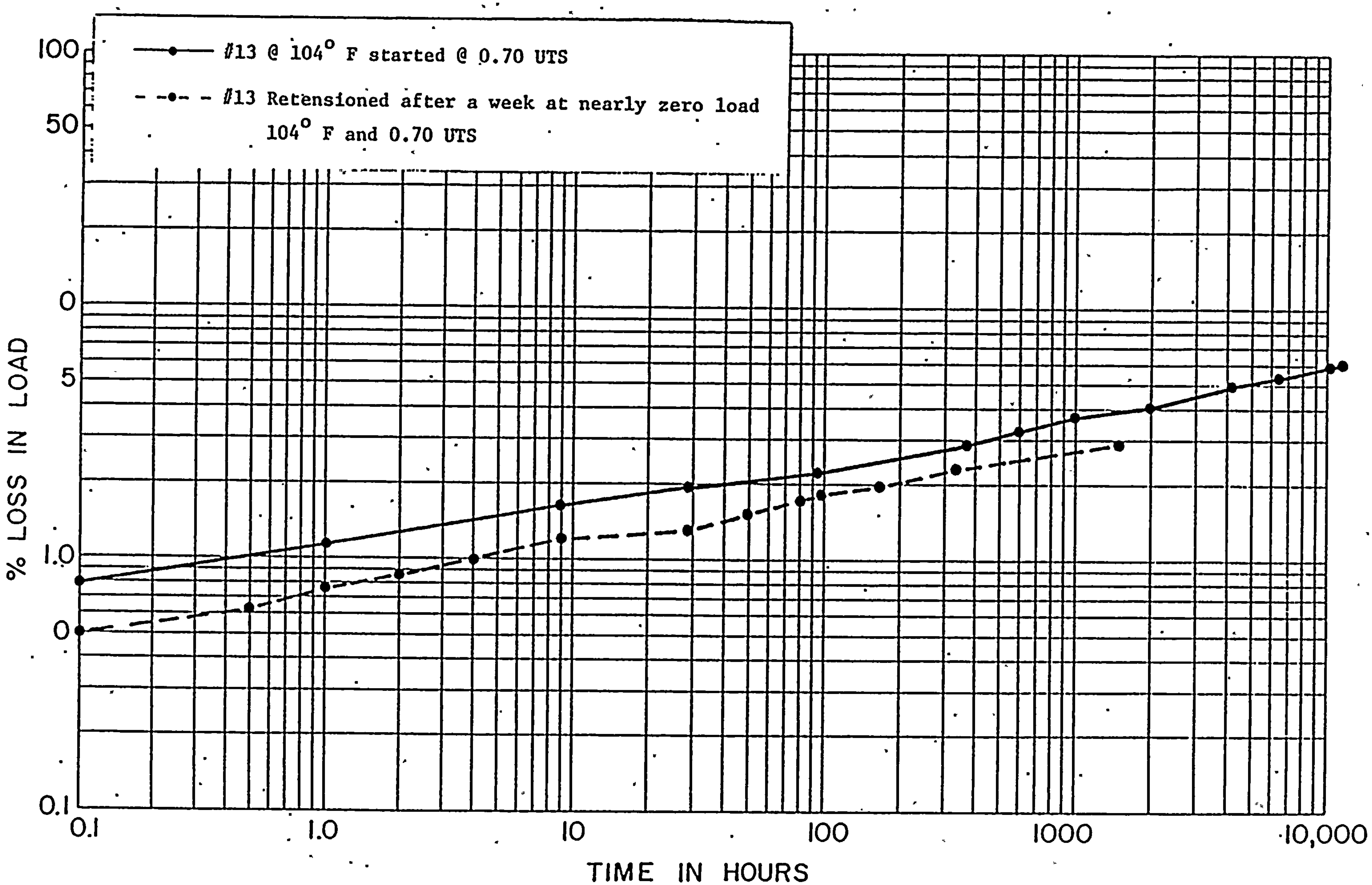

#13 @ 104° F started @ 0.70 UTS
#13 Retensioned after a week at nearly zero load 104° F and 0.70 UTS
% LOSS IN LOAD
100
50
0
5
1.0
0
0.1
0.1
1.0
10
100
1000
10,000
TIME IN HOURS

Fig. 10

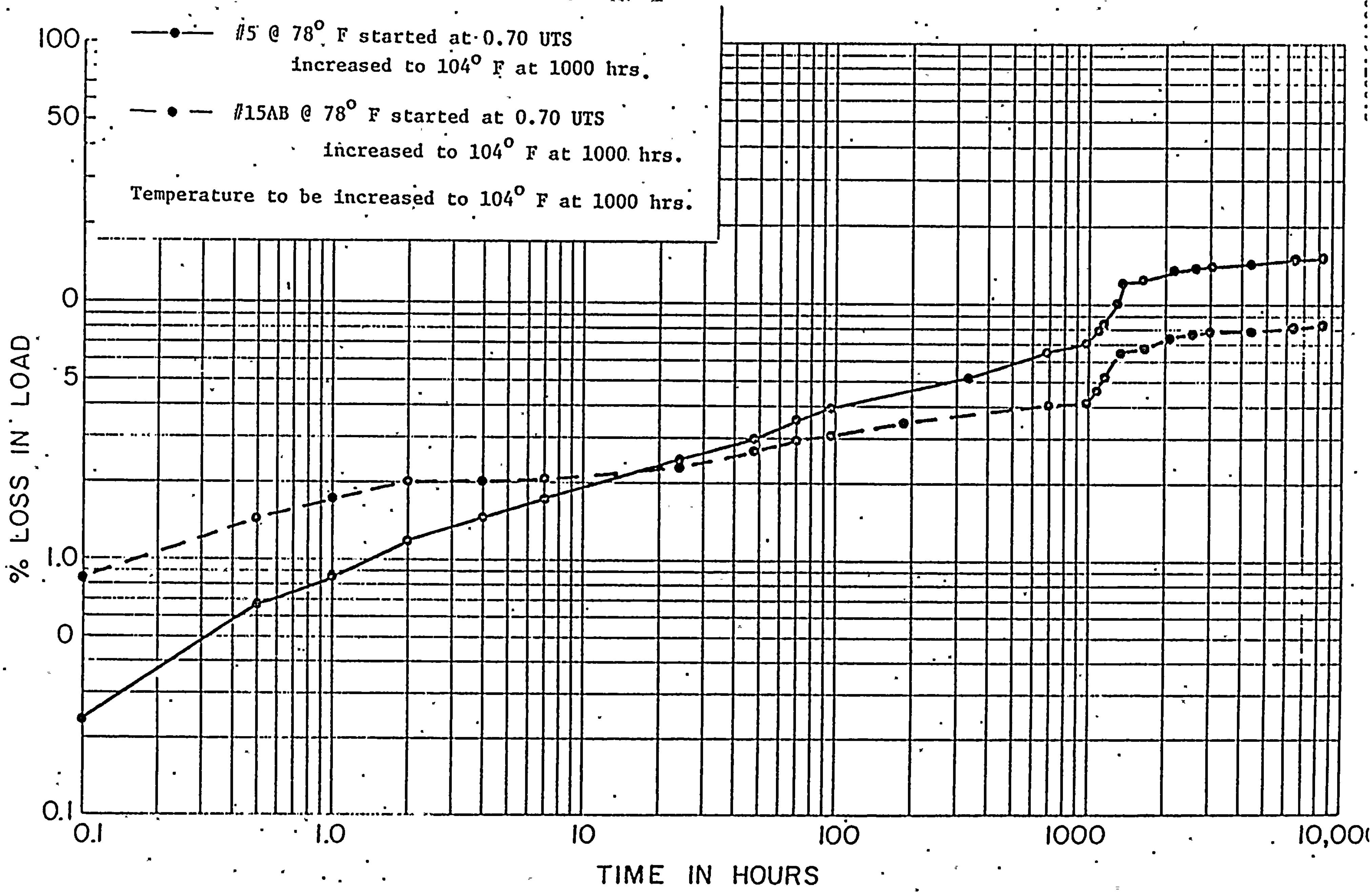

#5 @ 78° F started at 0.70 UTS
increased to 104° F at 1000 hrs.
#15AB @ 78° F started at 0.70 UTS
increased to 104° F at 1000 hrs.
Temperature to be increased to 104° F at 1000 hrs.
% LOSS IN LOAD
100
50
0
5
1.0
0
0.1
0.1
1.0
10
100
1000
10,00
TIME IN HOURS

Fig. 11

200.81.100.5

LEHIGH UNIVERSITY
Bethlehem, Pennsylvania 18015

Fritz Engineering Laboratory
Building 13

March 23, 1983

Mr. S. S. Shieh
Gilbert Associates
Building G2A 3143
P. O. Box 1498
Reading, PA 19603

Dear Mr. Shieh:

Enclosed is a copy of the data taken since August 17, 1981 on the relaxation tests of 1/4 inch diameter wire.

Sincerely yours,

Roger G. Slutter

RGS/df

Enclosures

APPENDIX A

LEHIGH UNIVERSITY
Bethlehem, Pennsylvania 18015

Fritz Engineering Laboratory
Building 13

200.81.100.5

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Sincerely yours,

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RGS/df

Enclosures

4-[illegible]-80	0	9:55	0.528	8840	104[illegible]	0		[illegible] reading
	1 min	9:56	0.528	8780	104	0.679		DIAL AT 0.540 7375
	2 min	9:57	0.528	8745	104°	1.07		DIAL AT 0.535 7425
	3 min	9:58	0.528	8735	104°	1.19		DIAL AT 0.530 - 7475
	4 m	9:59	0.528	8710	104°	1.47		
	5	10:00	0.528	8695	104.0	1.61		
	6	10:01	0.528	8685	104.0	1.75		#1
	30	10:25	0.528	8545	104.0	3.34		
	1 hr.	10:55	0.528	8490	104.0	3.96		
	3 hr.	12:55	0.528	8377	104°	5.24		
	4-hr.	13:55	0.528	8345	104°	5.60		
	7 hr.	4:55	0.528	8290	104°	6.22		
4-30-80	22 hr.	7:55	0.528	8145	104°	7.86		
5-1-80	45.4 hr	7:25	0.528	8042	104°	9.03		
5-2-80	722	10:10	0.528	7955	104°	10.0		
5-3-80	95.9	9:45	0.528	7920	104°	10.4		
[illegible]	8 days	8:15	0.528	7805	104°	11.71		
[illegible]	16 days	7:25	0.528 0.500	7720	104°	12.67		
[illegible]	24 days (685)	9:10	0.500	7635	104°	13.6		
6-16-80	48 DAY (1152)	9:55	0.500	7565	104°	14.4		
7-29-80	12 wk	8:15	0.500	7470	104°	15.5		
10-15-80	21 wk (1033)	10:55	0.535 0.535	7425	104°	16.0		
12-29-80	5856 hrs.	8:30	0.535	7380	104°	16.52		
4-29-81	1 yr. (8760)	9:55	0.535	7320	104°	17.2		
6-30-81	10,224	7:45	0.535	7290	104°	17.5		
8-17-81	11,376	9:15	0.535	7275	104°	17.7		
11-14-81	13,510	9:30	0.535	7260	104°	17.9		
1-30-82	15,358	8:40	0.535	7255	104°	17.9		
1-21-83	23,402	7:35	0.535	7180	100°	18.8		

#3

DATE	TIME	WATCH TIME	DIAL	LOAD	TEMP.	% LOSS
12-22-80	6 min	8:10	.2450	8220	103°	0.24
	30 min	8:34	.2450	8215	103°	0.30
	1 hr.	9:04	.2450	8205	103°	0.42
	2 hr.	10:04	.2450	8195	103°	0.55
	3 hr.	11:04	.2450	8195	103°	0.55
	4 hr	12:04	.2450	8195	103°	0.55
	9 hr	17:04	.2450	8195	103°	0.55
12-23-80	24 hrs	8:10	.2450	8175	103°	0.79
12-24-80	48 hrs	8:05	.2450	8160	103°	0.91
12-25-80	74 hrs	10:05	.2450	8160	103°	0.97
12-26-80	97 hrs	9:15	.2450	8150	103°	1.09
12-29-80	8 day (192)	8:15	.2450	8115	103°	1.52
1-7-81	386	10:20	.2450	8080	103°	1.94
1-24-81	792	8:00	.2450	8045	104°	2.37
2-[illegible]-81	1080	8:05	.2450	8015	104°	2.73
3-16-81	2016	9:26	.2450	7960	104°	3.52
6-1-81	3840	6:45	.2450	7905	104°	4.06
8-12-81	5688	10:05	.2450	7880	104°	4.37
11-14-81	7820	9:35	.2450	7860	104°	4.61
1-30-82	9670	8:45	.2450	7850	104°	4.85
1-21-83	18214	7:25	2450	7745	100°	6.01

JACKED TO 0.158 TO SET SHIMS. .014 OVER LOAD

#4

ATE	TIME	WATCH TIME	DIAL	LOAD	TEMP	% LOSS
-18-80	2 h	10:20	0.1255	8225	67°	0.18
	6 h	2:30 pm	0.1255	8220	67°	0.24
	8½ h.	4:45	0.1255	8170	670	0.85
9-80	24	1:50	0.1255	8200	67°	0.49
20-80	48	8:15	0.1255	8150	66°	1.09
21-80	72	9:45	0.1255	8145	67°	1.15
22-80	4 DAY 96	8:20	0.1255	8140	68°	1.21
-26-80	8 days 192	9:55	0.1255	8135	68°	1.27
-4-80	16 DAY 384	10:45	0.1255	8070	66°	2.06
-19-80	29 DAY 696	16:20	0.1255	8000	67°	2.91
-30-80	6 weeks ...3	8:40	0.1255	7960	68°	3.40
-12-81	3,509	13:10	0.1255	7800	66°	5.34
18	5,087	7:02	0.1255	7760	67°	5.82
-17-81	6551	8:08	0.1255	7720	68°	6.31
-14-8	8690	8:40	0.1255	7640	68°	7.28
-30-82	10,585	10:55	0.1255	7630	68°	7.40
-22-82	11,137	17:25	0.1255	7620	68°	7.52
-23-82	0		0.040	8240	70°	
	1 min	10:14	0.040	8230	70°	
	2 min		0.040	8225	70°	
	3 min		0.040	8230	70°	
	4 min		0.040	8230	70°	
	5 min		0.040	8225	70°	
	6 min		0.040	8215	70°	

#5

DATE	TIME	WATCH TIME	DIAL	LOAD	TEMP	% Loss
12-29-80	645 hrs	9:30	0.600	7210	104°	12.50
1-17-81	1104 hrs	16:00	0.600	7130	104°	13.47
2-13-81	1752	9:05	0.600	7120	104°	13.59
2-26-81	2014	16:40	0.600	7080	104°	14.08
24 week 6-1-81	4344	6:35	0.600	7020	103°	14.80
8-17-81	6192	10:25	0.600	6990	104°	15.17
11-14-81	8330	9:55	0.600	6970	104°	15.41
11-27-81	8640	8:00	0.600	6970	104°	15.41
11-27-81		8:30	0.600	6980	95°	
11-27-81		9:10	0.600	6980	85°	
11-27-81		10:35	0.600	6990	79°	
11-28-81		11:45	0.600	7020	74°	
[illegible]4-81		15:30	0.600	7005	75°	
12-29-81	9408	15:30	0.600	7010	76°	
1-30-82	10225	7:50	0.600	7005	75°	

20

6

TEMPERATURE = 104°

INITIAL LOAD = 8340 lbs.

STARTING DATE = 3-31-80

DATE	TIME	WATCH TIME	DIAL	LOAD	TEMP	% Lo
3-31-80	0	8:48	0.2515	8340 lbs.	103°	0
	1 min	8:49	0.2515	8780	103°	0.6
	2 min	8:50	0.2515	8745	103°	1.0
	3 min	8:51	0.2515	8720	103°	1.3
	4 min	8:52	0.2515	8695	103°	1.6
	5 min	8:53	0.2515	8675	103°	1.8
	6 min	8:54	0.2515	8660	103°	2.0
	30 min.	9:18	0.2515	8505	103°	3.7
	1 hr	9:48	0.2515	8425	103°	4.6
	2 hr	10:48	0.2515	8320	103°	5.8
	4 hr	12:48	0.2515	8236	103°	6.8
	6 hr	14:48	0.2515	8190	103°	7.4
	8 hr.	16:48	0.2515	8140	103°	7.9
4-1-80	23 hrs.	7:45	0.2515	7990	103°	9.6
4-2-80	48.1 hrs	8:55	0.2515	7835	104°	11.36
4-3-80	71 hrs	7:50	0.2515	7755	105°	12.2
4-4-80	4 days	8:25	0.2515	7685	104	13.0
4-5-80	5 days	8:45	0.2515	7655	105	13.4
4-8-80	8 days	8:00	0.2515	7605	105	14.1
4-16-80	16 day	8:15	0.2515	7480	104°	15.
4-30-80	719.5	8:05	0.2515	7385	104°	16.
5-14-80	44 DAY 1056	8:13	0.2515.	7320	104°	17.
6-23-80	12 week	14:55	0.2515	7285	104°	17.
9-18-80	4,104 24 week + 3 DAY	8:50	0.2515	7200	104°	18.
12-21-80	6480 hrs	13:40	0.2515	7160	104°	19
4-2-81	8808	8:40	0.2515	7135	104°	19.
6-25-81	10,824	8:20	0.2515	7125	104	19
8-17-81	11,096	8:52	0.2515	7125	104	19
11-14-81	14,230	9:15	0.2515	7110	104	1[illegible]

#6

DATE	TIME	WATCH TIME	DIAL	LOAD	TEMP.	% LOSS
-30-82	16;125	8:30	0.2515	7110	104	19.6
-21-83	24,669	7:10	0.2515	7025	100°	20.5

#7

#7 has two Kinks in 10 ft gage length

DATE	TIME	Watch Time	Dial	Load	Temp	
9-5-81	2 min	9:10	.651	8215	69°	0.30
"	3 min	9:11	.651	8210	69°	0.26
"	4 min	9:12	.651	8220	70°	0.24
"	5 min	9:13	.651	8220	69°	0.24
"	6 min	9:14	.651	8220	70°	0.24
"	30 min	9:38	.651	8200	70°	0.49
"	1 hr	10:09	.651	8195	69°	0.55
"	2 hr	11:09	.651	8165	69°	0.91
"	3 hr	12:09	.651	8160	69°	0.97
"	4 hr	13:09	.651	8165	70°	0.91
"	7½ hr	16:35	0.651	8160	70°	0.97
9-6-81	24 hr	9:15	.651	8100	70°	1.70
9-7-81	48 hr	9:15	.651	8085	70°	1.88
9-8-81	72 hr	8:10	.651	8080	70°	1.94
9-9-81	4 days	7:35	.651	8070	70°	2.06
9-12-81	7 days	8:00	.651	8050	70°	2.31
9-19-81	14 days	8:10	.651	8040	70°	2.43
9-26-81	21 days	8:10	.651	8030	69°	2.55
10-3-81	28 days	9:35	.651	8010	68°	2.77
11-14-81	1680	8:30	.651	7960	68°	3.40
1-30-82	3575	11:10	.651	7930	68°	3.76

#8

-TE	TIME	WATCH TIME	DIAL	LOAD	TEMP	% LOSS
			0.092	7730		
			0.650	7730		
-9-81	0	8:33	0.5975	8240	104°	0
	1 min	8:34	0.5975	8230	↓	0.121
	2	8:35	0.5975	8225		0.182
	3	8:36	0.5975	8225		0.182
	4	8:37	0.5975	8220		0.243
	5	8:38	0.5975	8220		0.243
	6	8:39	0.5975	8220		0.243
	30	9:03	0.5975	8210	↓	0.364
	1 hr	9:33	0.5975	8195		0.546
	2 hr	10:33	0.5975	8190		0.607
	3 hr	11:33	0.5975	8180		0.728
	4 hr	12:33	0.5975	8180		0.728
	7 hr.	16:36	0.5975	8175		0.789
10-81	23 hr	7:30	0.5975	8150	104°	1.092
-11-81	47 hr	8:[illegible]	0.5975	8130	104°	1.335
-12-81	73 hr	9:15	0.5975	8120	104°	1.456
-13-81						
-15-81	144 hr.	8:10	0.5975	8085	104°	1.881
-17-81	168 hr.	8:05	0.5975	8080	104°	1.941
-25-81 16 DAY	384	7:25	0.5975	8035	104°	2.49
-8-81 29 DAY	696	8:33	0.5975	7995	104°	2.97
-21-81	1008	8:17	0.5975	7945	104	3.58
-17-81	1656	9:00	0.5975	7920	104	3.88
-14-81	3790	9:25	0.5975	7820?	104	5.10
-30-82	5645	8:30	0.5975	7820	104	5.2
-21-83	14,229	7:00	0.5975	7660	100°	7.04

#9

DATE	TIME	WATCH TIME	DIAL	LOAD	TEMP	% LOSS
12-20-80	7 hr	20:53	.5630	8125	104°	1.40
12-21-80	19 2/3 hr.	9:30	.5630	8065	104°	2.12
12-22-80	42 1/6 hr	7:55	.5630	8995	104°	2.97
12-23-80	66 1/2 hr	8:15	.5630	7950	104°	3.52
12-24-80	90 1/2 hr.	8:15	.5630	7925	104°	3.82
12-29-80	211 hrs.	8:45	.5630	7890	104°	4.25
1-7-81	427 hrs.	9:30	.5630	7840	104°	4.85
1-27-81	906 hrs	8:15	.5630	7780	104°	5.58
2-5-81	1122 hrs	8:15	.5630	7720	104°	6.31
2-13-81	1314 3/4 hrs	9:00	.5630	7680	104°	6.80
ck 4-2-81 3-16-81	2058.25	8:15	.5630	7600	104°	7.77
[illegible]-81	3210.25	8:37	.5630	7560	104°	8.25
[illegible]5-81	5226	8:10	.5630	7515	104°	8.80
8-17-81	6498	10:35	.5630	7495	104°	9.04
11-14-81	8635	9:50	.5630	7460	104°	9.47
1-30-82	10,530	8:00	.5630	7460	75°	9.47 X

#10

DATE	TIME	WATCH TIME	DIAL	LOAD	TEMP.	% LOSS
11-13-80	0	8:19	.6790	8240	103°	0
	1 min	8:20	.6790	8235	103°	0.06
	2 min	8:21	.6790	8235	103°	0.06
	3 min	8:22	.6790	8230	103°	0.12
	4 min	8:23	.6790	8220	103°	0.24
	5 min	8:24	.6790	8215	103°	0.30
	6 min	8:25	.6790	8215	103°	0.30
	30 min	8:49	.6790	8200	103°	0.49
	1 hr.	9:18	.6790	8185	103°	0.67
	2 hr.	10:18	.6790	8180	103°	0.73
	4 hr	12:45	.6790	8160	103°	0.97
	9 3/4 hr.	17:45	.6790	8125	103°	1.40
11-14-80	24 hr	7:55	.6790	8095	103°	1.76
11-15-80	48 hr.	9:20	.6790	8065	103°	2.12
11-16-80	72 hr.	13:57	.6790	8055	103°	2.25
11-17-80	4 day 96	8:55	.6790	8020	103°	2.67
11-21-80	8 day 192	11:35	.6790	7980	103°	3.16
11-28-80	15 day 360	14:45	.6790	7905	103°	4.07
12-12-80	29 day 696	7:55	.6790	7865	104°	4.55
12-30-80	1008	8:25	.6790	7815	104°	5.16
2-5-81	1895 2/3 hrs.	8:00	.6790	7760	104°	5.83
6-12-81	24 week 5068.8	12:40	.6790	7720	104°	6.32
8-17-81	6653	10:15	.6790	7720	104°	6.31
11-14-81	8790	9:45	.6790	7690	104°	6.67
1-30-82	10,683	8:50	.6790	7700	104°	6.66
1-31-83	19,229	7:55	.6790?	7640?	100°	7.28

	0 MIN	9:06	0.4330	8840	1030	
	1 MIN	9:07	0.4330	8775		0
	2 MIN	9:08	0.4330	8750		1.02
	3 MIN	9:09	0.4330	8735		1.19
	4 MIN	9:10	0.4330	8720		1.36
	5 MIN	9:11	0.4330	8715		1.41
	6 MIN	9:12	0.4330	8710	103°	1.47
	30 MIN	9:36	0.4330	8650	1030	2.15
	1 HR	10:06	0.4330	8615	1040	2.55
	2 HR.	11:06	0.4330	8595	104°	2.77
	4 HR	1:06	0.4330	8565	104°	3.11
	7 HR	4:06	0.4330	8540	104°	3.39
-16-80	23 HR	8:06	0.4330	8480	104°	4.07
-17-80	49½ HR	10:25	0.4330	8390	1040	5.09
-18-80	71 Hr.	8:05	0.4330	8260	1040	6.56
-19-80	95.67 Hr.	8:40	0.4330	8235	1040	6.84
-20-80	124.67	13:40	0.4330	8200	104.0	7.23
-23-80	191	8:10	0.4330	8100	104°	8.37
-1-80	382	7:15	0.4330	8058	104°	8.85
-1-80	24 days 696	8:22	0.4330	7945	104°	10.12
-28-80	6 week 1008	9:05	0.4330	7815	104°	11.6
-17-80	13 week	9:45	0.4330	7640	104°	13.6
-24-80	23 week + 1 day 4,056	9:06	0.4330	7565	104°	14.4
-26-80	12-26-80 6120 hrs.	13:10	0.4330	7410	1040	15.27
-15-81	8,736	9:06	0.4330	7500	104.5°	15.16
-[illegible]-81	10,440	8:45	0.4330	7485	1040	15.33
-17-81	11,712	8:45	0.4330	7435	1040	15.89
-11-81	13,850	9:05	0.4330	7430	1040	15.95
-25-82	22,140	8:10	0.4330	7425	1040	16.0

	Hrs	Time	Grad	Press	Temp	
1-21-83	30,684	6:45	0.433	7285	100°	17.6%

#11

#12.

DATE	TIME	WATCH TIME	DIAL	824.0 LOAD	ORI. TEMP	% LOSS
12-23-80	4 min	8:29	.8750	8220	69°	0.24
	5 min	8:30	.8750	8215	69°	0.30
	6 min	8:31	.8750	8210	69°	0.36 okay
	30 min.	8:55	.8750	8180	69°	0.73 ?
	2 hr.	10:55	.8750	8240	70°	—
	3 hr.	11:55	.8750	8205	69°	0.42
	4 hr.	12:55	.8750	8200	69°	0.49
	8 hr.	16:30	.8750	8195	68°	0.55
-24-80	23½ hrs	7:55	.8750	8180	69°	0.73
12-26-80	73 hrs.	9:30	.8750	8200	62°	0.49
12-27-80	96 hrs	8:30	.8750	8200	63°	0.49
12-30-80	168 hrs	8:35	.8750	8165	68°	0.91
-7-81	362 hrs.	10:30	.8750	8160	68°	0.97
-2 -81	768 hrs.	8:10	.8750	8140	68°	1.21
-6-81	1080	8:15	.8750	8130	68°	1.33
-23-81	2160	8:20	.8750	8235	68	0.061 ?
-18-81	4245.5	6:55	.8750	8125	67°	1.40
-17-81	5686	8:24	.8750	8180	69°	0.73
8-17-81	Recheck			8120		1.46
11-14-81	7820	8:35	.8750	8160	68°	1.70
-30-82	9720	11:10	.8750	8090	68°	1.82

16.5 (1)
[illegible] (2)
[illegible] (3)
65.9 (4)
8240

#13

Date	Time	Watch Time	DIAL	LOAD	TEMP	% Loss
9-5-81	13.272	8:30	0.500	7730	104°	
9-5-81		8:50	—	[illegible]	104°	
Retensioned on 9-12-81						
9-12-81	0	8:21	0.478	8240	104°	
	1 min	8:22	0.478	8220	"	0.24
	2 "	8:23	0.478	8210	"	0.36
	3 "	8:24	0.478	8210	"	0.36
	4 "	8:25	0.478	8210	"	0.36
	5 "	8:26	0.478	8200	"	0.49
	6 min	8:27	0.478	8200	"	0.49
	30 min	8:51	0.478	8190	"	0.61
	1 hr.	9:21	0.478	8180	"	0.73
	2 hr.	10:20	0.478	8170	"	0.85
	3 hr.	11:20	0.478	8170	"	0.85
	4 hr.	12:20	0.478	8160	"	0.97
	9 hr.	16:50	0.478	8140	"	1.21
9-13-81	24 hr	9:15	0.478	8135	"	1.27
9-14-81	48 hr	8:25	0.478	8115	104°	1.52
9-15-81	72 hr	7:35	0.478	8100	104°	1.70
9-16-81	96 hr	7:40	0.478	8090	104°	1.82
9-19-81	7 days (163)	8:00	0.478	8080	104°	1.94
9-26-81	14 days	8:15	0.478	8050	104°	2.31
10-3-81	21 days	9:30	0.478	8040	104°	2.43
11-14-81	1512	9:00	0.478	8000	104°	2.91
1-30-82	3410	8:20	0.478	8000	104°	2.91
1-21-83	11,954	6:40	0.478	7870	100°	4.49

#15 A B

DATE	TIME	WATCH TIME	DIAL	LOAD	TEMP	% LOSS
12-30-80	665 hrs.	8:00	0.379	7680	104°	6.80
1-2-81	744	8:25	0.379	7635	104°	7.34
1-17-81	1104	16:00	0.379	7610	1040	7.65
2-13-81	1152 8:50	8:50	0.379	7540	104°	8.50 ?
2-26-81	2064 16:35	16:35	0.379	7600	104°	7.77
6-1-81	4344	6:40	0.379	7590	103°	7.89
8-17-81	6192	10:30	0.379	7575	1040	8.07
11-14-81	8330	10:00	0.379	7565	1040	8.19
11-27-81	8640	8:05	0.379	7565	1040	8.19
"		8:25	0.379	7565	95	
"		9:15	0.379	7570	85	
"		10:30	0.379	7580	79	
11-28-81		10:50	0.379	7590	74	
12-4-81		15:30	0.379	7580	75	
12-29-81	9408	15:30	0.379	7590	76	
1-30-82	10,225	7:55	0.379	7590	75	8.2

wire has kink within 10ft gage length

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#15AB10

[illegible]TE	TIME	WATCH TIME	DIAL	LOAD	TEMP	% LOSS
[illegible]-28-81	10,632	7:30	.885	7850	68°	4.73
[illegible]-28-81	10,632	7:31	.8365	8330-	OVERLOAD	
[illegible]-17-81	11,376	7:58	.885	7850	68°	4.73
[illegible]-17-81	11,376	7:59	.8365	8370	overload	
[illegible]1-14-81	13,510	8:50	.8365	8330	overload	
11-14-81	13,510	8:50	.885	7840	68°	4.85
[illegible]-30-82	15,400	11:00	.885	7830	68°	5.0