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U. S. Nuclear Regulatory Commission
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SUBJECT: Arkansas Nuclear One - Unit 1
Docket No. 50-313
License No. DPR-51
Arkansas Nuclear One, Unit 1 (ANO-1) Fifteenth
Year Reactor Building Tendon Surveillance Report

Gentlemen:

The Arkansas Power and Light Company (AP&L) has completed its review of issues associated with questions raised by the Nuclear Regulatory Commission (NRC) Staff pertaining to the Fifteenth Year Reactor Building Tendon Surveillance Report for Arkansas Nuclear One, Unit 1 (ANO-1).

The attached information responds to the questions telecopied to AP&L from Mr. Craig Harbuck of your staff on January 13, 1989 and subsequently referenced in your correspondence of February 3, 1989 (1CNA028902). Following the transmittal of the specific questions, a meeting between AP&L and the NRC Staff was conducted in Little Rock, Arkansas on May 18, 1989, at which time the questions and AP&L's associated responses, were thoroughly discussed. In fulfillment of the commitment made at that meeting, this submittal provides the written responses to the staff questions as were discussed on May 18, 1989.

The submission of this information fulfills the outstanding information requests on this issue and should enable the Staff to complete its review of the ANO-1 Fifteenth year Reactor Building Tendon Surveillance Report. Should you have any questions concerning this matter, please contact me.

Very truly yours,

James J. Fisicaro

James J. Fisicaro
Manager, Licensing

JJF:MWT:lw
Attachments

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AP&L RESPONSE TO NRC QUESTIONS REGARDING ANO-1
FIFTEENTH YEAR REACTOR BUILDING TENDON SURVEILLANCE REPORT

Question 1

In Section 2 under Item II on Page 2 maximum acceptable limits of 10% by weight for water are indicated and under Item III in third paragraph on Page 4 the finding of small quantities of water is mentioned. Discuss the difference between the two sources of water and the potential combined effect of the two sources of water on the tendon system as a whole.

Response 1

The first type of water is water absorbed by the grease. Viscosity grease was chosen for use on tendon coating for two primary reasons. The first, its coating adhesion, and second, its water absorption ability over time. This absorption characteristic is measured as a percent by weight of water. The Codes have set a 10% acceptance level. Levels over 10% require additional investigation or testing. Our grease characteristics are not below the acceptance level except for this isolated instance.

The second kind of water is free standing water, water not absorbed by the grease. The grease does not normally absorb water that is not moving through it or if it has had a short exposure time. Free standing water can be from the following causes:

1. Construction exposure
2. Concrete seepage
3. Bolt penetration of grease cans (vertical)
4. Unsealed inlet plugs
5. Condensation during grease contraction of high end grease caps.
6. Condensation prior to greasing

Item numbers 1 through 5 have been determined through experience and investigation at plants. Item 6 was determined by testing at V.C. Summer Power Plant which was completed by Gilbert & Associates.

Small quantities of free standing water are of little risk to the tendon as the grease prevents the water from touching the steel and causing corrosion or oxidation of the galvanizing because of the coating action of the grease and the pre-coating of the tendon at the factory.

However, large quantities of free standing water and high percentages of water emulsified in the grease are signs of excessive water remaining from construction or long term water penetration from the outside.

This type of water increases chances of hydrogen embrittlement of the anchorhead, and stress corrosion of the anchorhead or wires.

This last surveillance found no such condition of high water levels or emulsified water levels occurring together. This indicates no significant entry of water into the system and also indicates low potential for stress corrosion or hydrogen embrittlement.

Therefore, the water found in grease caps and the grease test of 10.3% water content are isolated occurrences and are not signs of degradation. The results of the surveillance and this additional examination supports the "use as is" condition stated in the report.

Question 2

In Section 2 on Table II there are very large differences between the grease removed and the grease added. Explain the reason for such large differences. From the results tabulated it appears that voids may have existed in the tendon sheathing or there may be leakage through the tendon sheathing into the surrounding concrete. In Section 8 the procedure described in Plant Procedure No. 1402.090 Subsection 8.0 appears to be deficient because there is no assurance that the tendon wires are adequately covered by the filler grease. The proper procedure should be: (1) drain the filler material as much as possible from the tendon sheathing, (2) measure the quantity of the collected filler material, and (3) refill the tendon sheathing and record the quantity of the filler material used. The difference between the filler material taken out and put in is a measure of voids in the grease filled space or leakage into concrete. It is to be noted that the procedure described in Section 7 and shown in the figure in Subsections 8.1.6 to determine the correct level of filler material (e.g., on Page D68 of 292), is inadequate as a means to detect tendon grease void for vertical tendons. It was not used for hoop (e.g., on Page D191 of 292) and dome (e.g., on Page D118 on 292) tendons as indicated because of the impracticality of the procedure. However, there is no equivalent procedure for the inspection of tendon grease voids for hoop and dome tendons. In view of the above, please discuss how you plan to change your procedures with respect to tendon grease surveillance.

Response 2

The main function for the sheathing filler material is to prevent corrosion of both the tendon wires and the anchorage components. The material used, Visconorust 2090P-4, accomplishes this by a characteristic which gives the filler material an affinity to adhere to steel surfaces and its ability to emulsify any moisture in the system thus nullifying its rusting ability.

During the ANO-1 fifteenth year surveillance, the records of drained vs. added volumes of sheath filler material indicated apparent variance in excess of 5% of the net duct volume. This variance occurred in vertical tendons V70 and V71 and in dome tendons 1D330, 2D208 and 3D120. The remaining seven tendons surveyed, including hoop tendons, had a variance which ranged from zero to 3.9% (see attached table #1). These percentages are based on the volume of the filler material in excess of the difference between the added and drained quantities in relation to the duct net volume.

The voids in the tendon sheathing may be attributed to a number of factors:

1. Visconorust 2090P-4 has a coefficient of expansion which yields an expansion of about 1% per every 20°F. Initial filling temperatures of the filler material range from 160°F to 220°F. Cold weather conditions can cool the filler material to 40°F, giving a contraction of 6% to 9% of the net duct volume.

2. Calculated voids between the wires which comprise the tendon bundle are approximately 7%, or greater, of the net duct volume. During the initial filling operation, the tendon bundle may be cold (ambient temperature of 40°F to 65°F) and as the filler material was pumped into the sheathing void, it solidified on the surface of the cold tendon bundle, leaving small voids between the wires. As the filler material gradually heated the tendon bundle, it is likely that the voids between the wires allowed migration of the filler material into the tendon bundle. Because this process is slow and gradual, it is reasonable to expect that it took place substantially after the filling operation was completed and possibly during the summer or at the operational temperature. In addition, this type of migration could also occur at other areas such as where tendons are in contact with the sheathing.

3. Characteristics of the initial filling method may induce air entrapment into the filler material. Pumping operations can introduce air into the filler material which may add up to as much as 2% of the net duct volume.

In summary, even under optimum filling conditions, voids ranging from 2% to 19% could be expected after the initial filling operation. Therefore, any void which is below 19% may be considered as an apparent void and may be related to the reasons indicated above. A true void is that which is in excess of 19%. Based on physical tests on the tendon wires and chemical test of the filler material, there seems to be little correlation between the 5% to 19% void and the structural integrity of the tendon and anchorage system.

In the process of tendon fabrication, all wires are protected from corrosion with Visconorust 1601 Amber material which adheres to the surface of the wires. Unless physically removed, this material provides a lasting protection against corrosion. Visconorust 2090P, the original grease, and Visconorust 2090 P-4 added during this most recent surveillance are compatible materials. Since none of the tendon surveillance program results indicated any evidence of wire or anchorage component corrosion, it can be concluded that the system is adequately protected.

On this basis, the voids encountered on the Arkansas Unit 1 may be reduced to one significant variance in dome tendon 3D120, which reflected a sizeable void of 45%. This tendon will be completely detensioned during the next surveillance and a wire will be extracted for inspection for any evidence of corrosion. The sheathing has been completely filled with the filler material during the fifteenth year surveillance.

As an attempt to explain the reason for the excessive void encountered in dome tendon 3D120, the history of tendons and sheathing filler material installation on the Arkansas Unit 1 was reviewed. Two scenarios were considered.

1. The tendon sheathing filler material installation procedure requires that the filler material be pumped from one end with the top vent and the valve on the far end open. The valve at the far end is closed after the filler material starts coming out. The filling operation continues until the material flows out through the vent. We believe that the tendon had been coated with sheathing filler material during the initial filling operation. However, due to possible improper sequence of closing of valves and vent during the installation of the sheathing filler, complete filling of the tendon was not attained.

2. The tendon sheathing is installed in the concrete forms prior to concreting. The requirement of the sheathing is to form the void inside the concrete wall for later installation of the tendons. The sheathing has no requirement for resisting any internal pressure. The joints between two pieces of sheathing or between the sheathing and the trumpet are secured by fitting a coupler over each end. To prevent leakage of cement paste into the sheathing, the joints were taped with duct tape. The layout of tendon sheathing through the containment is complicated and tendon sheathing for the different tendons often cross each other at numerous contact and non-contact points.

   The dome and vertical tendons cross each other in a configuration shown in figure 1. From this configuration it can be seen that the joint between the trumpet and sheathing for the dome tendon and the vertical tendon coincide at approximately the same location where the tendons intersect each others. Also it happened that a construction joint was located at this intersection. Since the trumpet-sheathing joints are located at the construction joint, it is possible that they had been disturbed by the construction workers during concrete placement and a path from the dome tendon to the vertical tendon through the concrete may have occurred.

During the initial installation of the system, the vertical tendons were installed and filled with the sheathing filler material prior to stressing and were left in this condition for a period of time due to problems with the stressing equipment. Upon resumption of the stressing operation, the vertical tendons were stressed, and since the initial sheathing filler material had contracted due to drop in temperature, the vertical tendons were topped and completely refilled with the sheathing filler material. The refilling operation eliminated the expansion chamber normally existing in these tendons.

Due to the loss of the expansion chamber in the vertical tendons, when the filler expanded with the increase in temperature it caused leakage through the gaskets at the end caps. The end caps and gaskets were replaced on all vertical tendons in 1979 to correct this problem. In the process, sheathing filler material from the vertical tendons drained out. The drained portion was later replaced.

If a path had occurred between the dome and vertical tendons at the intersection as described above, the filler material in the dome tendon could have been drained, undetected, along with the filler material from the vertical tendon. When the vertical tendon was later refilled with the filler material, the filler material could have flowed back into the dome tendon through the interconnecting path between the dome and vertical tendons. In this process, the dome tendon could have only partially been refilled near its end.

Since the filler material was drained from both ends of the dome tendon during the fifteenth year surveillance, this indicates that the tendon had been coated with the corrosion protection material. Although complete encapsulation with the sheathing filler material may have not existed at all times, coating of the tendon with filler material along with the initial coating applied during tendon fabrication should have provided sufficient protection.

In summary, the indicated voids in the tendon sheathing ducts are within the expected, except for dome tendon 3D120. Two postulated reasons for the void in this tendon were given. One related to the initial installation and the second due to possible interconnection between the dome tendon duct and a vertical tendon duct. From the collected information and the fifteenth year surveillance report the following could be concluded:

-The extent of voiding in tendon 3D120 appears to be an isolated case.

-The tendon had been treated with corrosion protection material during the fabrication process.

-The tendon had been covered with flowing sheathing filler material during the installation of the filler.

-Measured lift-off force in the tendon met the fifteenth year surveillance requirement

During the fifteenth year surveillance, the tendon was completely filled with sheathing filler material and the void was eliminated.

As a follow-up action, the tendon will be completely detensioned during the next surveillance. A wire will be extracted, examined and tensile tested to confirm the continued integrity of the tendon.

AP&L has recently revised the ANO-1 and ANO-2 Tendon Surveillance Procedures (1402.090 and 2402.098, respectively) to include methods to more accurately monitoring tendon grease loss and to assess its impact.

Minor sheathing filler streaks exist on the outside of the containment wall approximately at azimuth 120 Deg. and elevation 345'. The streaks have existed since 1984. From their appearance, the streaks are judged to have been related to a very minor leak which has no effect on the quantity of sheathing filler in the tendon or tendons from which it is leaking. Based on the location of the streaks, which coincides with the location of horizontal tendon drains, it is most likely that the leak is occurring in one or more of these drains. There are five drains at this location lined up along a vertical line. The drains are plugged with screw on caps which may not have been screwed on tight initially. The drains are recessed in the wall and covered with cementitious grout material. The wall in the area of the drains is also painted, making them difficult to locate. Attempts to uncover the drains by chipping at the grout could result in additional damage and does not seem warranted, since the leak is of a minor nature.

The levels of sheathing filler material in all vertical tendons were checked in 1979. The level of filler material in vertical tendons surveyed after 1979 was checked and found to correspond to earlier records. This indicates that at least until 1979 no measurable leakage had occurred from the vertical tendons that were inspected.

There should be no concern regarding the effect of sheathing filler on the concrete integrity or shear capacity. Sheathing filler is known not to penetrate the concrete except through cracks or under extremely high pressure (800 to 1000 psi). Shearing capacity of the containment is not compromised due to the following reasons:

- When sheathing filler is present in construction joints it should only be over small areas with voids and/or improper consolidation

- Maximum shearing stresses at containment discontinuities and openings occur under the application of prestressing forces. Shearing capacity of prestressed containments are pretested by the application of the prestressing force.
- Accident loads lead to the relief of shear stresses in the containment
- Seismic shear stresses are small
- Significant amount of shear capacity, which is unaccounted for, exists due to:
  a) Mechanical action of aggregate interlock
  b) Dowel action of the reinforcement bars

The existing condition does not constitute a structural problem.

Question 3

In examining Figures 4, 5 and 6 in Section 2 of the report, one can discern the trend of the tendon forces on the basis of the same tendons inspected. For instance, for vertical tendon No. V40, by joining the tendon forces for the first and second surveillances with a straight line and extending the line to forty years, the tendon force is found to be above the minimum required tendon force. However, for hoop tendons Nos. 21 H42, 31H40, 32 H14, and 32 H44, if the same process is repeated, the forces in these tendons reach the minimum required at ages of less than 13 years. It appears that because of the low tendon force in tendon 31 H40 discovered in the second surveillance, adjacent tendons 31H39 and 31H41 were detensioned in the second surveillance. Unfortunately, as these tendons were not detensioned in the subsequent surveillances, no conclusion can be drawn on the trend of these tendons. However, from the trends of the four similar hoop tendons inspected in two or three surveillances, the losses of tendon forces appear to be much more than expected and the tendon forces will be below the minimum required before the forth year life is reached. For dome tendon No. 1D20 the trend appears to be that the tendon force will be above the minimum required force. In view of the above observations discuss how you will modify the tendon surveillance procedure so as to ensure that the tendons inspected are truly representative of the tendon group as a whole and not only meet the tendon force requirements at the time of surveillances but also indicate a trend that the tendon forces will not fall below the tendon force requirements before subsequent surveillances. Also discuss the causes of tendon force losses which were larger than expected.

Response 3

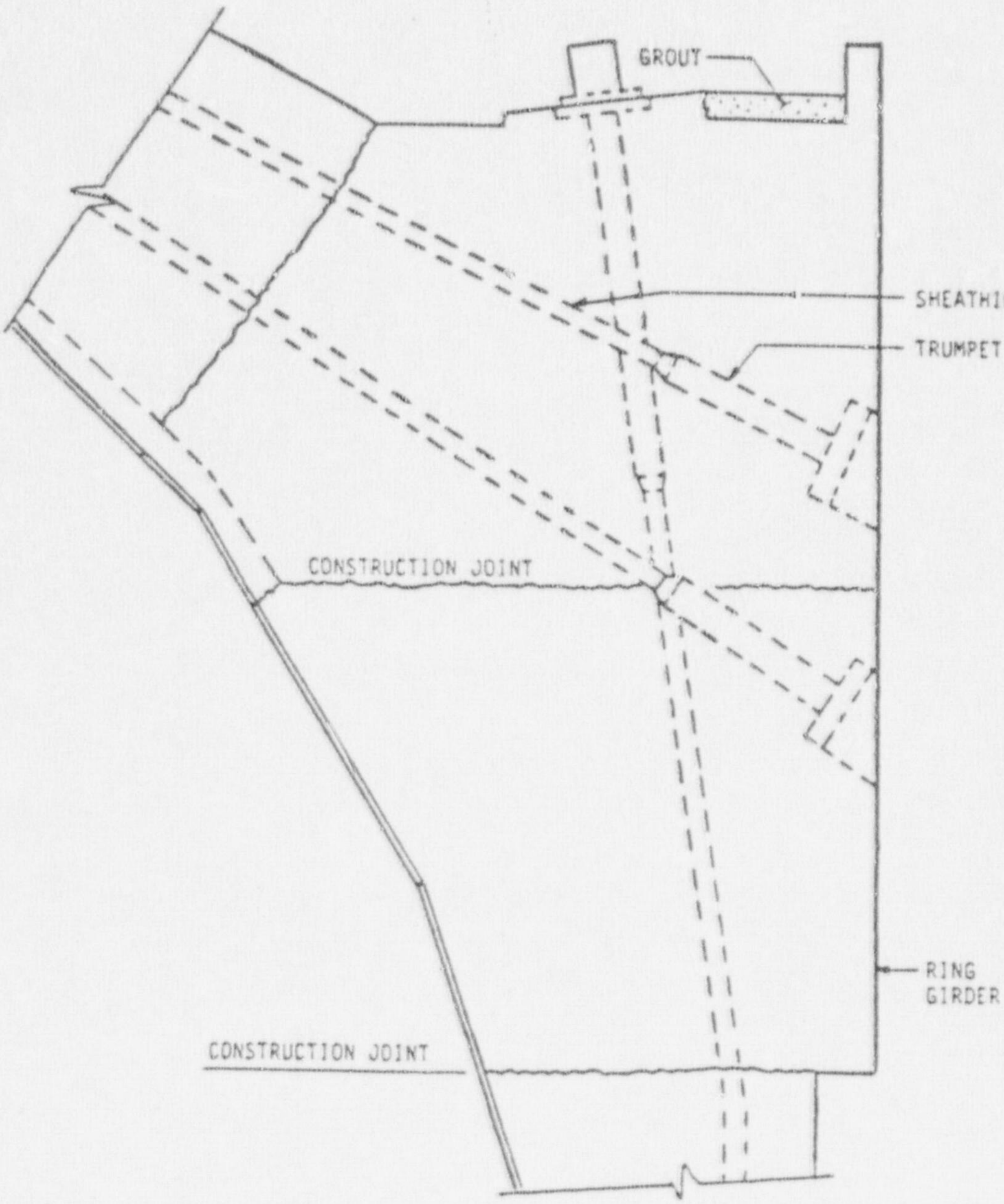
See attached Addendum.

TABLE 1
RECORD OF TENDON SHEATHING FILLER
15TH YEAR SURVEILLANCE

TENDON #	FIELD END		SHOP END		FINAL		PERCENT OF DUCT VOLUME
	DRAINED	ADDED	DRAINED	ADDED	LEFT-OUT	ADDED-IN	
V42	126	2	0.75	132.25		7.5	4.7
V70	0	0	0	14.95		14.95	9.3
V71	35	0.5	0.75	23.77	11.48		7.2
V72	0	0	0.25	0.25	0	0	0.0
V98	56	1	0.75	62.5		6.75	4.2
1D330	5	5	10	33		23	22.8
2D208	15	26.75	6.5	5		10.25	8.6
3D120	5	62.25	33	30.5		54.75	45.4
21H12	4	4	3	3	0	0	0.0
31H42	4	5	4	4.5		1.5	0.73
31H52	3.5	5	2.75	3.5		2.25	1.10
32H28	3.5	4.5	4	3.5		0.5	0.2

TABLE 2
RECORD OF DOME TENDON SHEATHING FILLER
ALL SURVEILLANCES

TENDON #	FIELD END		SHOP END		FINAL ADDED-IN (GAL.)	DUCT VOLUME (GAL.)	PERCENT OF DUCT VOLUME
	DRAINED	ADDED	DRAINED	ADDED			
1D320	3.5	5.0	3.5	4.5	2.5	121.8	2.1
1 1D328	5.0	7.0	2.0	5.0	5.0	106.7	4.7
S 2D207	4.0	5.0	4.0	4.0	1.0	116.6	0.9
T 2D210	5.0	5.0	4.5	4.5	0.0	121.4	0.0
3D110	5.0	5.0	5.0	5.0	0.0	121.9	0.0
3D120	2.5	4.0	4.0	4.0	1.5	120.5	1.2
1D20	12.0	0.0	21.0	37.0	4.0	121.8	3.3
3 1D26	2.0	0.0	3.0	13.0	8.0	111.7	7.2
R 2D08	25.0	0.0	16.0	45.0	4.0	118.5	3.4
D 2D11	20.0	50.0	23.0	0.0	7.0	122.5	5.7
3D08	15.0	0.0	22.0	42.0	5.0	118.9	4.2
3D21	6.0	0.0	4.0	3.5	-6.5	122.2	-5.3
1D7	1.5	2.5	4.0	4.0	1.0	115.5	0.9
5 1D12	4.0	4.0	1.5	2.0	0.5	122.4	0.4
T 2D22	3.0	3.0	13.0	12.5	-0.5	120.4	-0.4
H 2D29	1.0	2.5	1.0	3.0	3.5	104.5	3.3
3D2	5.0	5.0	3.0	5.0	2.0	105.1	1.9
3D24	7.0	7.0	4.0	6.0	2.0	107.1	1.9
10 1D303	4.0	3.0	4.5	2.8	-2.8	106.2	-2.6
T 2D228	4.5	2.6	4.5	3.3	-3.2	107.4	-2.9
H 3D102	6.0	4.5	5.3	3.0	-3.8	105.1	-3.6
15 1D330	5.0	5.0	10.0	33.0	23.0	100.6	22.9
T 2D208	15.0	26.8	6.5	5.0	10.3	118.5	8.6
H 3D120	5.0	62.3	33.0	30.5	54.8	120.5	45.4



DETAIL OF DOME VERTICAL
TENDONS AT THE RING GIRDER

FIGURE 1

ADDENDUM 1

ARKANSAS UNIT 1
FIFTEENTH YEAR TENDON SURVEILLANCE

EVALUATION IN RESPONSE TO US NRC COMMENT REGARDING HORIZONTAL TENDONS LIFT-OFF VALUES

1. INTRODUCTION

The purpose of this evaluation is to respond to the US NRC comments regarding tendon lift-off measurements reported in the Arkansas Unit 1 fifteenth year tendon surveillance report. The report also included results from earlier surveillance programs. The US NRC comments were made in letter 1CNA028902 to Arkansas Power and Light, dated February 3, 1989. The comment under consideration is specifically concerned with the lift-off measurements of horizontal (hoop) tendons which were surveyed in more than one surveillance program. The US NRC indicated that for those tendons, the projected stress level, based on connecting the points of measured lift-off readings for each of these tendons, is taking a downward slope which is steeper than the normal predictions for the time dependent losses and would drop to the minimum design requirement before the end of the system design service life.

2. EVALUATION

In order to respond to the US NRC's comments, the results from the first through the fifteenth year surveillance programs (five surveillance programs), along with the data from the initial prestressing of the system have been reviewed and evaluated. The evaluation included the following:

- Individual tendon lift-off results were plotted for comparison and detection of possible trends exhibited by tendons surveyed only one time and those that were surveyed more than one time.

- Individual tendon lift-off results for vertical, dome and horizontal tendons surveyed more than one time were plotted and evaluated to establish the effect of curvature on the lift-off measurements as a result of detensioning and retensioning.

- Statistical regression analysis was performed on the five horizontal tendons which were surveyed more than one time.

- Statistical regression analysis was performed on all horizontal tendons surveyed during the five surveillance programs completed to date.

The basis for the statistical regression analysis is included in Appendix A. The approach is computerized on a spread sheet software. Input and output computations are also tabulated in Appendix A.

3. DISCUSSION

Post-tensioning systems do experience time dependent losses due to creep of concrete and relaxation of tendon wires under stresses. The losses are reflected in the form of a drop in the prestressing level of the tendons and lower lift-off readings. It is common, due to material characteristics and behavior, to experience most of the time dependent losses during the first few years after stressing. Therefore a plot of stress level against natural time would follow a curve which would have a high rate of losses (steep slope) during the first few years and almost no change thereafter.

This behavior is experienced with all prestressing systems and has been demonstrated by the results of monitoring programs which had been performed on these systems. The same behavior can also be predicted statistically by performing regression analysis which utilizes partially existing measurements. Obviously, the accuracy of the statistical predictions improves with the increase in the size of the data base and with measurements that span a longer time interval.

A number of factors were found to also play a role in the results of tendon lift-off measurements, some of which are equipment calibration, measurement procedures and human factors.

Although a great effort is always made to ensure proper equipment calibration, it has been found that reading variations, from the true value, on the order of ± 2 percent could be encountered.

In performing lift-off measurements on tendons, the exact point at which the lift-off has occurred is not precisely determined or correlated to the pressure gauge readings. This is because the point of lift-off is based on the instant when the shim plates behind the anchor block become loose. This procedure is difficult to be exactly reproduced every time. Normally, the average of three readings is used to overcome this difficulty and to obtain as a representative reading as possible. The reading variations due to this factor are also on the order of ± 2 percent. The averaging is supposedly a reasonable approach to also account for the human factor.

Considering these factors, the measured lift-off readings for a sample tendon could possibly carry a variation from the true value by ± 5 percent.

4. RESULTS OF THE EVALUATION

The evaluation included review of and observations on the collected surveillance data and the two statistical regression analyses as described in section 2. of this report. The results of this evaluation are summarized as follows:

a. Comparison of lift-off results from five horizontal tendons surveyed more than one time with those of tendons surveyed only one time.

During the first four surveillance programs, five horizontal tendons (21H42, 31H40, 32H14, 32H44 and 32H40) were surveyed more than one time each. Later lift-off readings of these tendons exhibited increased losses beyond those experienced by other tendons which were surveyed only one time. Direct connection of two consecutive lift-off readings, of any of these tendons, show that the extension of the connecting lines intersects the minimum design requirement line before the end of the service design life of the system. However, tendons that were surveyed more than one time and with the second lift-off measurements performed before the third surveillance (early surveillance programs), had connecting lines with a steeper slope than those for the tendons that had their second lift-off measurements after the third year surveillance (late surveillance programs), (see figure 1).

Similarly, direct connection of points for the initial prestressing values of tendons that were surveyed only once with the measured lift-off values (see figure 2), showed a steeper slope of the connecting lines for those tendons that were surveyed before the third surveillance than those for the tendons that were surveyed after the third surveillance. In addition, the extensions of these lines also intersected the line for the minimum design requirement at a time earlier than the end of the system service life.

Although the general behavior of both groups of tendons (tendons surveyed more than one time and tendons surveyed only one time) is similar, one difference was observed. The difference is lower second measurement readings by approximately 5 percent. Since the lift-off measurements from both groups reflected similar behavior, then the forty year group extrapolation of the tendons measured more than one time would follow a similar pattern to that for the other tendons. Therefore, the extrapolated lines for both groups would run parallel to each others with an approximate 5 percent difference.

The steeper slopes during the early years, reduced slopes at later years and intersection of extensions of these lines with the minimum design requirement at times before the end of the service life of the system are common and reflect a normal behavior of a post-tensioning system. As time progresses, the slope will reduce to almost zero and remains above the minimum design requirement. This behavior will also be verified by the additional evaluation presented in item c below.

b. Comparison of vertical, dome and horizontal tendons surveyed more than one time.

As an attempt to identify the reason for the lower measured lift-off values of the horizontal tendons which were surveyed more than one time, comparison to similarly measured tendons of the vertical and dome groups was made and tendon results from the three groups were plotted as shown in figure 3. From this figure it can be seen that the slope of the line connecting the results from the horizontal tendon is approximately three times that of the dome tendon. Furthermore, the loss in the horizontal tendon stress between the first and the second surveillance programs is four times that for the dome tendon. It is interesting to note that the curvature angle of the horizontal tendons is also approximately four times the curvature angle of the dome tendons. This indicates that the prestressing loss experienced due to surveying a tendon more than one time is, approximately, linearly proportional to the amount of curvature. Although overstressing of the tendons to 80 % of their specified ultimate strength during retensioning is intended to compensate for most of the losses due to friction and curvature, apparently some residual back friction is slowly released with time after tendon anchorage seating causing a redistribution of possible lock-up forces and reduction of force level at the anchorage. This redistribution and slow release, is apparently acting similar to a creep-like time dependent loss, in addition to the usual time dependent concrete creep and tendon relaxation. The magnitude of this residual time dependent-like friction is proportional to the amount of curvature angle of the tendon. Although the detensioning and retensioning operation appears to result in an additional component of losses, the magnitude of the loss is significantly small and only affects an insignificant percentage of the total tendons. Therefore, such a loss is of no consequence to the overall integrity of the post-tensioning system.

c. Statistical regression analysis for five horizontal tendons surveyed more than one time.

During the first four surveillance programs, five horizontal tendons were surveyed more than one time each. Later lift-off readings of these tendons exhibited increased losses beyond those experienced by other tendons which were surveyed only one time. These tendons are the subject of this evaluation. Direct extrapolation of two consecutive readings of these tendons indicate a drop in the prestressing level to below the minimum design requirement prior to the end of the 40 years service life of the system.

Since the typical time dependent loss curve for a containment post-tensioning system exhibits a high rate of losses during the early years and reduces to almost zero at later years, the straight line extrapolations between two readings are not representative, especially for early readings. Therefore to obtain a more realistic and representative extrapolation for these five horizontal tendons, a statistical regression analysis has been performed. The analysis conservatively utilized only the data collected from surveillance programs of these particular tendons and their initial stressing forces. The initial stressing forces have been, conservatively, used without normalization, which accounts for the effect of elastic losses. The results of the regression analysis are shown in figure 4. The figure shows average, upper bound and lower bound extrapolation curves based on a 97.5 % confidence level. The slopes for these curves are steep during the first few years and reduce at later years. This is in conformance with the common behavior of post-tensioning systems verified by actual measurements. From figure 4, if a tangent to the curve representing the average values is drawn at a mid point between the 5 years to 10 years interval, the tangent will indicate an extrapolated average stress level falling down to the level of the minimum design requirement at approximately the 28 years mark of the system design life. This drop is similar to that indicated by the presently available data discussed in item a. However, the slope of the regression curve reduces with time and a tangent at a mid point between the 10 years and 15 years interval indicates that the extrapolated stress level will meet or exceed the minimum design requirement of the system at the 40 year mark which is the design service life. In fact, the regression curve extrapolated to the 40 years service life of the system shows an average stress level above the minimum design requirement by approximately 5 percent. Figure 6 shows the extrapolated average, upper bound and lower bound stress levels plotted on a semilog scale. In both figures 4 and 6 the lower bound stress level is shown to intersect the minimum design requirement at about the 5 years mark. This should not be considered significant since the lower bound has only 2.5 percent possibility of occurring in tendons that are surveyed more than one time and the average stress level is always above the minimum design requirement.

d. Statistical regression analysis for all surveyed tendons.

Due to a number of possible variations in equipment calibration, lift-off measurement procedures and human factors, the post-tensioning system stress level should be based on the average of a number of readings from different tendons. Although the regression analysis described in item c above was based on limited and selected low readings of a particular group of tendons, the results showed an extrapolated stress level exceeding the design requirements. However a more realistic and representative extrapolation should be obtained. Such extrapolation should be based on a wide data base representing as many tendons and lift-off measurements as possible. Therefore, a regression analysis which considered all the data obtained for the horizontal tendons from all the surveillance programs to date and the initial stressing forces for these tendons was performed. The initial stressing forces have been, conservatively, used without normalization, which accounts for the effect of elastic losses. The resulting average, upper bound and lower bound extrapolation curves are shown in figure 5. The analysis is based on a 97.5 % confidence level. The curves have the common shape of high slope at early years and reduced to almost zero slope at later years. If tangents to the average curve are drawn in a similar fashion to those drawn in the case of the five horizontal tendons in item c above, the tangent between the 5 years and 10 years interval would indicate an extrapolated stress level down to the minimum design requirement at approximately the 36 year mark of the system service life. A tangent between the 10 years and the 15 years interval indicates an extrapolated stress level which exceeds the minimum design requirement at the 40 years service life. In fact the regression curve extrapolated to the 40 years service life shows a stress level above the design requirement by approximately 8 percent. Figure 7 shows the extrapolated average, upper bound and lower bound stress levels plotted on a semilog scale.

5. CONCLUSIONS

The evaluation performed and the results obtained indicated that the post-tensioning system maintains it integrity and is expected to continue as such through the service life of the system. A few tendons exhibited lower than predicted lift-off values as a result of being surveyed more than one time. These lower values reflect an increase in tendon stress losses over those tendons which were surveyed only one time. Apparently detensioning and retensioning have introduced an additional component of back friction to the normal losses of concrete creep and tendon relaxation. This additional loss is likely to be the result of slow redistribution of back friction and residual tendon forces. Such a redistribution could have also been enhanced by seasonal variation of temperature. Extrapolation of system stress level based on early year surveillance results indicated possible reduction to below the design requirements, similar extrapolation based on later years surveillance results showed a stress level above the design requirement even past the service life of the system. Therefore, the concerns raised based on early year results are superficial and should be superceded by later year results. Future surveillance results should indicate an even better extrapolation.

Based on the above findings it can be concluded that the Arkansas Unit 1 post-tensioning system is functioning within its design parameters and the system is expected to maintain its integrity.

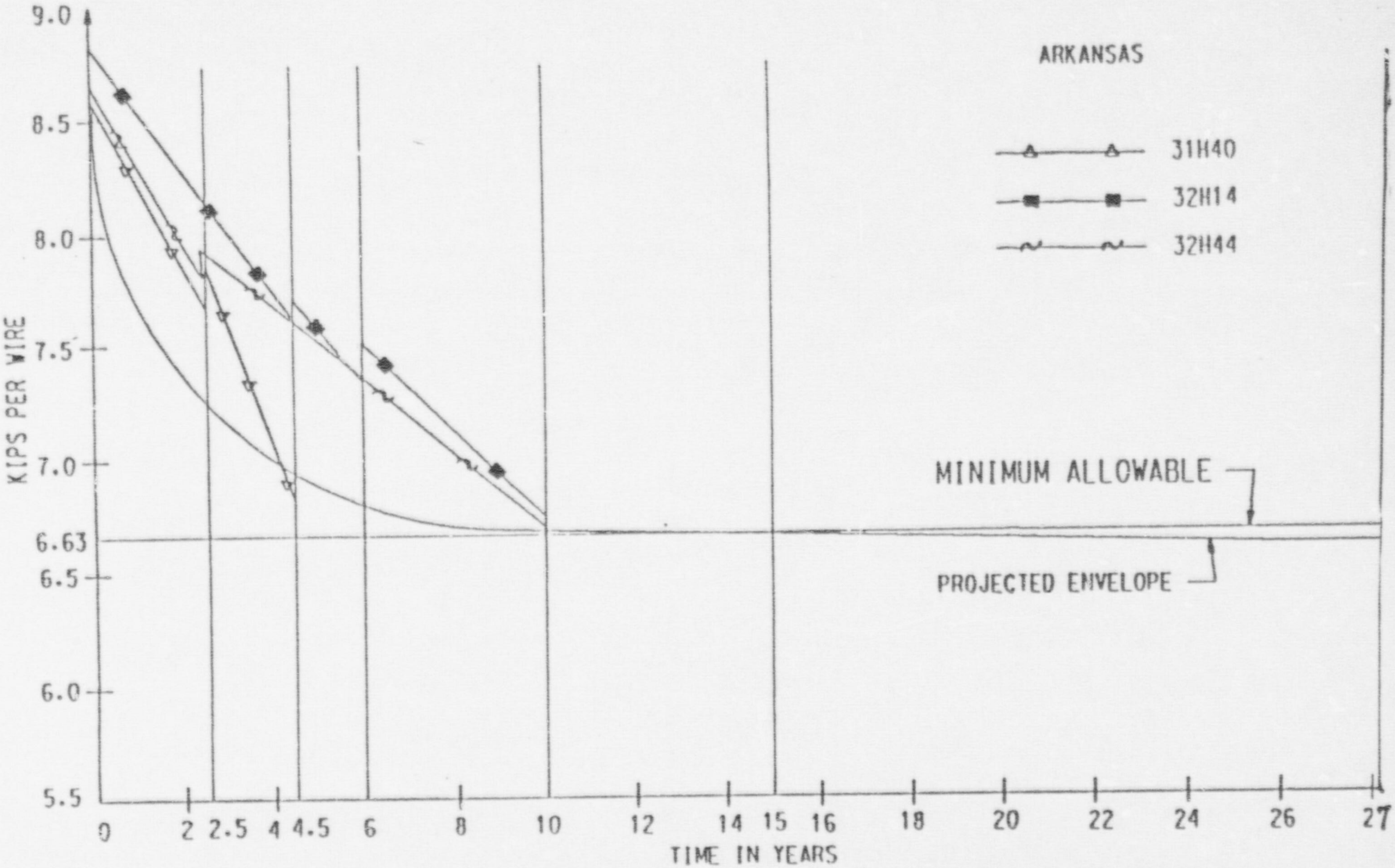


FIGURE 1 - TENDONS SURVEYED MORE THAN ONE TIME

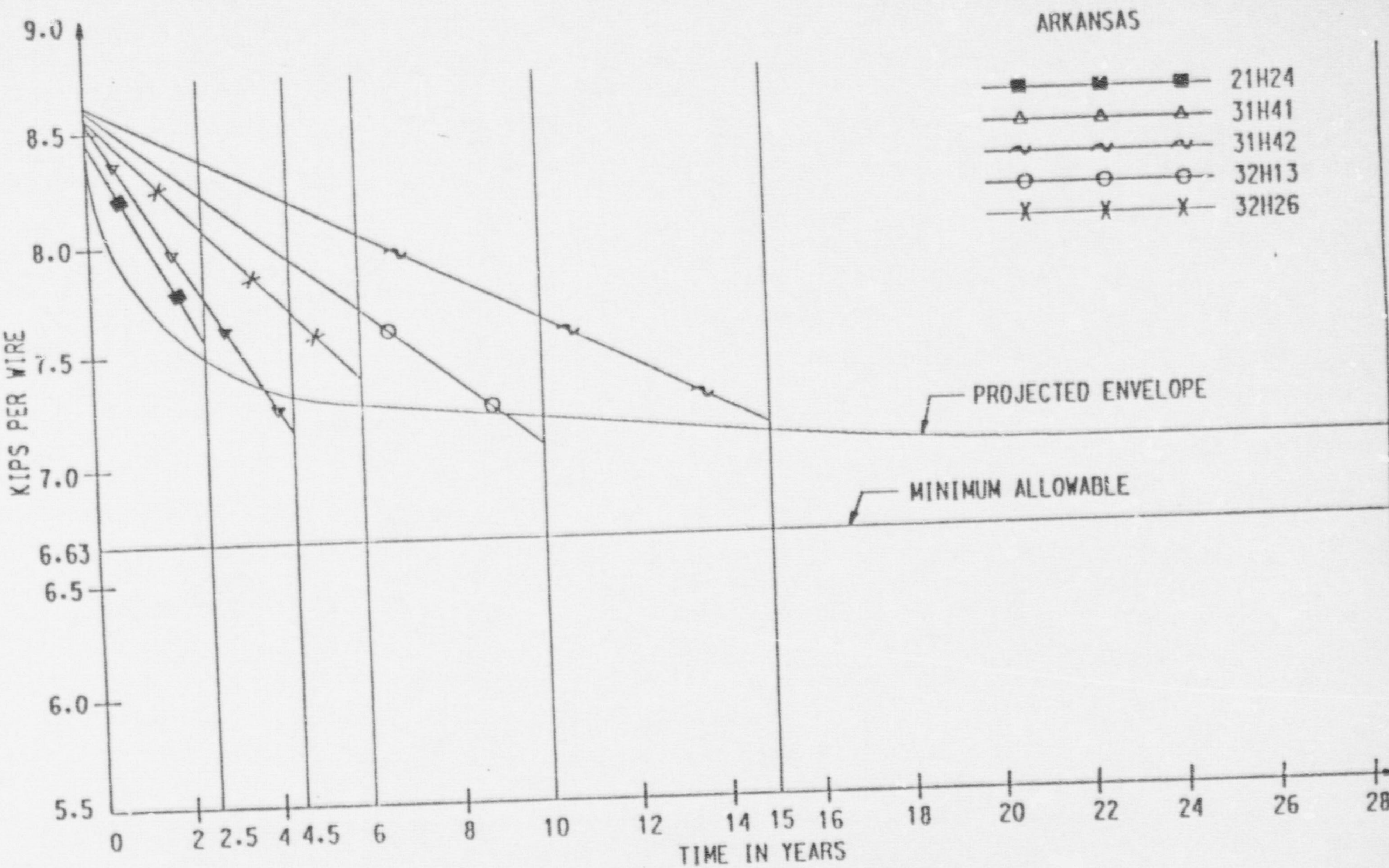


FIGURE 2 - TENDCNS SURVEYED ONE TIME ONLY

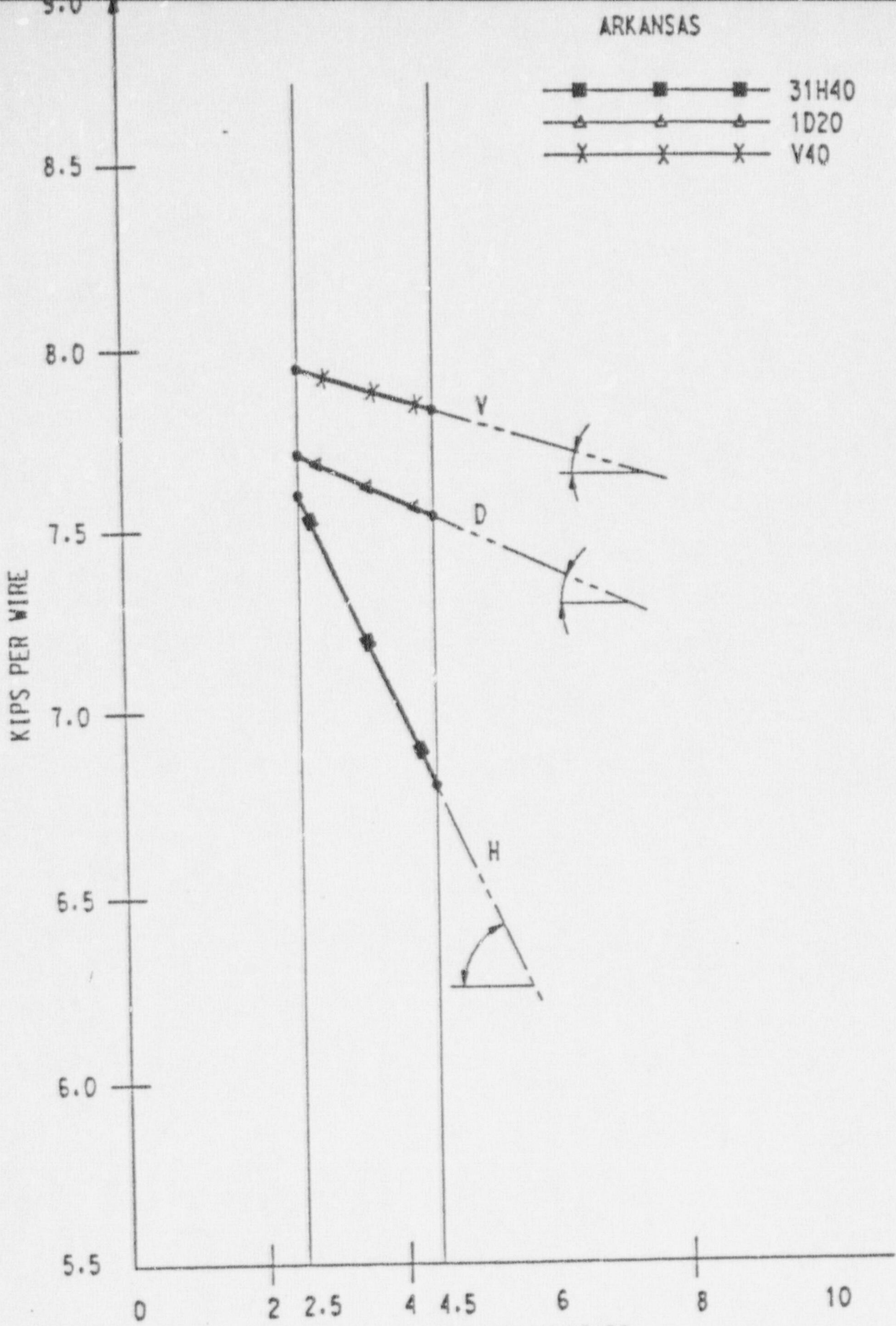
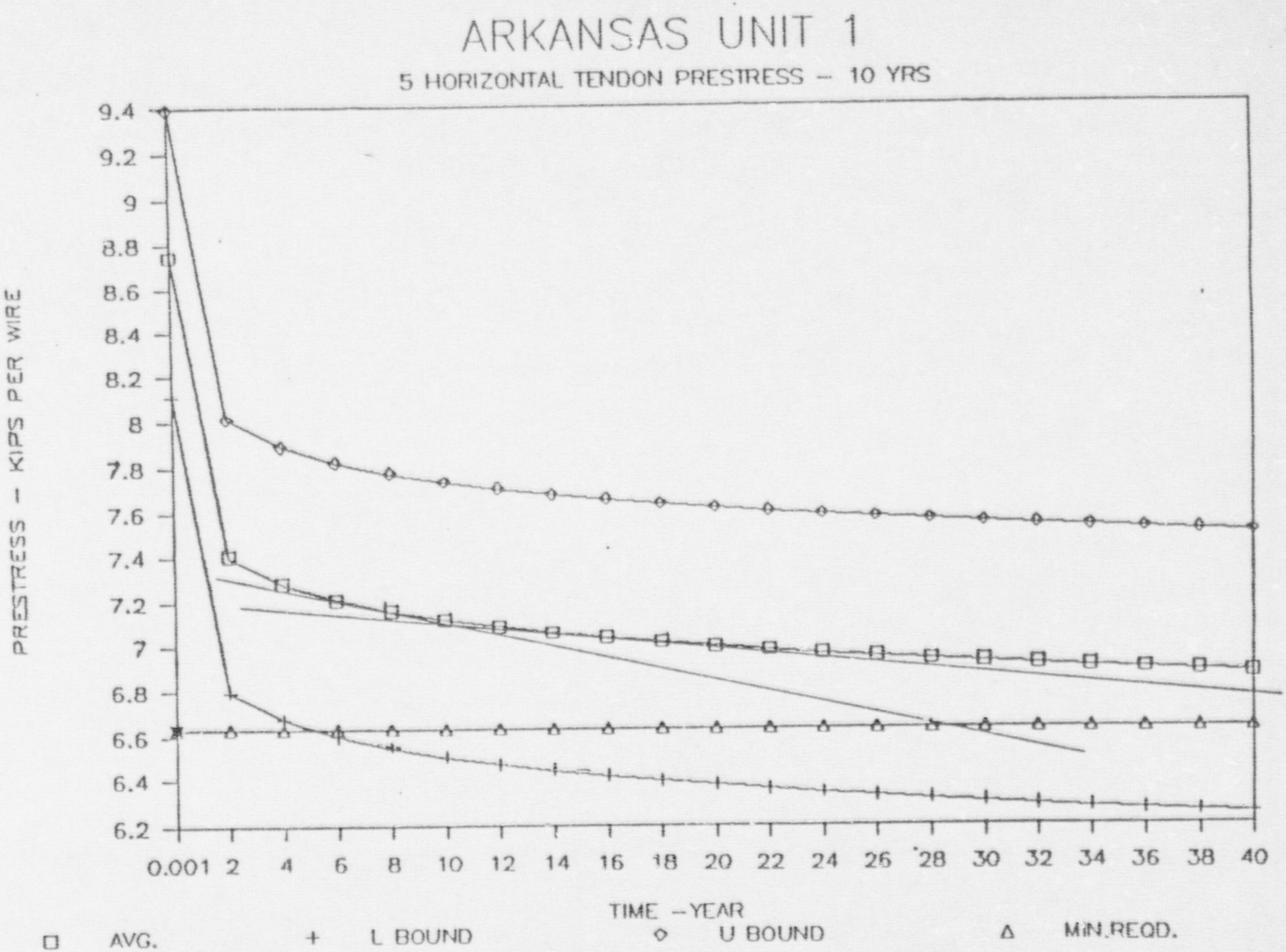


FIGURE 3 - RELATIONSHIP OF SLOPES AMONG VERTICAL, DOME AND HORIZONTAL TENDONS SURVEYED MORE THAN ONE TIME



ARKANSAS UNIT 1
5 HORIZONTAL TENDON PRESTRESS – 10 YRS
PRESTRESS – KIPS PER WIRE
9.4
9.2
9
8.8
8.6
8.4
8.2
8
7.8
7.6
7.4
7.2
7
6.8
6.6
6.4
6.2
0.001
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
TIME –YEAR
□ AVG.
+ L BOUND
◇ U BOUND
Δ MIN.REQD.

FIGURE 4

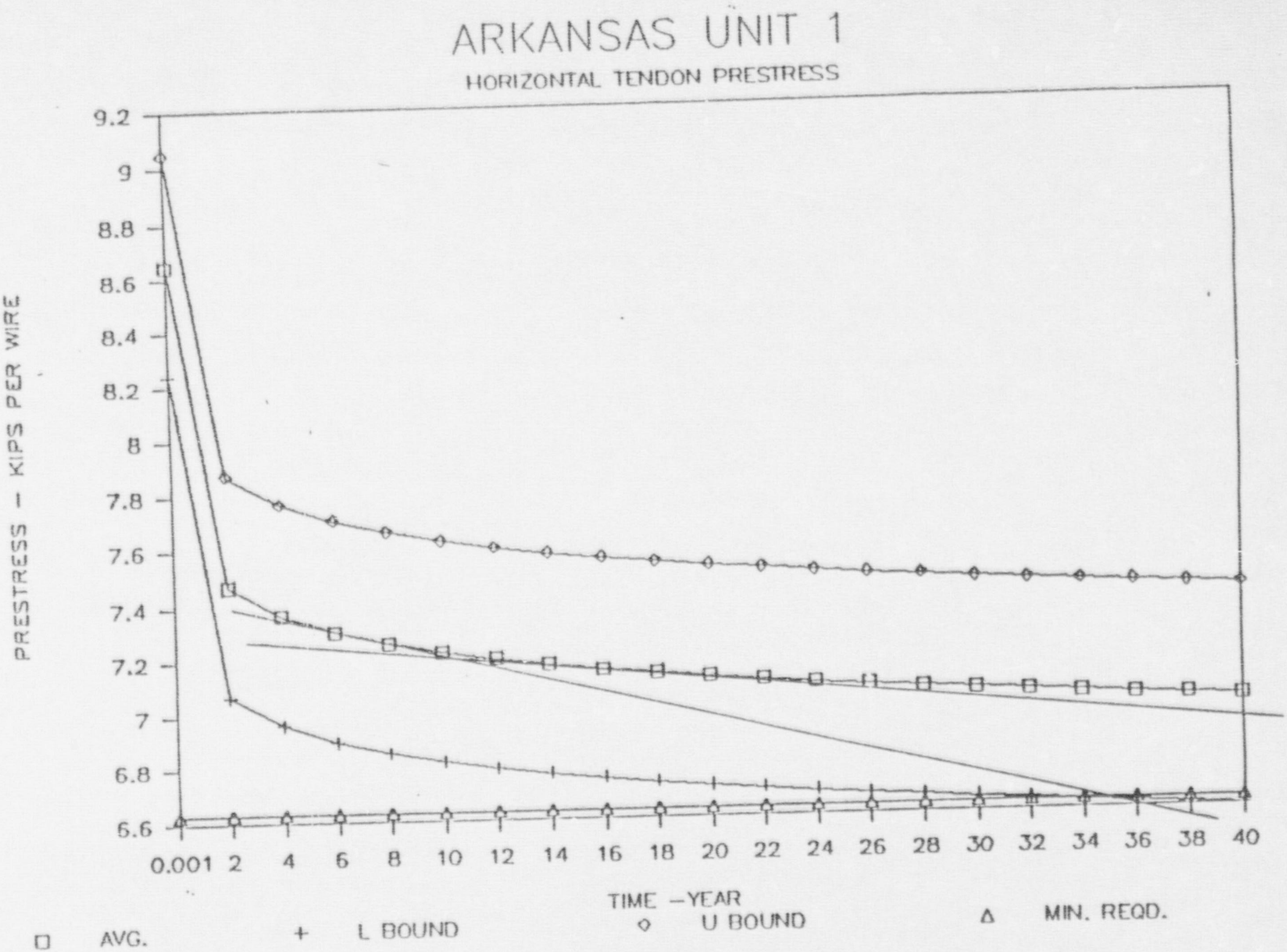

ARKANSAS UNIT 1
HORIZONTAL TENDON PRESTRESS
PRESTRESS - KIPS PER WIRE
9.2
9
8.8
8.6
8.4
8.2
8
7.8
7.6
7.4
7.2
7
6.8
6.6
0.001 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
TIME -YEAR
□ AVG.
+ L BOUND
◇ U BOUND
Δ MIN. REQD.

FIGURE 5

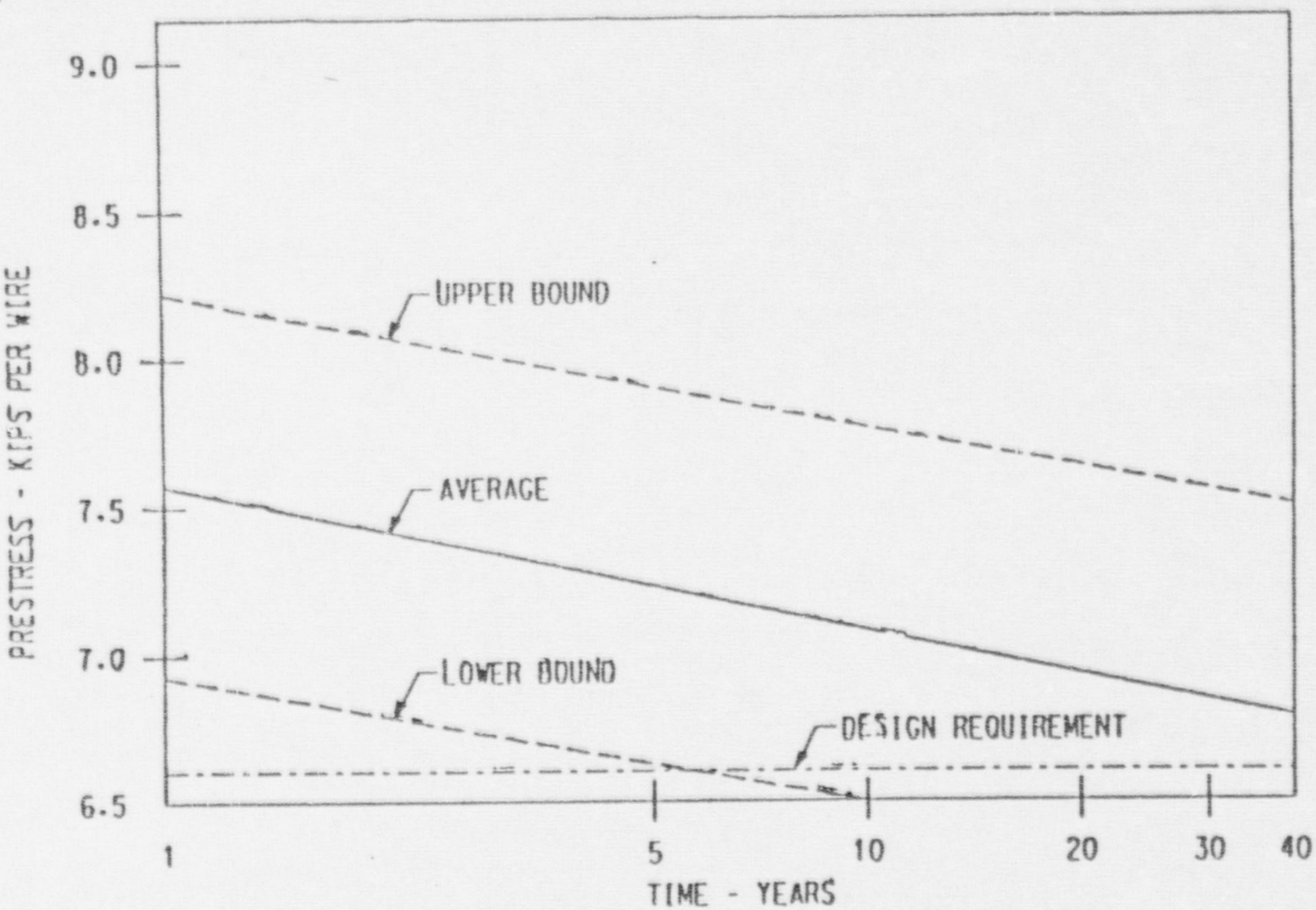


FIGURE 6 - WIRE FORCE VS. TIME - 5 HORIZONTAL TENDONS

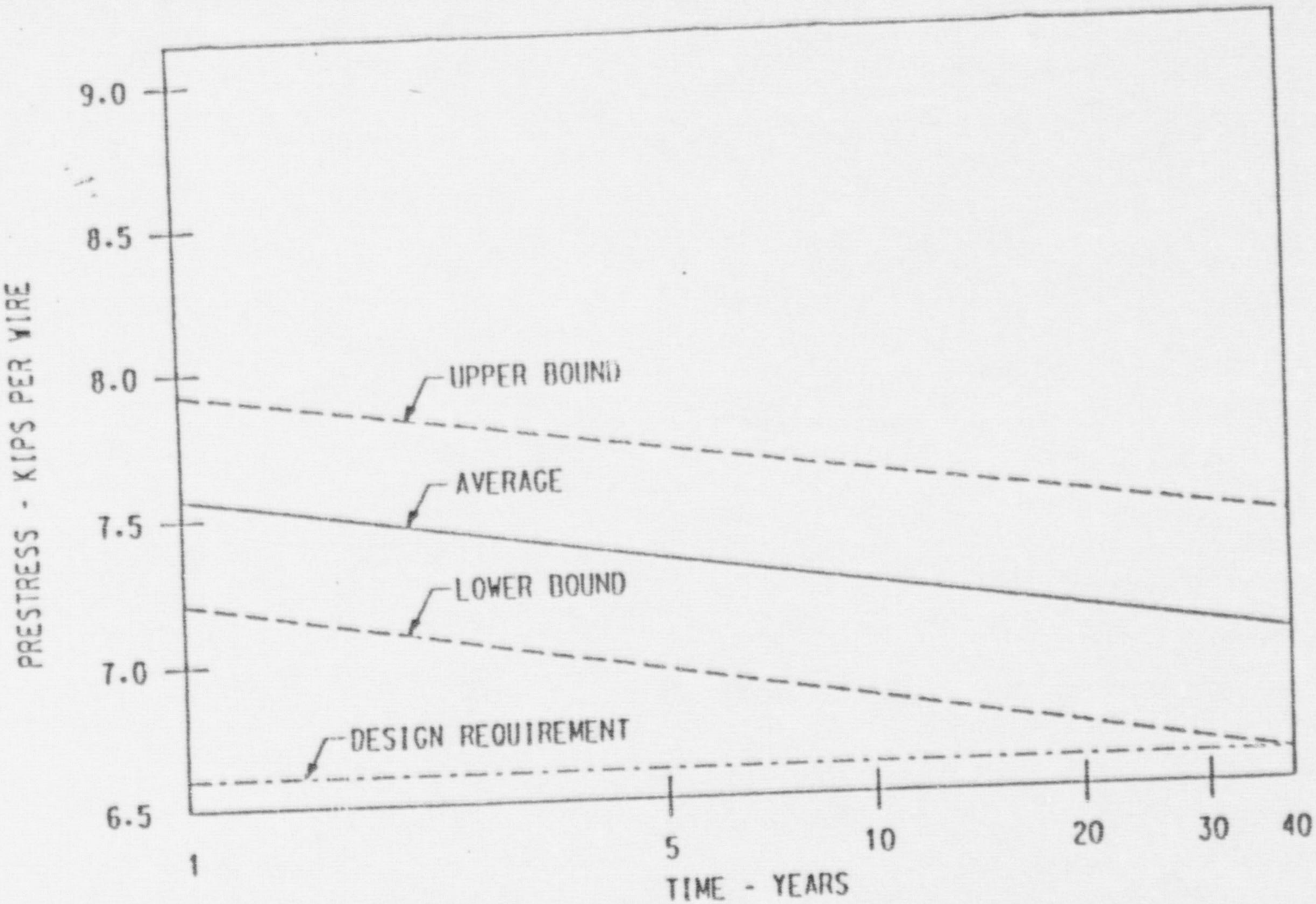


FIGURE 7 - WIRE FORCE VS. TIME - HORIZONTAL TENDONS

APPENDIX A

STATISTICAL REGRESSION ANALYSIS

I. INTRODUCTION

The purpose of this evaluation is to show, through scientifically accepted statistical regression analysis, that the horizontal post-tensioning system of the Arkansas unit 1 containment is performing its structural function as expected and is projected to maintain its integrity throughout the design service life of the containment. The analysis considered two conditions; 1) Evaluation of data on all surveyed horizontal tendons, and 2) Evaluation of data collected on five horizontal tendons which were surveyed more than one time and exhibited relatively low lift-off measurements.

II. BASIS FOR REGRESSION ANALYSIS

Per the shape of the curves of the relaxation loss at time functions exhibited in Fig. 5 of Ref. 1 and per the functional form of Eq. 3 of Ref. 1, it can be assumed that the tendon prestress force, Y at any time, T can be expressed as the logarithmic function of T given below.

$$Y = B_0 + B_1 \ln T \qquad (1)$$

Where B_0 and B_1 are constants to be estimated by regression analysis. Let $x = \ln T$, then Eq. 1 becomes

$$Y = B_0 + B_1 x \qquad (2)$$

Per Eq. 2, B_0 and B_1 can be determined by the linear regression analysis. Let $\hat{B}_0$ and $\hat{B}_1$ be the estimates for B_0 and B_1, respectively. Per Eqs. 9-12 and 9-13 on Pgs, 275 and 276 of Ref. 2,

$$\hat{B}_1 = \frac{\sum_{i=1}^{n} (x_i-\bar{x})\ (y_i-\bar{y})}{\sum_{i=1}^{n} (x_i-\bar{x})^2} \qquad (3)$$

$$\hat{B}_0 = \bar{y} - \hat{B}_1\bar{x} \qquad (4)$$

Where n = number of data points

x_i = ln T_i where T_i is the time at which the tendon prestress force is being measured, e.g., the initial time, the 1st surveillance, the 2nd surveillance, etc. Note that i = 1, 2,..., n.

y_i = the tendon prestress force at time, T_i for i = 1, 2,..., n

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i$$

$$\bar{y} = \frac{1}{n} \sum_{i=1}^{n} y_i$$

Let $\hat{y}$ be the estimate of y, then by Eq. 2 $\hat{y}$ can be expressed as:

$$\hat{y} = \hat{B}_0 + \hat{B}_1 x = \hat{B}_0 + \hat{B}_1 \ln T \qquad (5)$$

Physically $\hat{y}$ represents the <u>average</u> tendon prestress force at any time T.

Let y_L and y_u denote the <u>lower</u> and <u>upper</u> bound prestress force of a tendon at any time T, respectively. In the calculation, y_L is associated with 97.5% probability that the actual value of the tendon prestress force is larger than y_L; and y_u is associated with 2.5% probability that the actual value of the tendon prestress force is larger than y_u. Per Eq. 9.29 on Pg. 285 of Ref. 2, y_L and y_u can be determined from

$$y_L = \hat{y} - S_{\hat{y}}\, t_{n-2,\, 1-\frac{a}{2}} \qquad (6)$$

$$y_u = \hat{y} + S_{\hat{y}}\, t_{n-2,\, 1-\frac{a}{2}} \qquad (7)$$

where $t_{n-2,\, 1-\frac{a}{2}}$ is the t-statistics with n-2 degrees of freedom, and two sided confidence level of 100 (1-a)%. In

III. REFRENCES

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ARKANSAS UNIT 1 TENDONS
ALL SURVEILLANCE TENDONS

TABLE A - RECORDED PRESTRESS FORCE DATA AND RELATED STATISTIC CALCULATION

DATA NO.	TENDON NO.	TOTAL WIRE AREA (IN^2)	WIRE FORCE (K)	TENDON STRESS (KSI)	X= LnTi	(Xi-Xavg)^2	(Yi-Yavg)^2	(Xi-Xavg) (Yi-Yavg)
1	32H10	0.04909	8.781	178.88	-6.908	20.959	294.114	-78.514
2	32H20	0.04909	8.573	174.64	-6.908	20.959	166.736	-59.116
3	21H30	0.04909	8.513	173.42	-6.908	20.959	136.665	-53.520
4	31H40	0.04909	8.61	175.39	-6.908	20.959	186.769	-62.566
5	31H28	0.04909	8.61	175.39	-6.908	20.959	186.769	-62.566
6	31H29	0.04909	8.516	173.48	-6.908	20.959	138.098	-53.800
7	21H24	0.04909	8.484	172.83	-6.908	20.959	123.202	-50.816
8	31H27	0.04909	8.645	176.11	-6.908	20.959	206.765	-65.830
9	32H44	0.04909	8.657	176.35	-6.908	20.959	213.855	-66.950
10	21H36	0.04909	8.645	176.11	-6.908	20.959	206.765	-65.830
11	31H52	0.04909	8.456	172.26	-6.908	20.959	110.865	-48.204
12	32H32	0.04909	8.683	176.88	-6.908	20.959	229.626	-69.374
13	21H53	0.04909	8.61	175.39	-6.908	20.959	186.769	-62.566
14	21H45	0.04909	8.757	178.39	-6.908	20.959	277.584	-76.276
15	32H14	0.04909	8.811	179.49	-6.908	20.959	315.448	-81.312
16	21H42	0.04909	8.804	179.34	-6.908	20.959	310.403	-80.659
17	32H48	0.04909	8.822	179.71	-6.908	20.959	323.458	-82.337
18	31H38	0.04909	8.642	176.04	-6.908	20.959	205.011	-65.551
19	32H24	0.04909	8.573	174.64	-6.908	20.959	166.736	-59.116
20	31H40	0.04909	8.724	177.71	-6.908	20.959	255.636	-73.198
21	31H39	0.04909	8.642	176.04	-6.908	20.959	205.011	-65.551
22	31H41	0.04909	8.578	174.74	-6.908	20.959	169.377	-59.582
23	31H50	0.04909	8.645	176.11	-6.908	20.959	206.765	-65.830
24	32H46	0.04909	8.731	177.86	-6.908	20.959	260.216	-73.851
25	21H16	0.04909	8.484	172.83	-6.908	20.959	123.202	-50.816
26	31H11	0.04909	8.573	174.64	-6.908	20.959	166.736	-59.116
27	32H26	0.04909	8.508	173.31	-6.908	20.959	134.294	-53.054
28	31H47	0.04909	8.578	174.74	-6.908	20.959	169.377	-59.582
29	21H50	0.04909	8.61	175.39	-6.908	20.959	186.769	-62.566
30	31H35	0.04909	8.516	173.48	-6.908	20.959	138.098	-53.800
31	31H15	0.04909	8.666	176.53	-6.908	20.959	219.250	-67.789
32	32H13	0.04909	8.666	176.53	-6.908	20.959	219.250	-67.789
33	32H15	0.04909	8.666	176.53	-6.908	20.959	219.250	-67.789
34	21H41	0.04909	8.666	176.53	-6.908	20.959	219.250	-67.789
35	32H43	0.04909	8.666	176.53	-6.908	20.959	219.250	-67.789
36	31H52	0.04909	8.666	176.53	-6.908	20.959	219.250	-67.789
37	31H42	0.04909	8.666	176.53	-6.908	20.959	219.250	-67.789
38	21H12	0.04909	8.666	176.53	-6.908	20.959	219.250	-67.789
39	32H28	0.04909	8.666	176.53	-6.908	20.959	219.250	-67.789
40	32H10	0.04909	7.9	160.93	0.83	10.002	0.635	-2.520
41	32H20	0.04909	7.818	159.26	0.83	10.002	6.087	-7.803
42	21H30	0.04909	7.769	158.26	0.83	10.002	12.009	-10.960
43	31H40	0.04909	7.643	155.69	0.83	10.002	36.387	-19.077
44	31H28	0.04909	7.64	155.63	0.83	10.002	37.128	-19.270
45	31H29	0.04909	7.562	154.04	0.83	10.002	59.016	-24.295

(Continued)

DATA NO.	TENDON NO.	TOTAL WIRE AREA (IN^2)	WIRE FORCE (K)	TENDON STRESS (KSI)	X= LnTi	(Xi-Xavg)^2	(Yi-Yavg)^2	(Xi-Xavg)x (Yi-Yavg)
46	21H24	0.04909	7.549	153.78	0.83	10.002	63.155	-25.133
47	31H27	0.04909	7.437	151.50	0.83	10.002	104.623	-32.348
48	32H44	0.04909	7.829	159.48	0.83	10.002	5.032	-7.094
49	21H36	0.04909	7.611	155.04	1.194	12.415	44.676	-23.552
50	31H52	0.04909	7.967	162.29	1.194	12.415	0.323	2.001
51	32H32	0.04909	7.452	151.80	1.459	14.351	98.466	-37.591
52	21H53	0.04909	7.508	152.94	1.459	14.351	77.127	-33.269
53	21H45	0.04909	7.554	153.88	1.459	14.351	61.547	-29.719
54	32H14	0.04909	7.608	154.98	1.459	14.351	45.497	-25.552
55	21H42	0.04909	7.524	153.27	1.459	14.351	71.509	-32.034
56	32H48	0.04909	7.491	152.60	1.459	14.351	83.330	-34.581
57	31H38	0.04909	7.467	152.11	1.459	14.351	92.495	-36.433
58	32H24	0.04909	7.399	150.72	1.459	14.351	121.058	-41.681
59	32H40	0.04909	7.358	149.89	1.459	14.351	140.134	-44.845
60	31H39	0.04909	7.273	148.16	1.459	14.351	184.127	-51.404
61	31H41	0.04909	7.134	145.32	1.459	14.351	268.989	-62.130
62	31H50	0.04909	7.098	144.59	1.459	14.351	293.582	-64.909
63	31H40	0.04909	6.83	139.13	1.459	14.351	510.470	-85.590
64	32H46	0.04909	7.531	153.41	1.792	16.986	69.117	-34.264
65	21H16	0.04909	7.535	153.49	1.792	16.986	67.769	-33.928
66	31H11	0.04909	7.457	151.90	1.792	16.986	96.455	-40.477
67	32H26	0.04909	7.384	150.42	1.792	16.986	127.875	-46.605
68	31H47	0.04909	7.329	149.30	1.792	16.986	154.470	-51.223
69	21H50	0.04909	7.316	149.03	1.792	16.986	161.122	-52.314
70	32H14	0.04909	7.31	148.91	1.792	16.986	164.240	-52.818
71	21H42	0.04909	7.181	146.28	1.792	16.986	238.500	-63.648
72	32H40	0.04909	7.092	144.47	1.792	16.986	297.785	-71.120
73	31H35	0.04909	7.039	143.39	1.792	16.986	336.212	-75.570
74	31H15	0.04909	7.267	148.03	2.30	21.457	187.459	-63.422
75	32H13	0.04909	7.049	143.59	2.30	21.457	328.784	-83.993
76	32H15	0.04909	6.973	142.05	2.30	21.457	387.325	-91.165
77	21H41	0.04909	6.948	141.54	2.30	21.457	407.629	-93.524
78	32H43	0.04909	6.836	139.25	2.30	21.457	504.962	-104.092
79	32H14	0.04909	6.728	137.05	2.30	21.457	608.678	-114.283
80	32H44	0.04909	6.705	136.59	2.30	21.457	632.016	-116.453
81	31H52	0.04909	7.12	145.04	2.71	25.378	278.425	-84.059
82	31H42	0.04909	7.09	144.43	2.71	25.378	299.193	-87.138
83	21H12	0.04909	7.07	144.02	2.71	25.378	313.453	-89.190
84	32H28	0.04909	6.73	137.10	2.71	25.378	606.669	-124.081
				Yavg= 161.726	Xavg= -2.330	SUM1= 1540.389	SUM2= 16659.912	SUM3= -4855.10 BETA1= -3.152 BETA0= 154.383
						t= 1.995		16.552

ARKANSAS UNIT 1 TENDONS
ALL SURVEILLANCE TENDONS

TABLE B - THE AVERAGE, LOWER BOUND AND UPPER BOUND PRESTRESS AS A TIME FUNCTION FOR CURVE PLOTTING

DATA NO.	Ti (yr.)	Xi= LnTi	Sy^2	AVG. PRE-STRESS KIP/WIRE	LOWER BOUND PRE-STRESS	UPPER BOUND PRE-STRESS
1	0.001	-6.90775	16.97429	8.65	8.244	9.051
2	2	0.693147	16.84726	7.47	7.069	7.873
3	4	1.386294	16.89745	7.36	6.962	7.767
4	6	1.791759	16.93160	7.30	6.898	7.704
5	8	2.079441	16.95797	7.26	6.854	7.660
6	10	2.302585	16.97965	7.22	6.819	7.626
7	12	2.484906	16.99815	7.19	6.790	7.598
8	14	2.639057	17.01436	7.17	6.766	7.574
9	16	2.772588	17.02881	7.15	6.746	7.554
10	18	2.890371	17.04187	7.13	6.727	7.536
11	20	2.995732	17.05381	7.12	6.711	7.520
12	22	3.091042	17.06482	7.10	6.696	7.505
13	24	3.178053	17.07503	7.09	6.682	7.492
14	26	3.258096	17.08458	7.07	6.670	7.479
15	28	3.332204	17.09354	7.06	6.658	7.468
16	30	3.401197	17.10198	7.05	6.647	7.457
17	32	3.465735	17.10997	7.04	6.637	7.448
18	34	3.526360	17.11756	7.03	6.628	7.438
19	36	3.583518	17.12479	7.02	6.619	7.429
20	38	3.637586	17.13170	7.02	6.610	7.421
21	40	3.688879	17.13830	7.01	6.602	7.413
				AVG1= 7.215	AVG2= 6.811	AVG3= 7.620

ARKANSAS UNIT 1 TENDONS
FIVE TENDONS WITH DOUBLE MEASURMENTS

TABLE A - RECORDED PRESTRESS FORCE DATA AND RELATED STATISTIC CALCULATION

DATA NO.	TENDON NO.	TOTAL WIRE AREA (IN^3)	WIRE FORCE (K)	TENDON STRESS (KSI)	X= LnTi	(Xi-Xavg)^2	(Yi-Yavg)^2	(Xi-Xavg)X (Yi-Yavg)
1	21H42	0.04909	8.804	179.34	-6.908	34.254	493.645	-130.035
2	31H40	0.04909	8.61	175.39	-6.908	34.254	333.654	-106.906
3	32H14	0.04909	8.811	179.49	-6.908	34.254	500.002	-130.870
4	32H44	0.04909	8.656	176.33	-6.908	34.254	368.765	-112.390
5	32H40	0.04909	8.724	177.71	-6.908	34.254	423.885	-120.497
6	31H40	0.04909	7.643	155.69	0.875	3.727	2.052	-2.765
7	32H44	0.04909	7.829	159.48	0.875	3.727	5.554	4.550
8	21H42	0.04909	7.524	153.27	1.459	6.319	14.872	-9.694
9	31H40	0.04909	6.83	139.13	1.482	6.435	323.775	-45.645
10	32H14	0.04909	7.608	154.98	1.459	6.319	4.602	-5.393
11	32H40	0.04909	7.358	149.89	1.459	6.319	52.388	-18.194
12	21H42	0.04909	7.181	146.28	1.841	8.385	117.584	-31.399
13	32H14	0.04909	7.31	148.91	1.792	8.105	67.499	-23.389
14	32H40	0.04909	7.092	144.47	1.792	8.105	160.190	-36.031
15	32H14	0.04909	6.728	137.05	2.303	11.274	402.867	-67.394
16	32H44	0.04909	6.705	136.59	2.322	11.407	421.895	-69.374
				Yavg= 157.126	Xavg= -1.055	SUM1= 251.389	SUM2= 3693.227	SUM3= -905.426 BETA1= -3.602 BETA0= 153.326
						t= 2.145		30.868

ARKANSAS UNIT 1 TENDONS
FIVE TENDONS WITH DOUBLE MEASURMENTS

TABLE B - THE AVERAGE, LOWER BOUND AND UPPER BOUND PRESTRESS AS A TIME FUNCTION FOR CURVE PLOTTING

DATA NO.	Ti (yr.)	Xi= LnTi	Sy^2	AVG. PRE-STRESS KIP/WIRE	LOWER BOUND PRE-STRESS	UPPER BOUND PRE-STRESS
1	0.001	-6.90775	37.00334	8.75	8.108	9.389
2	2	0.693147	33.17260	7.40	6.798	8.011
3	4	1.386294	33.52919	7.28	6.672	7.891
4	6	1.791759	33.79247	7.21	6.598	7.822
5	8	2.079441	34.00376	7.16	6.545	7.773
6	10	2.302585	34.18165	7.12	6.504	7.735
7	12	2.484906	34.33607	7.09	6.470	7.704
8	14	2.639057	34.47300	7.06	6.442	7.678
9	16	2.772588	34.59633	7.04	6.417	7.656
10	18	2.890371	34.70875	7.02	6.395	7.636
11	20	2.995732	34.81220	7.00	6.376	7.618
12	22	3.091042	34.90813	6.98	6.358	7.602
13	24	3.178053	34.99765	6.96	6.342	7.588
14	26	3.258096	35.08165	6.95	6.327	7.574
15	28	3.332204	35.16082	6.94	6.313	7.562
16	30	3.401197	35.23574	6.93	6.300	7.550
17	32	3.465735	35.30688	6.91	6.288	7.540
18	34	3.526360	35.37464	6.90	6.277	7.530
19	36	3.583518	35.43935	6.89	6.266	7.520
20	38	3.637586	35.50130	6.88	6.256	7.511
21	40	3.688879	35.56074	6.87	6.247	7.502
				AVG1= 7.112	AVG2= 6.490	AVG3= 7.733