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DUKE POWER

March 14, 1996

U.S. Nuclear Regulatory Commission
Attention Document Control Desk
Washington, DC 20555

Subject: Duke Power Company
Oconee Nuclear Station, Unit 3
Docket No. 50-287
Reactor Building Post-Tensioning System
Sixth Surveillance
Request for Additional Information

In a letter dated January 19, 1996, the NRC requested additional information regarding the Unit 3 Reactor Building Post-Tensioning System sixth surveillance. This letter required Duke to submit the information by February 23, 1996. However, additional time was necessary to complete our review of the response and supporting analyses. As discussed in a phone conversation with your staff on February 21, 1996, it was agreed that it would be acceptable to delay our response until March 14, 1996. Accordingly, please find attached the reply to questions provided by the NRC.

If there are any questions you may contact D. A. Nix at (864) 885-3634.

Very truly yours,

J W Hampton

J. W. Hampton
Site Vice- President

Attachment

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A001
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<u>NRC Request #1a, Re-analyze lift-off data from all surveillances and modify, if applicable, each lift-off force by the difference between "as-found" and "as-left" values obtained from preceding surveillances.</u>

Each tendon lift-off force, modified as necessary for the difference between 'as-found' and 'as-left' forces, along with pertinent inspection data from all surveillances performed on Oconee Nuclear Station, Unit 3, is tabulated in Appendix A. Tabulation of data and required computations were performed using Microsoft Excel©, Version 5.0.

<u>NRC Request #1b, Plot all lift-off force data (i.e., individual data obtained without averaging or taking mean values) on a graph similar to that shown in Figure 2 of Regulatory Guide (RG) 1.35.1 and include the minimum required value (MRV) identified for each group of tendons. Perform a regression analysis for each group of tendons on the basis of the plotted data to establish the trend of the prestress force.</u>

<u>Time versus Lift-off Force Plots</u>
Appendix B contains time versus lift-off force plots for all tendons inspected on Oconee Nuclear Station, Unit 3. Plotted lift-off forces are the modified values as directed per NRC request *1a*. Minimum required value (MRV) for the respective tendon group - dome, horizontal, and vertical - is also shown on each plot. Plots were performed using Microsoft Excel©, Version 5.0.

<u>Regression Analyses</u>
A regression analysis was performed for each tendon group - dome, horizontal, and vertical - on the basis of the plotted data (i.e., time versus modified lift-off forces). Regression analysis summaries and best-fit line plots are also contained in Appendix B.

Regression analyses were performed on a Hewlett-Packard HP 48GX calculator using the pre-programmed statistical function, *FIT DATA* [Reference 23]. The HP 48 can use any of four general regression models in the attempt to quantify the relationship between data in two columns from the current statistical matrix:

Linear Fit	$y = b + mx$
Logarithmic Fit	$y = b + m \ln x$
Exponential Fit	$y = be^{mx}$ or $\ln y = \ln b + mx$
Power Fit	$y = bx^{m}$ or $\ln y = \ln b + m \ln x$

For each general model, *FIT DATA* will determine an intercept (b) and a slope (m) that correspond to the least-squares fit for that model. It also computes and returns the covariance and the correlation coefficient for the regression. Regression analysis revealed that a logarithmic function provided the best-fit line for the plotted data. Plots were performed using Microsoft Excel©, Version 5.0.

<u>Conclusion</u>
Computation of modified tendon lift-off forces in accordance with NRC item *1a* is conservative. The requested computation adjusts all subsequent lift-off force observations for detensioned tendons that experienced a change between 'as-found' and 'as-left' seating forces. Modified values computed for these tendons do not account for the associated change in prestress loss due to steel

relaxation and concrete creep. Each of these time-dependent sources of prestress loss is also directly proportional to prestressing force; therefore, change in a tendon seating force will cause a commensurate change in rate and magnitude of prestress loss due to steel relaxation and concrete creep. In most instances, surveillance tendons have sustained an increased loss of prestress relative to general tendon population.

While identification of a tendon at a prestressing force well below design is unacceptable, minor variations in level of prestress among tendons, even within same group, are expected. The containment structure relies on an *average* level of prestress in order to satisfy its design basis requirements. The post-tensioning system is considered to be acceptable provided *average* prestressing level for a tendon group is equal to, or greater than, the MRV for that group. In order to remain acceptable, level of prestress must exceed its MRV throughout life of the plant. Despite conservative manner in which modified tendon lift-off forces were computed, average dome tendon surveillance group lift-off force remains within 95.7 percent of its MRV, while average lift-off force for horizontal and vertical tendon surveillance groups each exceeds its MRV.

Observed tendon lift-off forces are subject to various sources of error, the greatest of which is associated with actual measurement. Ram/gauge calibration and lift-off pressure reading accuracy may produce either slightly conservative, or non-conservative, tendon lift-off force observations. As per reference [31], gauge reading tolerance is +/-0.5 percent of span, where span equals 10,000 psig (i.e., 50 psig). As per reference [8], acceptable lift-off pressure reading is +/-50 psig. Combined effects of these tolerances produce a typical lift-off force reading accuracy for a ninety (90) wire tendon of +/-0.14 kips per wire [Reference 24]. Oconee has recently purchased new tendon surveillance equipment which will greatly improve accuracy of our lift-off force measurements in the future.

Computation of MRV for each tendon group is based upon design prestressing forces stipulated in references [9], [10], and [11]. Containment structure analyses which support these design prestressing forces were performed using 1960s technology and methodologies. A re-analysis of the Oconee Nuclear Station Containment structures (one similar to that performed in 1994 for Florida Power & Light Company's Turkey Point Units 3 & 4 Containment structures), using state-of-the-art analytical methods and tools, would in all probability demonstrate ability of the containment structure to satisfy all design licensing basis requirements under prestressing forces lower than original design MRVs. This analysis would recognize and quantify "active" behavior of the post-tensioning system when the containment structure is subjected to effects of internal pressurization (i.e., increase in applied prestressing force as the structure expands [Reference 29]).

Oconee recognizes original estimates for loss of prestress may have been non-conservative. Computation of prestress loss due to steel relaxation was based upon an assumed average tendon seating stress of 70 percent of nominal Ultimate Tensile Strength (UTS) and following ambient temperature conditions [Reference 30]:

Vertical Tendon Group	79°F
Horizontal Tendon Group	71°F
Dome Tendon Group	74°F

Actual seating stresses were in the range of 71 and 73.5 percent of nominal UTS [Reference 24]. Actual ambient temperature conditions (in particular those of the dome tendon group) are believed to have exceeded assumed values. Both preceding conditions would contribute to increased prestress loss as a result of steel relaxation.

Proposed Corrective Actions

1. In order to validate current level of prestress force and loss of prestress trends for each tendon group indicated in this response, Oconee will analyze surveillance data for Units 1 and 2 in a manner similar to that performed in response to NRC request 1a for Unit 3. Surveillance data for each unit will then be adjusted, as necessary, to account for excessive steel relaxation and/or creep of concrete as discussed above.

2. Based upon the outcome of the analyses conducted in corrective action #1, Oconee will perform, as necessary, calculations demonstrating acceptability of *average* prestress force of tendon groups - dome, horizontal, or vertical - which fall below the respective MRV. Because accuracy of computed average prestress force for each tendon group will be increased by maximizing the number of sample data points used in each calculation, average prestress forces for each unit will be computed as follows:

   a. Unit 1: average prestress force for each tendon group - dome, horizontal, and vertical - will be calculated from recorded surveillance data for both Units 1 and 2.

   b. Unit 3: average prestress force for each tendon group will be calculated from surveillance data for both Units 2 and 3.

   c. Unit 2: average prestress force for each tendon group will be calculated from surveillance data for all three (3) units.

   Oconee believes this methodology for average prestress force computation is a reasonable extrapolation of guidance provided in section IWL-2421 of reference [32] section C.1.5 of reference [33]. Section IWL-2421 of reference [32] concerns modification of examination requirements for sites with two plants, "if both containments utilize the same prestressing system and are essentially identical in design, if post-tensioning operations for the two containments were completed not more than 2 years apart, and if both containments are similarly exposed to, or protected from, the outside environment." Section C.1.5 of reference [33] also concerns modification of examination requirements for any two containments at the same site which are shown to satisfy all three of the following conditions:

      a. The containments are identical in all aspects such as size, tendon system, design, materials of construction, and method of construction.

      b. Their ISITs [Initial Structural Integrity Tests] were performed within two years of each other.

      c. There is no unique situation that may subject either containment to a different potential for structural or tendon deterioration.

   All three Oconee containments utilize the same prestressing system; are essentially identical in design, materials of construction, and method of construction; and, are exposed to the same outside environment. No unique situation exists that may subject any containment to a different potential for structural or tendon deterioration. Post-tensioning operations and ISITs for each of the Oconee containments occurred during the time frames tabulated below. Time frames for the performance of these activities for Units 1 and 2 and for Units 2 and 3 satisfy the maximum 2 year separation criteria of both references [32] and [33].

Unit	Post-Tensioning Operations	ISIT
1	May - November 1970 [Reference 12]	July 29 - August 4, 1971 [Reference 34]
2	July - December 1971 [Reference 13]	June 14 - 22, 1973 [Reference 35]
3	November 1972 - June 1973 [Reference 14]	May 1 - 7, 1974 [Reference 36]

3. Oconee will identify and evaluate potential causes of loss of prestress force in excess of those values computed during original plant design.

4. Oconee will revise Technical Specification Section 4.4.2 in order to allow the implementation of a random tendon selection process in accordance with Reg. Guide 1.35 for the next scheduled tendon surveillance in April 1997 (Oconee Unit 1 Outage EOC17). By allowing Oconee to obtain new data, this change to our containments' post-tensioning system surveillance program will enhance our knowledge of the current state of the post-tensioning system and our ability to predict its future state.

5. If corrective actions 1, 2 and 4 indicate that the Oconee containments' post-tensioning system provides an *average* level of prestress which is less than that necessary to satisfy its design basis requirements throughout the life of the plant, Oconee will re-analyze the containment structure using state-of-the-art analytical methods and tools in order to establish new MRV for each tendon group. Oconee firmly believes that each of these MRVs will be less than the respective value documented in response to NRC request *1c*.

NRC Request #1c, Indicate how the MRV is determined for each group of tendons.

Appendix C contains computations of the Minimum Required Value (MRV) for each tendon group and the supporting information for these calculations. MRVs are shown in the table below. Analysis was performed using Microsoft Excel©, Version 5.0.

Unit	Tendon Group	MRV [kips/tendon]	MRV for typical 90 wire tendon [kips/wire]
1	Dome	633.9	7.04
1	Horizontal Tendons (Elev. 954+4 to 787+8)	586.3	6.51
1	Horizontal Tendons (Elev. 787+8 to 776+0)	583.3	6.48
1	Vertical	656.2	7.29
2	Dome	633.9	7.04
2	Horizontal Tendons (Elev. 954+4 to 787+8)	585.3	6.50
2	Horizontal Tendons (Elev. 787+8 to 776+0)	583.3	6.48
2	Vertical	652.4	7.25
3	Dome	633.9	7.04
3	Horizontal Tendons (Elev. 954+4 to 787+8)	584.3	6.49
3	Horizontal Tendons (Elev. 787+8 to 776+0)	583.3	6.48
3	Vertical	660.0	7.33

NRC Request #1d, Provide all data used in the regression analysis performed in response to Request # 1b.

All data used in the regression analyses performed for NRC request 1b is contained in Appendix B.

NRC Request #2, Indicate whether Oconee plans to adopt a random tendon selection process for the next scheduled tendon surveillance.

Oconee Nuclear Station agrees with the NRC that random tendons should be selected for future surveillances.

The NRC has proposed 10CFR50.55(a) be revised to incorporate ASME Code, Section XI, Subsection IWL, 1992 Edition through 1992 Addenda. This rule, expected to be approved by the NRC in 1996, will mandate tendon surveillances be performed in accordance with IWL. IWL requires tendons be selected at random for surveillance, and imposes requirements similar to those currently found in Reg. Guide 1.35. Tendon surveillance requirements would then be incorporated into the Licensee's ISI Plan. If the proposed rule is approved, Oconee will be required to comply with provisions of IWL and tendons will be randomly selected for future surveillances.

Oconee prefers to avoid a temporary programmatic change which would randomly select tendons for surveillance. However, because Oconee does not anticipate NRC approval of the proposed rule change in time for the next scheduled post-tensioning system surveillance in April 1997 (Oconee Unit 1 Outage EOC17), Oconee will implement a random tendon selection process in accordance with Reg. Guide 1.35 for 1EOC17 inspection. This action will require a change to Oconee Nuclear Station Technical Specification Section 4.4.2.

NRC Request #3

Shim thicknesses were recorded during tendon inspection activities and were listed in the surveillance report for the purpose of completeness. These values bear no further significance; however, they may be used to approximate tendon seating forces.

Tendon projections along with force measurements were recorded for detensioned/retensioned tendons in accordance with Reference 8. Measured elongations and the associated recorded changes in the applied force are shown in the table below.

Tendon	Shop End		Field End	
	Δ Force [kips]	Elongation [inches]	Δ Force [kips]	Elongation [inches]
3D28	612.7	3-3/4	612.2	3-15/16
13H9	612.2	3-11/16	612.7	4
53H10	612.7	3-1/2	612.2	4
61V16	618.8	5-1/8	606.1	5-3/4

<u>NRC Request #4, "Excessive loss/addition of grease to vertical surveillance tendons"</u>

During each inspection of the nine surveillance tendons, an amount of grease is lost from tendon sheaths when tendon anchorage caps are removed. The amount of grease lost increases when the tendon is detensioned for wire removal. During this procedure, shims are removed and the tendon is often worked back and forth within its sheath in order to facilitate wire removal. The amount of grease lost and replaced can also be affected by ambient temperature at the time of the inspection as this directly affects the viscosity of the corrosion protective grease within the sheath.

The tendency for grease to escape through the open sheath end is most pronounced during the detensioning of a vertical surveillance tendon. Once top and bottom anchorage caps and shims are removed, the effect of gravity on a column of grease approximately 205 feet tall [Reference 1], aided by the movement of the tendon within the sheath, tends to cause a significant volume of grease to flow out of the lower end of the tendon sheath.

Although every effort is made to replace the lost grease, the amount returned has historically been less than that removed. This phenomenon is attributed to the fact that voids tend to be formed at various locations along the length of the tendon sheath as grease flows out the open sheath end. In order to completely refill the tendon sheath, the remaining grease would have to be sufficiently heated to reduce its viscosity to the point that all intermediate voids collapsed. This would in turn allow new grease to fill the sheath from the top.

Differences between the amount of grease lost and that replaced during any one surveillance period can result from:

1) grease losses incurred during previous inspections,

2) natural consolidation of the remaining grease within the sheath over time as a result of ambient temperature effects (i.e., reduced viscosity), and

3) forced flow of the grease column during wire removal (i.e., movement of the tendon back and forth within the tendon sheath).

NRC Request #4, "Potential corrosion of tendon wires resulting from grease loss"

As a result of the pre-installation measures taken to assure the protection of the tendons and the corrosion preventive properties of the sheath filler outlined below, minor losses of grease will not result in corrosion of the tendons. The only tendons which may have lost any appreciable quantity of grease are the surveillance tendons which have had their caps repeatedly removed and have undergone several iterations of detensioning/retensioning activities. Despite the fact these tendons represent the worst case for grease loss, not one wire sample of the one hundred and sixty-two (162)[Footnote 1] samples visually examined and tensile tested to date has demonstrated any form of corrosion or failed to conform to the requirements of ASTM A421 [Reference 5].

Each tendon consists of ninety inch diameter wires with buttonheaded BBRV type anchorages, furnished by The Prescon Corporation. A thin film of No-Ox-Id (R) 500, as manufactured by Dearborn Chemical Company or Visconorust 1601, manufactured by Viscosity Oil Company, was applied to the prestressing steel after fabrication in accordance with the manufacturer's instructions. The steel was then wrapped before shipment to the site. The steel was not handled, shipped, or stored in a manner that would expose it to inclement weather or injurious agents such as chloride containing solutions.

Corrosion protection of the tendons is provided by grease injected into the sheaths under pressure. Grease is Visconorust 2090P manufactured by Viscosity Oil Company. The grease was sampled and laboratory tested to establish conformance with specifications and for deleterious substances such as water soluble chlorides, nitrates, and sulfides.

Visconorust 2090P Casing Filler is a petroleum based corrosion preventive designed for bulk application and extended protection. Its corrosion preventive properties include [References 2, 3 and 4]:

1) A three phase protective system starting with a polar agent preferentially wetting the wires and displacing any moisture, rust preventive additives molecularly attached to the wetting agent and a petroleum barrier completing the resistant coating.

2) The property to emulsify any moisture picked up in the system while being pumped through the casing and either carrying it out the other end or nullifying its rusting ability if the moisture is trapped in the casing.

3) Reserve Alkalinity - Base Number of 3. The basic formulation of Visconorust 2090P is very stable and resistant to exterior moisture encroachment as well as mild acids and alkali. However, because of the probability of picking up moisture as the rust preventive is pumped through the tendons, an additional safety factor, besides the barrier action, is available to neutralize any acids that might form between the interface of the moisture and rust preventive.

Footnotes:

1. Six surveillances have been completed for each of Oconee Units 1, 2 and 3. During each inspection period one wire is removed from one tendon of each group - hoop, vertical, and dome - and visually examined along its entire length. Three wire samples are obtained from each wire removed - one at each end and one at the middle. Thus, a total of 54 wires have been visually examined and 162 wire samples tensile tested to date (3 samples per wire * 3 wires per inspection period * 6 inspection periods per unit * 3 units). [Reference 8]

4) Only trace amounts of water soluble chlorides, sulfides, or nitrates (1 PPM, 1 PPM, and 4 PPM, respectively).

5) A plugging agent designed to supplement the natural tendency of the microwax crystals and amorphus solid components to form a filter cake bridging any hair line cracks in the concrete, with which the casing filler might come in contact.

6) Self-healing qualities at the ambient temperature expected during operation, to take care of any voids created by wire movement.

7) Thixotropic properties that provide pumpability below 50°F.

NRC Request question #4, "Potentially detrimental effect of grease on concrete"

Prestressed concrete ducts are lined with steel sheaths to prevent interaction between concrete and corrosion-inhibiting grease. Grease leakage can occur at tendon anchorage with a small potential for leakage through tendon ducts. The containment concrete shell is 3-3/4 feet thick in the vertical wall and 3-1/4 feet thick in the dome, and any grease penetration into concrete would be minor (i.e., a few inches). Grease used is a petroleum-based product. According to references [6] and [7], products derived from petroleum, when free of fatty oil additives or other potentially acidic materials, are identified as "[M]aterials that do not attack concrete" and are considered normally harmless to mature concrete. Some of these materials can, however, cause undesirable discoloration. To date, there exists no evidence which supports the assumption that corrosion preventive grease has any detrimental effect on concrete.

References

1. *Oconee Nuclear Station, Reactor Building Containment Report*, by J. A. Johnson (Duke Power Company) dated 24 April 1991.

2. Oconee Nuclear Station FSAR Section 3.8.1.1.

3. Oconee Nuclear Station FSAR Section 3.8.1.6.2.3.

4. Oconee Nuclear Station FSAR Section 3.8.1.6.2.6.

5. ASTM A421.

6. Waddell, J. J., *Concrete Construction Handbook*, 2nd Edition, McGraw-Hill Book Co., New York, NY, 1974.

7. ACI 515.1R-79 (Revised 1985), *A Guide to the Use of Waterproofing, Dampproofing, Protective, and Decorative Barrier Systems for Concrete*.

8. Procedure MP/0/A/1400/022, *Tendon - Reactor Building - Surveillance*.

9. Original plant calculations performed by Bechtel Corporation, Gaithersburg, Maryland, circa 1971.

10. Duke Power Company drawing O-0077A, *Oconee Nuclear Station - Units 1, 2 & 3, Reactor Building, Prestressing Requirements, Roof and Misc. Details*.

11. Duke Power Company drawing O-0077B, *Oconee Nuclear Station - Units 1, 2 & 3, Reactor Building, Prestressing Requirements, Wall Details*.

12. *Prestressing Report, Reactor Building, Duke Power Company, Oconee Nuclear Station, Unit 1*, dated April 1971 by Bechtel Corporation.

13. *Prestressing Report, Reactor Building, Duke Power Company, Oconee Nuclear Station, Unit 2*, dated March 1972 by Bechtel Corporation.

14. *Prestressing Report, Reactor Building, Duke Power Company, Oconee Nuclear Station, Unit 3*, dated October 1973 by Bechtel Corporation.

15. Duke Power Company drawing O-0077C, *Oconee Nuclear Station - Units 1, 2 & 3, Reactor Building, Prestressing Requirements, Typical Details*.

16. Duke Power Company, Oconee Nuclear Station FSAR Section 3.8.1.1.

17. Duke Power Company, Oconee Nuclear Station FSAR Section 3.8.1.7.6.

18. Duke Power Company, Oconee Nuclear Station Technical Specification Section 4.4.2.

References (cont.)

19. Prescon Corporation drawing OM 100-225, *Oconee Nuclear Station, 150° - 210°, Horizontal Tendon Placement from Elev. 775+0 to Elev. 831+0.*

20. Prescon Corporation drawing OM 100-226, *Oconee Nuclear Station, 210° - 270°, Horizontal Tendon Placement from Elev. 775+0 to Elev. 831+0.*

21. Prescon Corporation drawing OM 100-292, *Oconee Nuclear Station, 30° - 90°, Horizontal Tendon Placement from Elev. 825+0 to Elev. 886+0.*

22. Prescon Corporation drawing OM 100-297, *Oconee Nuclear Station, 330° - 30°, Horizontal Tendon Placement from Elev. 825+0 to Elev. 886+0.*

23. *Hewlett-Packard HP 48G Series User's Guide*, ©Copyright Hewlett-Packard Company 1993.

24. Duke Power Company Calculation OSC-2125, *Reactor Building Post-Tensioned Tendon Surveillance Program Review.*

25. Oconee Nuclear Station Unit 3 Containment Building Tendon Surveillance Report, Fourth Inspection.

26. Oconee Nuclear Station Unit 3 Containment Building Tendon Surveillance, Third Inspection field surveillance data for containment tendon 53H10.

27. Oconee Nuclear Station Unit 3 Containment Building Tendon Surveillance Report, Fifth Inspection.

28. Proposed Resolution to OEP IN 91-80.

29. Oconee Nuclear Station FSAR Section 3.8.1.5.2.

30. Letter dated 6 October 1969 from L. Q. Mills (Prescon Corporation) to M. Malcom (Bechtel Corporation).

31. Procedure IP/0/B/1603/001, *Calibration of Pressure Test Gauges.*

32. ASME Code, Section XI, Subsection IWL, 1992 Edition through 1992 Addenda.

33. Regulatory Guide 1.35, *Inservice Inspection of Ungrouted Tendons in Prestressed Concrete Containments*, Revision 3 dated July 1990.

34. *Duke Power Company, Oconee Nuclear Station, Unit 1, Docket No. 50-269, Structural Integrity Test Report of the Reactor Containment Building* prepared by Bechtel Corporation, Gaithersburg, Maryland and dated 29 October 1971.

References (cont.)

35. *Duke Power Company, Oconee Nuclear Station, Unit 2, Docket No. 50-270, Structural Integrity Test Report of the Reactor Containment Building* prepared by Bechtel Corporation, Gaithersburg, Maryland and dated 20 September 1973.

36. *Duke Power Company, Oconee Nuclear Station, Unit 3, Docket No. 50-287, Structural Integrity Test Report of the Reactor Containment Building* prepared by Bechtel Power Corporation, Gaithersburg, Maryland and dated 5 August 1974.

APPENDIX A

Table A-1: Dome Tendons - Surveillance Data and Modified Lift-off Forces

Surv. Tendon Id.	Inspection / Date	Surv. Interval mnths.	Time from Installation hrs.	Method of Ram Pressure to Force Conversion	Shop End Lift-off Pressure (psi)[2]		Shop End Lift-off Force (kips)[2]		Field End Lift-off Pressure (psi)[2]		Field End Lift-off Force (kips)[2]		Average Lift-off Force (kips)[2]	
1D28	Date Stressed 12/7/72[1, 4]			Ram Area[9]		6600		793.3		6650		799.3		796.3
	1st 4/75[4]	28	20440	Ram Area[9]	5566	6335	669	761.5	5616	6393	675	768.4	672.0	765.0
	2nd 5/79[4]	49	56210	Ram Area[9]	5808		698.1		5650		679.1		688.6	
	3rd 9/82[4]	40	85410	Ram Area[9]	5967	5867	717.2	705.2	5800	5800	697.2	697.2	707.2	701.2
	4th 3/87[5]	54	124830	Calibration									742.0	723.0
	5th 3/91[7]	48	159870	Calibration			720.9	697.4			579.7	667.6	650.3	682.5
	6th 6/95	51	197100	Calibration	5800		695.5		5950		716.6		706.1	
2D28	Date Stressed 12/7/72[1, 4]			Ram Area[9]		6600		793.3		6500		781.3		787.3
	1st 4/75[4]	28	20440	Ram Area[9]	5666		681.1		5800		697.2		689.1	
	2nd 5/79[4]	49	56210	Ram Area[9]	5417	5475	651.1	658.1	5750	5800	691.2	697.2	671.1	677.6
	3rd 10/82[4]	41	86140	Ram Area[9]	5400	6000	649.1	721.2	5533	5767	665.1	693.2	657.1	707.2
	4th 3/87[5]	53	124830	Calibration									723	
	5th 3/91[7]	48	159870	Calibration			667.6	667.6			667.9	667.9	667.8	667.8
	6th 6/95	51	197100	Calibration	5600		671.2		5700		685.9		678.6	
3D28[8]	Date Stressed 12/7/72[1, 4]			Ram Area[9]		6500		781.3		6700		805.3		793.3
	1st 4/75[4]	28	20440	Ram Area[9]	5716		687.1		5900		709.2		698.1	
	2nd 5/79[4]	49	56210	Ram Area[9]	5550		667.1		5683		683.1		675.1	
	3rd 10/82[4]	41	86140	Ram Area[9]	5583	5825	671.1	700.2	5700	6200	685.1	745.2	678.1	722.7
	4th 3/87[5]	53	124830	Calibration									736	
	5th 3/91[7]	48	159870	Calibration			679.3	661.7			667.9	644.3	673.6	653.0
	6th 6/95	51	197100	Calibration	5500	5900	661.4	710.4	5800	5600	695.5	671.2	678.5	690.8

Table A-1: Dome Tendons - Surveillance Data and Modified Lift-off Forces (cont.)

Surv. Tendon Id.	Inspection / Date	Surv. Interval mnths.	Time from Installation hrs.	Cumulative Number of Wires Missing/Removed[3]	Initial Number of Wires[1]	Effective Number of Wires	Force per Wire[2] kips		Stress[Note 2] f_p = force / ΠR^2[2] (R = 0.25" / 2) ksi	
1D28	Date Stressed 12/7/72[1, 4]				93	93		8.56		174.4
	1st 4/75[4]	28	20440	1		92	7.23	8.31	147.2	169.4
	2nd 5/79[4]	49	56210	1		92	7.49		152.5	
	3rd 9/82[4]	40	85410	1		92	7.69	7.62	156.6	155.3
	4th 3/87[5]	54	124830	2		91	8.07	7.95	164.3	161.9
	5th 3/91[7]	48	159870	2		91	7.15	7.50	145.6	152.8
	6th 6/95	51	197100	2		91	7.76		158.1	
2D28	Date Stressed 12/7/72[1, 4]				93	93		8.47		172.5
	1st 4/75[4]	28	20440			93	7.41		151.0	
	2nd 5/79[4]	49	56210	1		92	7.22	7.37	147.0	150.0
	3rd 10/82[4]	41	86140	1		92	7.14	7.69	145.5	156.6
	4th 3/87[5]	53	124830	1		92	7.86		160.1	
	5th 3/91[7]	48	159870	2		91	7.26	7.34	147.9	149.5
	6th 6/95	51	197100	2		91	7.46		151.9	
3D28[8]	Date Stressed 12/7/72[1, 4]				93	93		8.53		173.8
	1st 4/75[4]	28	20440			93	7.51		152.9	
	2nd 5/79[4]	49	56210			93	7.26		147.9	
	3rd 10/82[4]	41	86140	1		92	7.29	7.86	148.5	160.0
	4th 3/87[5]	53	124830	1		92	8.00		163.0	
	5th 3/91[7]	48	159870	1		92	7.32	7.10	149.2	144.6
	6th 6/95	51	197100	2		91	7.37	7.59	150.2	154.6

Table A-1: Dome Tendons - Surveillance Data and Modified Lift-off Forces (cont.)

Surv. Tendon Id.	Inspection / Date	Surv. Interval mnths.	Time from Installation hrs.	Force per Wire[2] kips		$\Delta_{\text{seating force per wire}}$ = force/wire$_{\text{'as-left'}}$ - force/wire$_{\text{'as found'}}$ kips	$\Sigma\Delta_{\text{seating force per wire}}$ kips	Modified force/wire = force/wire$_{\text{'as found'}}$ - $\Sigma\Delta_{\text{seating force per wire from previous surv.}}$ kips	Time[Note 12] from Installation years
1D28	Date Stressed 12/7/72[1, 4]				8.56			8.56	0.01
	1st 4/75[4]	28	20440	7.23	8.31	1.09	1.09	7.23	2.33
	2nd 5/79[4]	49	56210	7.49			1.09	6.40	6.42
	3rd 9/82[4]	40	85410	7.69	7.62	-0.07	1.02	6.60	9.75
	4th 3/87[5]	54	124830	8.07	7.95	-0.12	0.90	7.04	14.25
	5th 3/91[7]	48	159870	7.15	7.50	0.35	1.26	6.24	18.25
	6th 6/95	51	197100	7.76			1.26	6.50	22.50
2D28	Date Stressed 12/7/72[1, 4]				8.47			8.47	0.01
	1st 4/75[4]	28	20440	7.41				7.41	2.33
	2nd 5/79[4]	49	56210	7.22	7.37	0.15	0.15	7.22	6.42
	3rd 10/82[4]	41	86140	7.14	7.69	0.54	0.69	6.99	9.83
	4th 3/87[5]	53	124830	7.86			0.69	7.16	14.25
	5th 3/91[7]	48	159870	7.26	7.34	0.08	0.77	6.56	18.25
	6th 6/95	51	197100	7.46			0.77	6.68	22.50
3D28[8]	Date Stressed 12/7/72[1, 4]				8.53			8.53	0.01
	1st 4/75[4]	28	20440	7.51				7.51	2.33
	2nd 5/79[4]	49	56210	7.26				7.26	6.42
	3rd 10/82[4]	41	86140	7.29	7.86	0.56	0.56	7.29	9.83
	4th 3/87[5]	53	124830	8.00			0.56	7.44	14.25
	5th 3/91[7]	48	159870	7.32	7.10	-0.22	0.34	6.76	18.25
	6th 6/95	51	197100	7.37	7.59	0.22	0.56	7.03	22.50

Table A-2: Horizontal Tendons - Surveillance Data and Modified Lift-off Forces

Surv. Tendon Id.	Inspection / Date	Surv. Interval mnths.	Time from Installation hrs.	Method of Ram Pressure to Force Conversion	Shop End Lift-off Pressure (psi)[2]		Shop End Lift-off Force (kips)[2]		Field End Lift-off Pressure (psi)[2]		Field End Lift-off Force (kips)[2]		Average Lift-off Force (kips)[2]	
13H9[8]	Date Stressed 2/6/73[1, 4]			Ram Area[9]	Not available.				Not available.					
	1st 4/75[4]	26	18980	Ram Area[9]	5750	6200	691.2	745.2	5800	6416	697.2	771.2	694.2	758.2
	2nd 7/77[4]	27	38690	Ram Area[9]	6100		733.2		5983		719.2		726.2	
	3rd 3/82[4]	56	79570	Ram Area[9]	5883	5867	707.1	705.2	5925	5950	712.2	715.2	709.7	710.2
	4th 8/87[5]	65	127020	Calibration									708	705
	5th 3/91[7]	43	158410	Calibration			620.7	667.6			679.9	662.5	650.3	665.1
	6th 6/95	51	195640	Calibration	5600	5700	671.2	683.3	5500	5500	661.4	661.4	666.3	672.4
51H9	Date Stressed 2/6/73[1, 4]			Ram Area[9]		6600		793.3		6550		787.3		790.3
	1st 4/75[4]	26	18980	Ram Area[9]	5700		685.1		5583		671.1		678.1	
	2nd 7/77[4]	27	38690	Ram Area[9]	5650	6300	679.1	757.3	5633	6350	677.1	763.3	678.1	760.3
	3rd 2/83[4]	67	87600	Ram Area[9]	5933	5783	713.1	695.1	5967	5883	717.2	707.1	715.2	701.1
	4th 8/87[5]	54	127020	Calibration									691	
	5th 3/91[7]	43	158410	Calibration			714.9	674.1			645	703.9	680.0	689.0
	6th 6/95[10]	51	195640	Calibration	5700		683.3		6000		722.7		703.0	
53H10	Date Stressed 2/6/73[1, 4]			Ram Area[9]		6550		787.3		6600		793.3		790.3
	1st 4/75[4]	26	18980	Ram Area[9]	5683		683.1		Note 5		Note 5		683.1	
	2nd 7/77[4]	27	38690	Ram Area[9]	5650		679.1		5633		677.1		678.1	
	3rd 3/83[4]	68	88330	Ram Area[9]	5850	5816	703.2	699.1	Note 6	5942	Note 6	714.2	703.2	706.7
	4th 8/87[5]	53	127020	Calibration									693	
	5th 3/91[7]	43	158410	Calibration			667.6	644.2			680.3	645	674.0	644.6
	6th 6/95[11]	51	195640	Calibration	5200	5600	624.7	673.7	5200	5500	622.7	659.1	623.7	666.4

Table A-2: Horizontal Tendons - Surveillance Data and Modified Lift-off Forces (cont.)

Surv. Tendon Id.	Inspection / Date	Surv. Interval mnths.	Time from Installation hrs.	Cumulative Number of Wires Missing/Removed[3]	Initial Number of Wires[1]	Effective Number of Wires	Force per Wire[2] kips		Stress[Note 2] f_p = force / ΠR^2[2] (R = 0.25" / 2) ksi	
13H9[8]	Date Stressed 2/6/73[1, 4]				93	93				
	1st 4/75[4]	26	18980	1		92	7.46	8.24	152.1	167.9
	2nd 7/77[4]	27	38690	1		92	7.89		160.8	
	3rd 3/82[4]	56	79570	1		92	7.71	7.72	157.1	157.3
	4th 8/87[5]	65	127020	2		91	7.70	7.75	156.8	157.8
	5th 3/91[7]	43	158410	2		91	7.15	7.31	145.6	148.9
	6th 6/95	51	195640	3		90	7.32	7.47	149.2	152.2
51H9	Date Stressed 2/6/73[1, 4]				93	93		8.50		173.1
	1st 4/75[4]	26	18980			93	7.29		148.5	
	2nd 7/77[4]	27	38690	1		92	7.29	8.26	148.5	168.3
	3rd 2/83[4]	67	87600	1		92	7.77	7.62	158.4	155.3
	4th 8/87[5]	54	127020	1		92	7.51		153.0	
	5th 3/91[7]	43	158410	2		91	7.39	7.57	150.6	154.2
	6th 6/95[10]	51	195640	2		91	7.73		157.4	
53H10	Date Stressed 2/6/73[1, 4]				93	93		8.50		173.1
	1st 4/75[4]	26	18980			93	7.35		149.6	
	2nd 7/77[4]	27	38690			93	7.29		148.5	
	3rd 3/83[4]	68	88330	2[Note 6]		91	7.56	7.77	154.0	158.2
	4th 8/87[5]	53	127020	2		91	7.62		155.1	
	5th 3/91[7]	43	158410	2		91	7.41	7.08	150.9	144.3
	6th 6/95[11]	51	195640	5		88	6.85	7.57	139.6	154.3

Table A-2: Horizontal Tendons - Surveillance Data and Modified Lift-off Forces (cont.)

Surv. Tendon Id.	Inspection / Date	Surv. Interval mnths.	Time from Installation hrs.	Force per Wire[2] kips		$\Delta_{\text{seating force per wire}}$ = force/wire$_{\text{'as-left'}}$ - force/wire$_{\text{'as found'}}$ kips	$\Sigma\Delta_{\text{seating force per wire}}$ kips	Modified force/wire = force/wire$_{\text{'as found'}}$ - $\Sigma\Delta_{\text{seating force per wire from previous surv.}}$ kips	Time[Note 12] from Installation years
13H9[8]	Date Stressed 2/6/73[1, 4]								0.01
	1st 4/75[4]	26	18980	7.46	8.24	0.78	0.78	7.46	2.17
	2nd 7/77[4]	27	38690	7.89			0.78	7.12	4.42
	3rd 3/82[4]	56	79570	7.71	7.72	0.01	0.78	6.94	9.08
	4th 8/87[5]	65	127020	7.70	7.75	0.05	0.83	6.91	14.50
	5th 3/91[7]	43	158410	7.15	7.31	0.16	1.00	6.31	18.08
	6th 6/95	51	195640	7.32	7.47	0.15	1.15	6.32	22.33
51H9	Date Stressed 2/6/73[1, 4]				8.50			8.50	0.01
	1st 4/75[4]	26	18980	7.29				7.29	2.17
	2nd 7/77[4]	27	38690	7.29	8.26	0.97	0.97	7.29	4.42
	3rd 2/83[4]	67	87600	7.77	7.62	-0.15	0.82	6.80	10.00
	4th 8/87[5]	54	127020	7.51			0.82	6.69	14.50
	5th 3/91[7]	43	158410	7.39	7.57	0.18	1.00	6.57	18.08
	6th 6/95[10]	51	195640	7.73			1.00	6.73	22.33
53H10	Date Stressed 2/6/73[1, 4]				8.50			8.50	0.01
	1st 4/75[4]	26	18980	7.35				7.35	2.17
	2nd 7/77[4]	27	38690	7.29				7.29	4.42
	3rd 3/83[4]	68	88330	7.56	7.77	0.20	0.20	7.56	10.08
	4th 8/87[5]	53	127020	7.62			0.20	7.41	14.50
	5th 3/91[7]	43	158410	7.41	7.08	-0.32	-0.12	7.20	18.08
	6th 6/95[11]	51	195640	6.85	7.57	0.72	0.60	6.97	22.33

Table A-3: Vertical Tendons - Surveillance Data and Modified Lift-off Forces

Surv. Tendon Id.	Inspection / Date	Surv. Interval mnths.	Time from Installation hrs.	Method of Ram Pressure to Force Conversion	Shop End Lift-off Pressure (psi)[2]		Shop End Lift-off Force (kips)[2]		Field End Lift-off Pressure (psi)[2]		Field End Lift-off Force (kips)[2]		Average Lift-off Force (kips)[2]	
23V14	Date Stressed 2/21/73[1, 4]			Ram Area[9]		6550		787.3		6700		805.3		796.3
	1st 4/75[4]	26	18980	Ram Area[9]	6100	6466	733.2	777.2	6000	6416	721.2	771.2	727.2	774.2
	2nd 7/78[4]	39	47450	Ram Area[9]	6200		745.2		5975		718.2		731.7	
	3rd 11/82[4]	52	85410	Ram Area[9]	6200	6105	745.2	733.8	6167	6100	741.3	733.2	743.3	733.5
	4th 7/87[5]	56	126290	Calibration									748	742
	5th 3/91[7]	44	158410	Calibration			720.9	709.2			714.5	702.7	717.7	706.0
	6th 6/95	51	195640	Calibration	5900		710.4		6050		725.8		718.1	
45V16	Date Stressed 2/19/73[1, 4]			Ram Area[9]		6500		781.3		6600		793.3		787.3
	1st 4/75[4]	26	18980	Ram Area[9]	5700		685.1		6000		721.2		703.2	
	2nd 7/78[4]	39	47450	Ram Area[9]	5800	5850	697.2	703.2	5850	5925	703.2	712.2	700.2	707.7
	3rd 11/82[4]	52	85410	Ram Area[9]	6000	5767	721.2	693.2	6033	5883	725.2	707.1	723.2	700.2
	4th 7/87[5]	56	126290	Calibration									699	
	5th 3/91[7]	44	158410	Calibration			697.4	673.8			679.3	679.3	688.4	676.6
	6th 6/95	51	195640	Calibration	5800		698.2		6000		719.7		709.0	
61V16[8]	Date Stressed 2/19/73[1, 4]			Ram Area[9]		6550		787.3		6650		799.3		793.3
	1st 4/75[4]	26	18980	Ram Area[9]	5766		693.1		6000		721.2		707.1	
	2nd 7/78[4]	39	47450	Ram Area[9]	5800		697.2		5633		677.1		687.1	
	3rd 11/82[4]	52	85410	Ram Area[9]	5733	6083	689.1	731.2	6000	5650	721.2	679.1	705.2	705.2
	4th 7/87[5]	56	126290	Calibration									717	
	5th 3/91[7]	44	158410	Calibration			709.2	644.4			644.2	667.6	676.7	656.0
	6th 6/95	51	195640	Calibration	5300	5600	636.9	673.7	5750	5550	689.4	665.1	663.2	669.4

Table A-3: Vertical Tendons - Surveillance Data and Modified Lift-off Forces (cont.)

Surv. Tendon Id.	Inspection / Date	Surv. Interval mnths.	Time from Installation hrs.	Cumulative Number of Wires Missing/Removed[3]	Initial Number of Wires[1]	Effective Number of Wires	Force per Wire[2] kips		Stress[Note 2] f_p = force / ΠR^2[2] (R = 0.25" / 2) ksi	
23V14	Date Stressed 2/21/73[1, 4]				93	93		8.56		174.4
	1st 4/75[4]	26	18980	1		92	7.82	8.42	159.3	171.4
	2nd 7/78[4]	39	47450	1		92	7.95		162.0	
	3rd 11/82[4]	52	85410	1		92	8.08	7.97	164.6	162.4
	4th 7/87[5]	56	126290	2		91	8.13	8.15	165.6	166.1
	5th 3/91[7]	44	158410	2		91	7.89	7.76	160.7	158.0
	6th 6/95	51	195640	2		91	7.89		160.8	
45V16	Date Stressed 2/19/73[1, 4]				93	93		8.47		172.5
	1st 4/75[4]	26	18980			93	7.56		154.0	
	2nd 7/78[4]	39	47450	1		92	7.53	7.69	153.4	156.7
	3rd 11/82[4]	52	85410	1		92	7.86	7.61	160.1	155.0
	4th 7/87[5]	56	126290	1		92	7.60		154.8	
	5th 3/91[7]	44	158410	2		91	7.48	7.43	152.4	151.5
	6th 6/95	51	195640	2		91	7.79		158.7	
61V16[8]	Date Stressed 2/19/73[1, 4]				93	93		8.53		173.8
	1st 4/75[4]	26	18980			93	7.60		154.9	
	2nd 7/78[4]	39	47450			93	7.39		150.5	
	3rd 11/82[4]	52	85410	1		92	7.58	7.66	154.5	156.1
	4th 7/87[5]	56	126290	1		92	7.79		158.8	
	5th 3/91[7]	44	158410	1		92	7.36	7.13	149.8	145.3
	6th 6/95	51	195640	2		91	7.21	7.36	146.8	149.9

Table A-3: Vertical Tendons - Surveillance Data and Modified Lift-off Forces (cont.)

Surv. Tendon Id.	Inspection / Date	Surv. Interval mnths.	Time from Installation hrs.	Force per Wire[2] kips		$\Delta_{\text{seating force per wire}}$ = force/wire$_{\text{'as-left'}}$ - force/wire$_{\text{'as found'}}$ kips	$\Sigma\Delta_{\text{seating force per wire}}$ kips	Modified force/wire = force/wire$_{\text{'as found'}}$ - $\Sigma\Delta_{\text{seating force per wire from previous surv.}}$ kips	Time[Note 12] from Installation years
23V14	Date Stressed 2/21/73[1, 4]				8.56			8.56	0.01
	1st 4/75[4]	26	18980	7.82	8.42	0.60	0.60	7.82	2.17
	2nd 7/78[4]	39	47450	7.95			0.60	7.36	5.42
	3rd 11/82[4]	52	85410	8.08	7.97	-0.11	0.49	7.48	9.75
	4th 7/87[5]	56	126290	8.13	8.15	0.02	0.51	7.64	14.42
	5th 3/91[7]	44	158410	7.89	7.76	-0.13	0.38	7.37	18.08
	6th 6/95	51	195640	7.89			0.38	7.51	22.33
45V16	Date Stressed 2/19/73[1, 4]				8.47			8.47	0.01
	1st 4/75[4]	26	18980	7.56				7.56	2.17
	2nd 7/78[4]	39	47450	7.53	7.69	0.16	0.16	7.53	5.42
	3rd 11/82[4]	52	85410	7.86	7.61	-0.25	-0.09	7.70	9.75
	4th 7/87[5]	56	126290	7.60			-0.09	7.68	14.42
	5th 3/91[7]	44	158410	7.48	7.43	-0.05	-0.13	7.57	18.08
	6th 6/95	51	195640	7.79			-0.13	7.92	22.33
61V16[8]	Date Stressed 2/19/73[1, 4]				8.53			8.53	0.01
	1st 4/75[4]	26	18980	7.60				7.60	2.17
	2nd 7/78[4]	39	47450	7.39				7.39	5.42
	3rd 11/82[4]	52	85410	7.58	7.66	0.08	0.08	7.58	9.75
	4th 7/87[5]	56	126290	7.79			0.08	7.71	14.42
	5th 3/91[7]	44	158410	7.36	7.13	-0.23	-0.14	7.27	18.08
	6th 6/95	51	195640	7.21	7.36	0.15	0.01	7.35	22.33

Appendix A Notes

1. See reference [14].
2. Double entries appear for detensioned/retensioned tendons only and represent as-found and as-left conditions, respectively.
3. A blank represents a value of zero.
4. Lift-off / seating pressures were obtained from reference [24].
5. See reference [25].
6. Two (2) wires were removed during Third Inspection. See reference [26].
7. See reference [27].
8. Tendon was detensioned for wire removal during Sixth Inspection period.
9. Force = Ram Pressure (psi) * 120.2 in^2 / 1000 lbs/kip. See reference [24].
10. Testing suspended at documented force, 'Field End' only. Safety concerns prohibited increased ram pressures necessary to achieve lift-off. See reference [28].
11. Two attempts were made to remove a wire from this tendon. In each case, the field-end wire buttonhead was cut off. Neither wire sample was successfully extracted. Upon retensioning the tendon, a single unseated buttonhead was also identified at each end (field and shop). A wire sample was obtained from tendon 13H9.
12. Time of initial seating force is identified as 0.01 years in order to accommodate logarithmic scale for time.

APPENDIX B

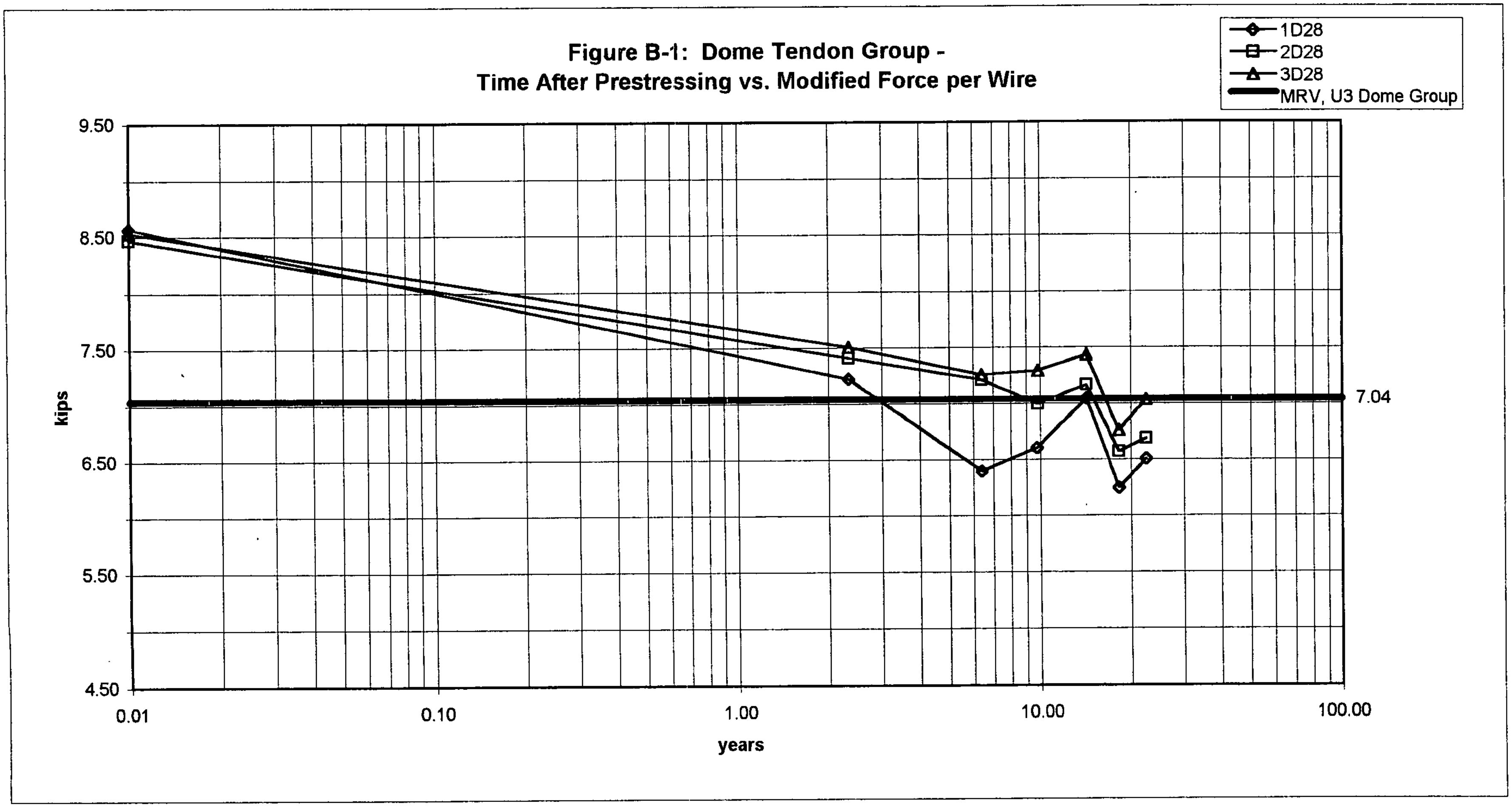
Figure B-1: Dome Tendon Group -
Time After Prestressing vs. Modified Force per Wire
1D28
2D28
3D28
MRV, U3 Dome Group
9.50
8.50
7.50
6.50
5.50
4.50
kips
0.01
0.10
1.00
10.00
100.00
years
7.04

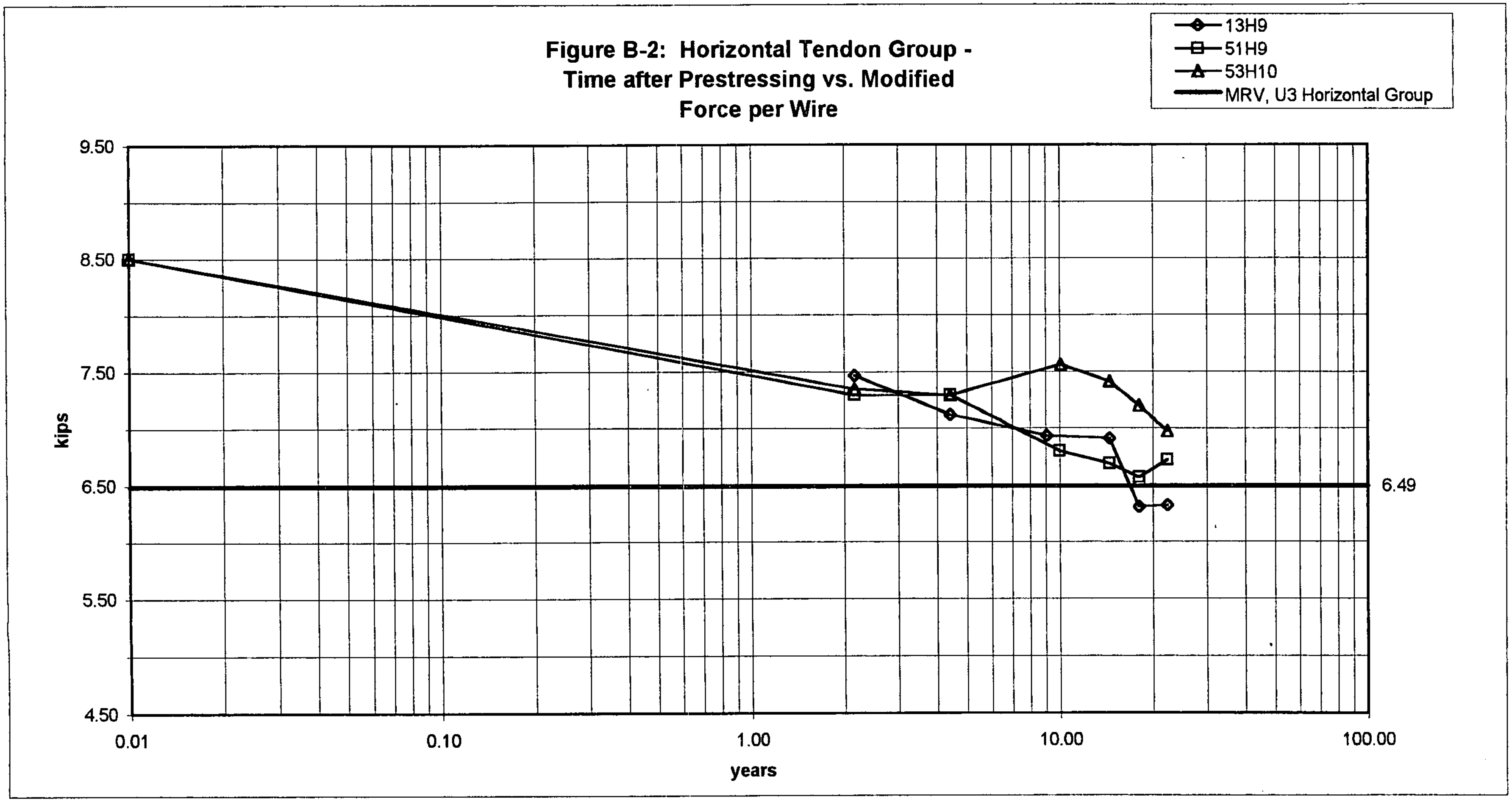
Figure B-2: Horizontal Tendon Group - Time after Prestressing vs. Modified Force per Wire
13H9
51H9
53H10
MRV, U3 Horizontal Group
9.50
8.50
7.50
6.50
5.50
4.50
kips
6.49
0.01
0.10
1.00
10.00
100.00
years

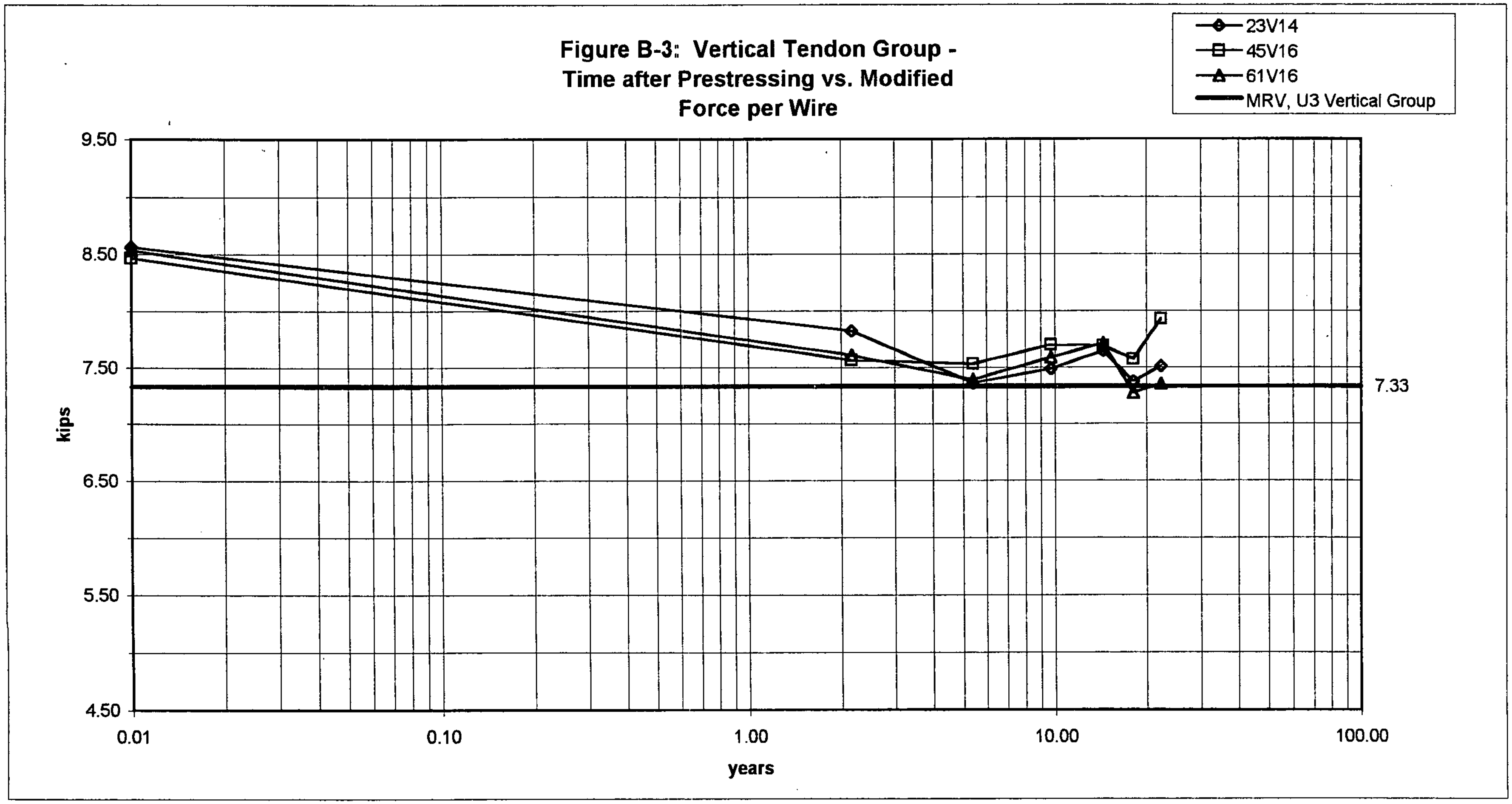
Figure B-3: Vertical Tendon Group - Time after Prestressing vs. Modified Force per Wire
23V14
45V16
61V16
MRV, U3 Vertical Group
9.50
8.50
7.50
6.50
5.50
4.50
kips
7.33
0.01
0.10
1.00
10.00
100.00
years

DOME TENDON GROUP - REGRESSION ANALYSIS SUMMARY

STATISTICAL DATA

Time from Installation years	Modified force per wire kips
0.01	8.56
2.33	7.23
6.42	6.40
9.75	6.60
14.25	7.04
18.25	6.24
22.50	6.50
0.01	8.47
2.33	7.41
6.42	7.22
9.83	6.99
14.25	7.16
18.25	6.56
22.50	6.68
0.01	8.53
2.33	7.51
6.42	7.26
9.83	7.29
14.25	7.44
18.25	6.76
22.50	7.03

REGRESSION STATISTICS

Covariance = -1.524
Correlation = -0.8926

EQUATION OF BEST FIT LINE

f(x) = 7.483 + (-0.2306) * LN(x)

years	MRV
0.01	7.04
100	7.04

OUTPUT DATA

Observation years	Predicted force per wire, f(x) kips
0.01	8.54
0.10	8.01
1	7.48
2	7.32
3	7.23
4	7.16
5	7.11
6	7.07
7	7.03
8	7.00
9	6.98
10	6.95
11	6.93
12	6.91
13	6.89
14	6.87
15	6.86
16	6.84
17	6.83
18	6.82
19	6.80
20	6.79
21	6.78
22	6.77
23	6.76
24	6.75
25	6.74
26	6.73
27	6.72
28	6.71
29	6.71
30	6.70
31	6.69
32	6.68
33	6.68
34	6.67
35	6.66
36	6.66
37	6.65
38	6.64
39	6.64
40	6.63

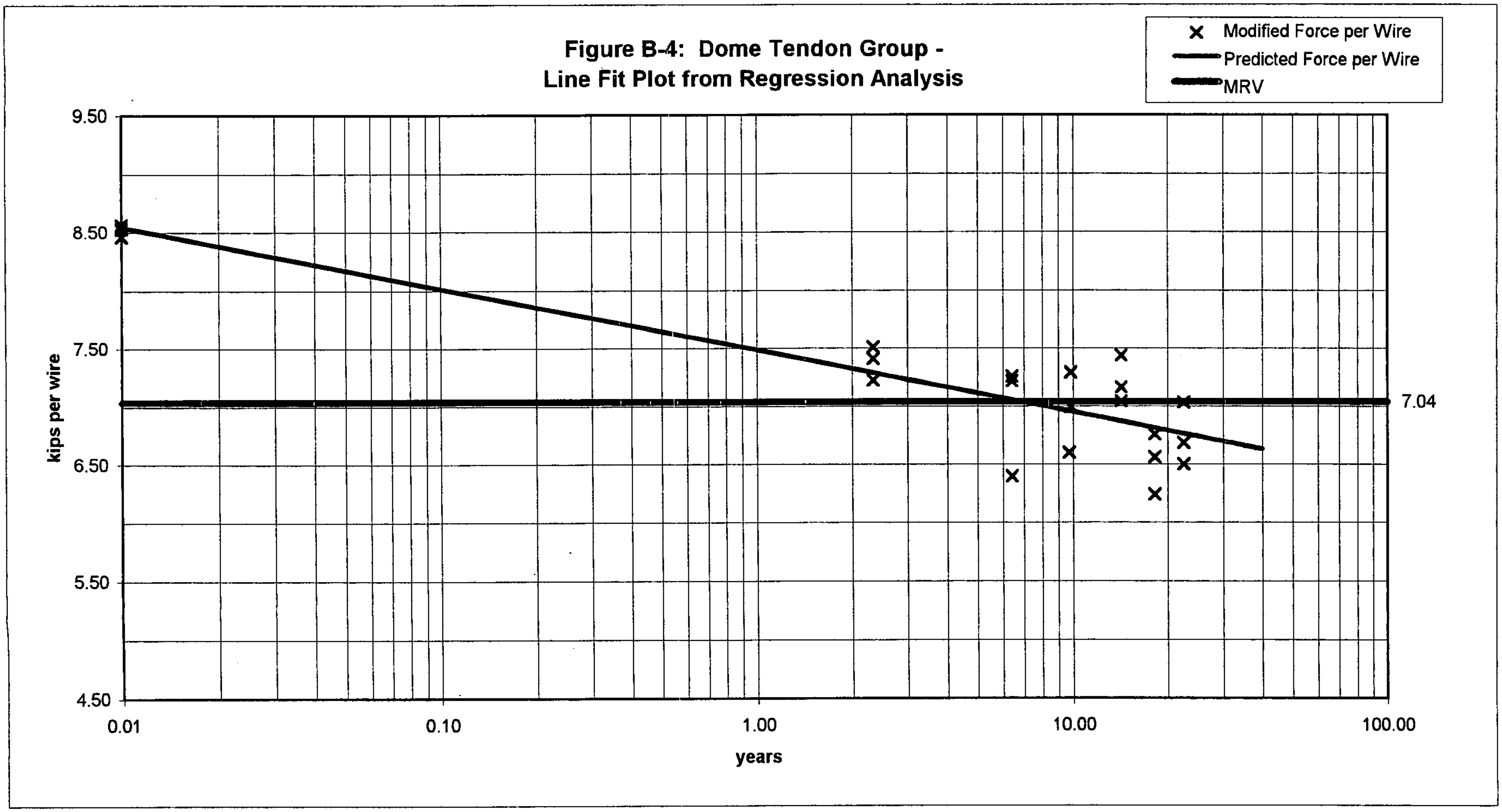
Figure B-4: Dome Tendon Group -
Line Fit Plot from Regression Analysis
Modified Force per Wire
Predicted Force per Wire
MRV
9.50
8.50
7.50
6.50
5.50
4.50
kips per wire
7.04
0.01
0.10
1.00
10.00
100.00
years

HORIZONTAL TENDON GROUP - REGRESSION ANALYSIS SUMMARY

STATISTICAL DATA

Time from Installation years	Modified force per wire kips
2.17	7.46
4.42	7.12
9.08	6.94
14.50	6.91
18.08	6.31
22.33	6.32
0.01	8.50
2.17	7.29
4.42	7.29
10.00	6.80
14.50	6.69
18.08	6.57
22.33	6.73
0.01	8.50
2.17	7.35
4.42	7.29
10.08	7.56
14.50	7.41
18.08	7.20
22.33	6.97

REGRESSION STATISTICS

Covariance = -1.147
Correlation = -0.8770

EQUATION OF BEST FIT LINE

f(x) = 7.507 + (-0.2278) * LN(x)

years	MRV
0.01	6.49
100	6.49

OUTPUT DATA

Observation years	Predicted force per wire, f(x) kips
0.01	8.56
0.10	8.03
1	7.51
2	7.35
3	7.26
4	7.19
5	7.14
6	7.10
7	7.06
8	7.03
9	7.01
10	6.98
11	6.96
12	6.94
13	6.92
14	6.91
15	6.89
16	6.88
17	6.86
18	6.85
19	6.84
20	6.82
21	6.81
22	6.80
23	6.79
24	6.78
25	6.77
26	6.76
27	6.76
28	6.75
29	6.74
30	6.73
31	6.72
32	6.72
33	6.71
34	6.70
35	6.70
36	6.69
37	6.68
38	6.68
39	6.67
40	6.67

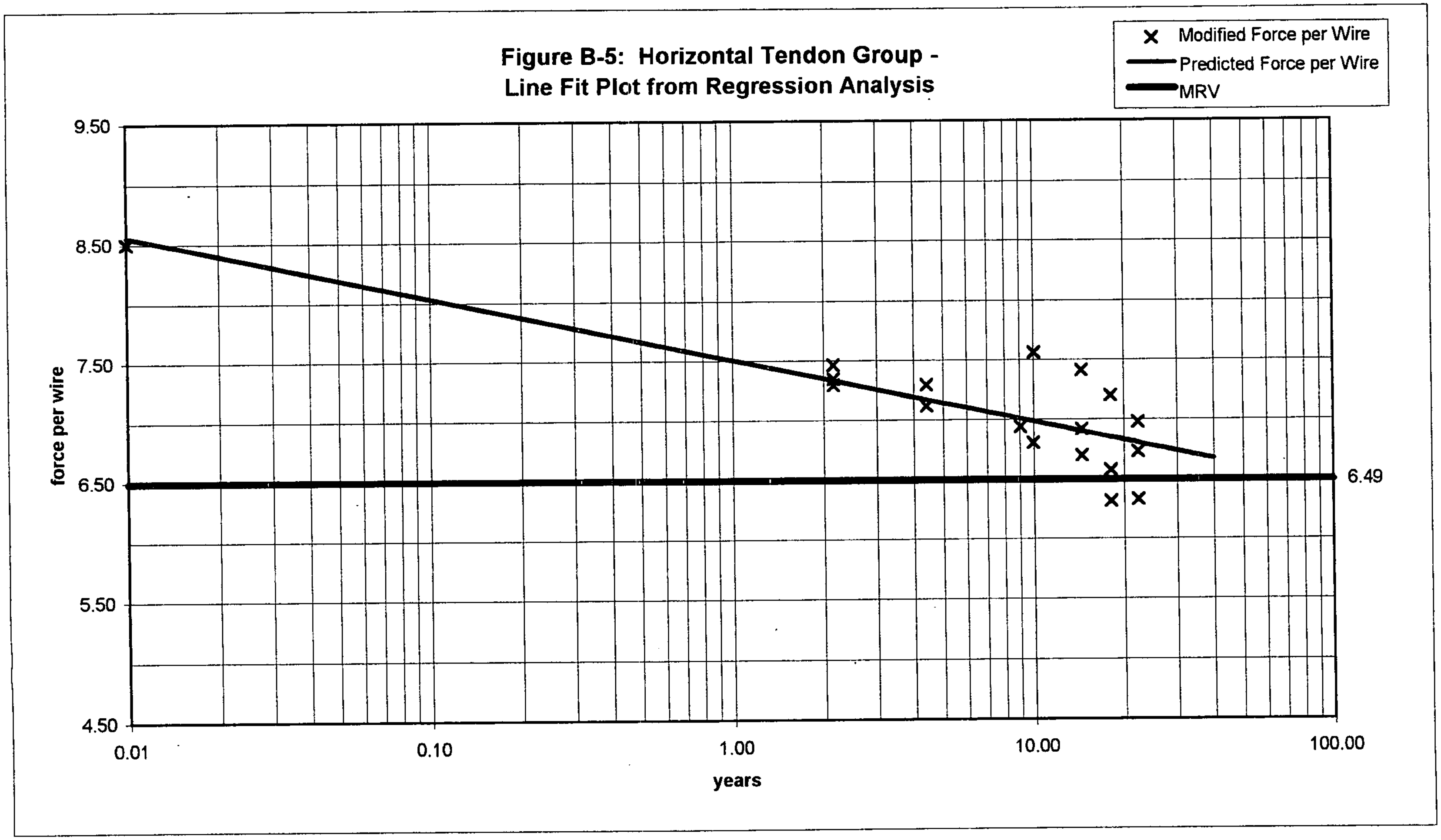
Figure B-5: Horizontal Tendon Group -
Line Fit Plot from Regression Analysis
Modified Force per Wire
Predicted Force per Wire
MRV
9.50
8.50
7.50
6.50
5.50
4.50
force per wire
0.01
0.10
1.00
10.00
100.00
years
6.49

VERTICAL TENDON GROUP - REGRESSION ANALYSIS SUMMARY

STATISTICAL DATA

Time from Installation years	Modified force per wire kips
0.01	8.56
2.17	7.82
5.42	7.36
9.75	7.48
14.42	7.64
18.08	7.37
22.33	7.51
0.01	8.47
2.17	7.56
5.42	7.53
9.75	7.70
14.42	7.68
18.08	7.57
22.33	7.92
0.01	8.53
2.17	7.60
5.42	7.39
9.75	7.58
14.42	7.71
18.08	7.27
22.33	7.35

REGRESSION STATISTICS

Covariance = -0.8607
Correlation = -0.8821

EQUATION OF BEST FIT LINE

f(x) = 7.860 + (-0.1306) * LN(x)

years	MRV
0.01	7.33
100	7.33

OUTPUT DATA

Observation years	Predicted force per wire, f(x) kips
0.01	8.46
0.10	8.16
1	7.86
2	7.77
3	7.72
4	7.68
5	7.65
6	7.63
7	7.61
8	7.59
9	7.57
10	7.56
11	7.55
12	7.54
13	7.53
14	7.52
15	7.51
16	7.50
17	7.49
18	7.48
19	7.48
20	7.47
21	7.46
22	7.46
23	7.45
24	7.44
25	7.44
26	7.43
27	7.43
28	7.42
29	7.42
30	7.42
31	7.41
32	7.41
33	7.40
34	7.40
35	7.40
36	7.39
37	7.39
38	7.38
39	7.38
40	7.38

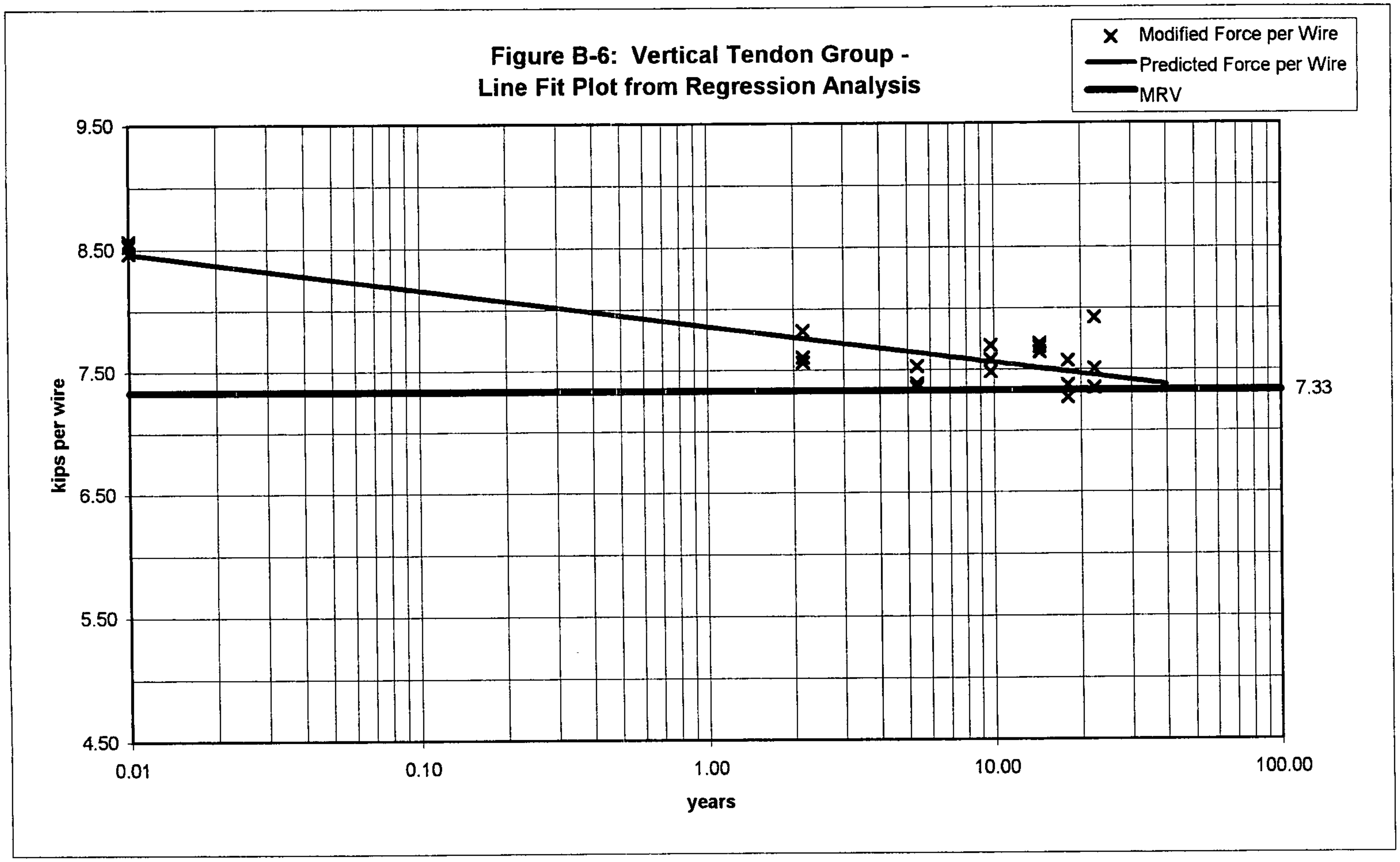
Figure B-6: Vertical Tendon Group - Line Fit Plot from Regression Analysis
Modified Force per Wire
Predicted Force per Wire
MRV
9.50
8.50
7.50
6.50
5.50
4.50
kips per wire
7.33
0.01
0.10
1.00
10.00
100.00
years

APPENDIX C

MRV = (Force Required [kips/ft] * Length [ft]) / Number of Effective Tendons
(Minimum Required Value (MRV) is based upon design forces stipulated in references 9, 10, and 11.
MRV is computed for each unit for vertical tendons, horizontal tendons below elevation 954+4 to 787+8, horizontal tendons above elevation 787+8 to 776+0, and dome tendons.)

where,

Number of Effective Tendons = Total Number of Tendons - Surveillance Tendons - Missing Tendons
(Final effective prestress force excludes contribution of original surveillance tendons [Reference 12, 13, 14].)

Table C-1
Force Required [References 9, 10, and 11]

Tendon Group	Force [kips/ft]
Vertical Tendons	300
Horizontal Tendons (Elev. 954+4 to 787+8)	700
Horizontal Tendons (Elev. 787+8 to 776+0)	500
Dome Tendons	360

Table C-2
Length [References 10, 11, and 15]

Tendon Group	Length [ft]
Vertical Tendons	Circumference of Reactor Building @ c.g. of vertical tendons. C = 2 * π * R = 2 * π * 59'-10 1/2" C = 376.21 [ft]
Horizontal Tendons (Elev. 954+4 to 787+8)	Distance from c/l of horizontal tendon @ elev. 954+4 to c/l of horizontal tendon @ elev. 787+8. D = 166.67 [ft]
Horizontal Tendons (Elev. 787+8 to 776+0)	Distance from c/l of horizontal tendon @ elev. 787+8 to c/l of horizontal tendon @ elev. 776+0. D = 11.67 [ft]
Dome Tendons (3 groups of 54 @ 120°)	Horizontal distance as measured on arc of dome @ diameter of reactor building. D = C * 60° / 180° = 2 * π * R * 60° / 180° = 2 * π * 44'-6 3/4" * 60° / 180° D = 93.33 [ft]

Table C-3
Total Number of Tendons [References 16 and 17]

Unit	Tendon Group	Number
All	Dome - 3 groups of 54 @ 120°	162
All	Vertical	176
	(Horizontal - 6 groups of 105 + 2 additional)	
All	Horizontal Tendons (Elev. 954+4 to 787+8)	602
All	Horizontal Tendons (Elev. 787+8 to 776+0)	30

Table C-4
Surveillance Tendons [Reference 18]

Unit	Tendon Group	Tendon Id.	Elevation (horizontal tendons only)
All	Dome	1D28	
1 & 3	Dome	2D28	
2	Dome	2D29	
All	Dome	3D28	
All	Horizontal	13H9	793+2 2/3 [Reference 19]
All	Horizontal	51H9	793+9 1/3 [Reference 20]
All	Horizontal	53H10	794+4 [Reference 19]
All	Vertical	23V14	
All	Vertical	45V16	
All	Vertical	61V16	

Table C-5
Missing Tendons

Unit	Tendon Group	Tendon Id.	Elevation (Horizontal Tendons Only)
1	Vertical	34V14 [Reference 12]	
1	Horizontal	24H34 [Reference 12]	835+5 1/3 [Reference 21]
1	Horizontal	31H34 [Reference 12]	834+10 2/3 [Reference 22]
2	Horizontal	31H21 [Reference 13]	813+2 2/3 [Reference 19]
3	Vertical	34V013 [Reference 14]	
	Vertical	34V025 [Reference 14]	

Table C-6
Effective Tendons
Number of Effective Tendons = Total Number of Tendons - Surveillance Tendons - Missing Tendons

Unit	Tendon Group	Total Number of Tendons	Surveillance Tendons	Missing Tendons	Number of Effective Tendons
1	Dome	162	3	0	159
1	Horizontal Tendons (Elev. 954+4 to 787+8)	602	3	2	597
1	Horizontal Tendons (Elev. 787+8 to 776+0)	30	0	0	30
1	Vertical	176	3	1	172
2	Dome	162	3	0	159
2	Horizontal Tendons (Elev. 954+4 to 787+8)	602	3	1	598
2	Horizontal Tendons (Elev. 787+8 to 776+0)	30	0	0	30
2	Vertical	176	3	0	173
3	Dome	162	3	0	159
3	Horizontal Tendons (Elev. 954+4 to 787+8)	602	3	0	599
3	Horizontal Tendons (Elev. 787+8 to 776+0)	30	0	0	30
3	Vertical	176	3	2	171

Table C-7
MRV
MRV = (Force Required [kips/ft] * Length [ft]) / Number of Effective Tendons

Unit	Tendon Group	Force Required [kips/ft]	Length [ft]	Number of Effective Tendons	MRV [kips/tendon]	MRV for typical 90 wire tendon [kips/wire]
1	Dome	360	93.33	159 / 3 groups = 53	633.9	7.04
1	Horizontal Tendons (Elev. 954+4 to 787+8)	700	166.67	597 / 3 tendons = 199 per hoop	586.3	6.51
1	Horizontal Tendons (Elev. 787+8 to 776+0)	500	11.67	30 / 3 tendons = 10 per hoop	583.3	6.48
1	Vertical	300	376.21	172	656.2	7.29
2	Dome	360	93.33	159 / 3 groups = 53	633.9	7.04
2	Horizontal Tendons (Elev. 954+4 to 787+8)	700	166.67	598 / 3 tendons = 199.3 per hoop	585.3	6.50
2	Horizontal Tendons (Elev. 787+8 to 776+0)	500	11.67	30 / 3 tendons = 10 per hoop	583.3	6.48
2	Vertical	300	376.21	173	652.4	7.25
3	Dome	360	93.33	159 / 3 groups = 53	633.9	7.04
3	Horizontal Tendons (Elev. 954+4 to 787+8)	700	166.67	599 / 3 tendons = 199.7 per hoop	584.3	6.49
3	Horizontal Tendons (Elev. 787+8 to 776+0)	500	11.67	30 / 3 tendons = 10 per hoop	583.3	6.48
3	Vertical	300	376.21	171	660.0	7.33