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0CAN112201 10 CFR 50.55a

November 10, 2022

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

SUBJECT: Request for Alternative Frequency to Containment Unbonded Post-Tensioning System Inservice Inspection (ANO-CISI-002)

Arkansas Nuclear One – Units 1 and 2
NRC Docket Nos. 50-313, and 50-368
Renewed Facility Operating License Nos. DPR-51 and NPF-6

In accordance with Title 10 of the Code of Federal Regulations (10 CFR) 50.55a, *Codes and Standards*, paragraph (z)(1), Entergy Operations, Inc. (Entergy) requests the U.S. Nuclear Regulatory Commission's (NRC) approval of the enclosed request for an alternative from the requirements of Section XI, Subsection IWL of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (BPV) Code. Per the ASME BPV Code, the periodic visual examination and physical testing of containment building concrete are required in accordance with Table IWL-2500-1 L-A, as well as physical testing of unbonded post-tensioning systems in accordance with Table IWL-2500-1 L-B.

Examination and testing to date have indicated the post-tensioning systems at the Arkansas Nuclear One (ANO) station will continue to maintain their safety-related function through the period of extended operation. Therefore, Entergy proposes to extend the unbonded post-tensioning system examination and testing interval from 10 years to 20 years for ANO Units 1 and 2 (ANO-1 and ANO-2).

Entergy also proposes an alternative to the requirements of IWL-2523 to limit the scope of wire strands required to be removed (under IWL-2523.1) and examined (in accordance with IWL-2523.2).

This request for alternative will remain in effect for the remainder of the current Fifth Containment Inservice Inspection (CISI) interval and subsequent CISI intervals for ANO-1 and ANO-2 and will continue until the end of the current renewed operating license. The renewed operating license for ANO-1 expires on May 20, 2034, and on July 17, 2038, for ANO-2.

Approval of the proposed alternative is requested by November 30, 2023. Once approved, the alternative shall be implemented within 30 days.

There are no new regulatory commitments made in this submittal.

If there are any questions or if additional information is needed, please contact Riley Keele, Manager, Regulatory Assurance, Arkansas Nuclear One, at 479-858-7826.

Respectfully,

Philip Couture

Digitally signed by Philip Couture
Date: 2022.11.10 16:04:59 -06'00'

Phil Couture

PC/rwc

Enclosure: Request for Alternative – ANO-CISI-002

Attachment: Containment Post-Tension System Inservice Inspection Basis for Proposed Extension of Examination Interval Technical Report

cc: NRC Region IV Regional Administrator

NRC Senior Resident Inspector – Arkansas Nuclear One

NRC Project Manager – Arkansas Nuclear One

ENCLOSURE

0CAN112201

REQUEST FOR ALTERNATIVE
ANO-CISI-002

REQUEST FOR ALTERNATIVE
ANO-CISI-002

Components / Numbers:	Arkansas Nuclear One, Unit 1 (ANO-1) and Unit 2 (ANO-2) Concrete Containment Unbonded Post-Tensioning System
Code Classes:	American Society of Mechanical Engineers (ASME) Code Class CC
Code:	ASME Section XI, 2007 Edition with the 2008 Addenda
Examination Category:	L-B
Item Number(s)	L2.10, L2.20, L2.30, L2.40, and L2.50
Description:	Examination and Testing of Unbound Post-Tensioning Systems
Unit / Inspection Interval Applicability:	ANO-1 / Fifth (5th) 10-Year Interval ANO-2 / 5th 10-Year Interval

I. APPLICABLE CODE EDITION AND ADDENDA

The code of record for the ANO-1 5th Containment Inservice Inspection (CISI) interval is the 2007 Edition with the 2008 Addenda of the ASME Boiler and Pressure Vessel Code, Section XI, hereinafter referred to as ASME Section XI.

Pursuant to Request for Alternative ANO-2-ISI-021 as approved by the NRC (Reference 1), the code of record for the ANO-2 5th CISI interval is the 2007 Edition with the 2008 Addenda except for Sub-article IWA-2430 which is to the 2013 Edition.

Table 1

Unit	CISI Interval	ASME Code Section XI	Current Interval Start Date	Current Interval End Date[1]	Renewed License End Date
ANO-1	5th	2007 Edition with the 2008 Addenda	May 31, 2017	May 30, 2027	May 20, 2034
ANO-2	5th	2007 Edition with the 2008 Addenda	March 26, 2020	March 25, 2030	July 17, 2038

Notes:
1. The interval end date is subject to change using the provisions of IWA-2430(c)(1).

II. CODE REQUIREMENTS

ASME Section XI, IWL-2421 permits sites with multiple plants to extend the containment inspection and testing frequency from 5-years to 10-years provided certain criteria are met. Under the provisions of Request for Alternative ANO-CISI-001[1] as approved by the NRC (Reference 2), ANO-1 and ANO-2 utilize the provisions of IWL-2421 for Examination Category L-B, Item No. L2.10 and L2.20.

For Examination Category L-B, Item No. L2.30, L2.40, and L2.50, ANO-1 and ANO-2 inspection and testing frequencies are in accordance with ASME Section XI, IWL-2420.

1. Table IWL-2500-1, Examination Category L-B, Item No. L2.10 with the frequency specified by ASME Section XI, IWL-2421.

   On a 10-year frequency, selected tendons are required to be tested for force and elongation in accordance with IWL-2522.

2. Table IWL-2500-1, Examination Category L-B, Item No. L2.20 with the frequency specified by ASME Section XI, IWL-2421.

   On a 10-year frequency, selected tendons are required to be de-tensioned and single wire samples removed and examined for corrosion and mechanical damage as well as tested to obtain yield strength, ultimate tensile strength, and elongation on each removed wire in accordance with IWL-2523.2. Tendons selected for wire samples are subsequently re-tensioned as required by IWL-2523.3.

3. Table IWL-2500-1, Examination Category L-B, Item No. L2.30 with the frequency specified by ASME Section XI, IWL-2420.

   On a 5-year frequency, a detailed visual examination is required on tendon anchorage hardware and adjacent concrete extending 2 feet from the edge of the bearing plate in accordance with IWL-2524. The quantity of free water released from the anchorage end cap as well as any which drains from the tendon during examination shall be documented.

4. Table IWL-2500-1, Examination Category L-B, Item No. L2.40 and L2.50 with the frequency specified by ASME Section XI, IWL-2420.

   On a 5-year frequency, samples of selected tendon corrosion protection medium (CPM) and free water are required to be obtained and analyzed in accordance with IWL-2525 and IWL-2526.

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[1] With NRC approval of this request, Request for Alternative ANO-CISI-001 will be retired as it will no longer be the basis for examination frequencies for Examination Category L-B, Item No. L2.10 and L2.20.

III. REASON FOR REQUEST

ASME Section XI requires periodic visual examination of containment concrete, anchorage hardware, and physical testing of post-tensioning systems. The examination and testing to date along with the evaluation provided in the attachment of this enclosure indicates that the ANO post-tensioning system is expected to maintain its safety-related function through the period of extended operation.

While this relief request is based on maintaining an acceptable level of quality and safety, there are additional benefits obtained by implementing the proposed alternatives. Physical testing requires exposing the involved personnel to industrial safety hazards. Removing the tendon end caps and load testing or de-tensioning / re-tensioning the tendons also unnecessarily cycles the tendons and exposes the system to an unsealed environment during testing. Below are specific hazards and undesirable conditions that will either be eliminated or performed less frequently thus reducing overall plant and personnel risk:

a. Most tendons are located at heights well above ground level that requires working at heights with the inherent risks associated with such work.

b. This work is often performed from hanging platforms open to outside weather conditions. The platform must be moved to a parked location to exit the platform.

c. Some areas are in difficult to reach locations that have only one small access point.

d. Requires working with high pressure hydraulics.

e. Requires working in the vicinity of high energy plant systems.

f. Requires working with solvents and hot petroleum products and associated fumes.

g. Requires working with containers and pressurized lines filled with heated CPM (grease).

h. Requires working in the vicinity of high levels of stored elastic energy (greater than 1 million foot-pounds) in the tendons. Sudden rotation during force measurement has resulted in high-speed shim ejection.

i. Handling of heavy loads (test equipment) that also exposes plant equipment to hazards as well as the involved personnel.

j. While tendon testing is most often not performed in radiation areas, there are occasionally some tendons tested in areas that involve radiation fields.

k. Performing examination/testing on a reduced frequency reduces the repetitive loading required for force measurement or de-tensioning and re-tensioning.

l. Reducing the frequency of tendon end cap removal minimizes the opportunities for exposing the tendon hardware to environmental conditions.

m. Reducing the frequency of tendon end cap removal will reduce environmental waste (e.g., solvents, used grease, other consumables).

IV. PROPOSED ALTERNATIVE AND BASIS FOR RELIEF

Proposed Alternative

In accordance with the provisions of 10 CFR 50.55a(z)(1), the following alternatives are proposed on the basis that they, when combined with the other requirements of ASME Section XI, Article IWL, will provide an acceptable level of quality and safety.

The attachment to this request provides a basis to extend the frequency for Item No. L2.10 from 10 years to 20 years and for Item No. L2.30, L2.40, and L2.50 from 5 years to 10 years. However as noted below and in Table 2, in some instances, the full extensions are not applied so that ANO-1 and ANO-2 examination schedules can be aligned to allow concurrent examinations in the event both units enter into a second extended period of operation.

As an alternative to the requirements of ASME Section XI, IWL-2420 and IWL-2421 as summarized in Section III of this request, the following alternative is proposed for use at ANO-1 and ANO-2 as described below and shown in Table 2.

a. Table IWL-2500-1, Examination Category L-B, Item No. L2.10.

ANO Unit 1:

In lieu of the 10-year frequency permitted by IWL-2421, the next test of tendons for ANO-1 is deferred for 15 years from the previous examination (2013) and is scheduled for 2028. Because the ANO-1 renewed operating license expires on May 20, 2034, additional testing beyond 2028 would not be scheduled. To continue with a 20-year schedule into a second extended period of operation will require a separate request for alternative under the second extended operating license.

ANO Unit 2:

In lieu of the 10-year frequency permitted by IWL-2421, the testing of tendons for ANO-2 is deferred for 18 years from the previous examination (2020) and would be scheduled for 2038. However, the ANO-2 renewed operating license expires July 17, 2038. The test scheduled for 2038 would not be performed unless ANO-2 enters into a second extended period of operation. At that time, the 2038 test would either be performed prior to the expiration of the current extended operating license under this request for alternative or it would be performed under the second extended operating license with additional NRC approval.

b. Table IWL-2500-1, Examination Category L-B, Item No. L2.20.

ANO Units 1 and 2

In lieu of removing and testing selected tendon wires in accordance with the schedule specified by ASME Section XI, IWL-2421, the removal and testing of selected tendon wires will only be performed when required by the Responsible Engineer (RE).

c. Table IWL-2500-1, Examination Category L-B, Item No. L2.30.

ANO Unit 1:

In lieu of the 5-year frequency specified by IWL-2420, the next detailed visual examination for ANO-1 will be performed on a 10-year frequency with the next examination scheduled for 2028. Because the ANO-1 renewed operating license expires on May 20, 2034, additional examination beyond 2028 would not be scheduled. To continue with a 10-year schedule into a second extended period of operation will require a separate request for alternative under the second extended operating license.

ANO Unit 2:

In lieu of the 5-year frequency specified by IWL-2420, the next detailed visual examination for ANO-2 would be extended for 8 years and scheduled for 2028. The subsequent detailed visual examination would occur in 2038, however, the ANO-2 renewed operating license expires July 17, 2038. The detailed visual examination scheduled for 2038 would not be performed unless ANO-2 enters a second extended period of operation. At that time, the 2038 examination would either be performed prior to the expiration of the current extended operating license under this request for alternative or it would be performed under the second extended operating license with additional NRC approval.

d. Table IWL-2500-1, Examination Category L-B, Item No. L2.40 and L2.50.

ANO Unit 1:

In lieu of the 5-year frequency specified by IWL-2420, the sampling of selected tendon CPM and free water testing for ANO-1 will be performed on a 10-year frequency with the next sampling scheduled for 2028. Because the ANO-1 renewed operating license expires on May 20, 2034, additional examination beyond 2028 would not be scheduled. To continue with a 10-year schedule into a second extended period of operation will require a separate request for alternative under the second extended operating license.

ANO Unit 2:

In lieu of the 5-year frequency specified by IWL-2420, the next sampling of selected tendon CPM and free water testing for ANO-2 would be extended for 8 years and scheduled for 2028. The subsequent sampling would occur in 2038, however, the ANO-2 renewed operating license expires July 17, 2038. The sampling scheduled for 2038 would not be performed unless ANO-2 enters a second period of extended operation. At that time, the 2038 sampling would either be performed prior to the expiration of the current extended operating license under this request for alternative or it would be performed under the second extended operating license with additional NRC approval.

ANO Units 1 and 2:

Additionally, for ANO-1 and ANO-2 the testing of CPM for corrosive ion and reserve alkalinity will not be tested on a 10-year frequency. Testing of CPM material for corrosive ion and reserve alkalinity will only be performed when:

- Active corrosion is found on anchorage components and / or wires
- Free water deemed significant by the RE is found at anchorages (free water will be analyzed for pH)
- CPM absorbed water content exceeds the limits in Table IWL-2525-1
- And, as otherwise specified by the RE

Table 2

Proposed Tendon Surveillance Schedule (includes the two most recent Unit 1 and Unit 2 surveillance years for reference)[a]

Year	Unit 1		Unit 2	
	Visual Examination (L2.30) and CPM / Free Water Testing (L2.40[b], L2.50)	Tendon Force Measurement (L2.10)	Visual Examination (L2.30) and CPM / Free Water Testing (L2.40[b], L2.50)	Tendon Force Measurement (L2.10)
2013	Completed	Completed[c]	N/A	N/A
2014	N/A	N/A	Completed	Completed[c]
2018	Completed	N/A	N/A	N/A
2020	N/A	N/A	Completed	Completed[c]
2028	Perform	Perform	Perform	N/A

Table 2

Proposed Tendon Surveillance Schedule (includes the two most recent Unit 1 and Unit 2 surveillance years for reference)[a]

Year	Unit 1		Unit 2	
	Visual Examination (L2.30) and CPM / Free Water Testing (L2.40[b], L2.50)	Tendon Force Measurement (L2.10)	Visual Examination (L2.30) and CPM / Free Water Testing (L2.40[b], L2.50)	Tendon Force Measurement (L2.10)
2038	Perform[d]	N/A	Perform[d]	Perform[d]
2048	Perform[d]	Perform[d]	Perform[d]	N/A
2058	Perform[d]	N/A	Perform[d]	Perform[d]

Note a: The proposed schedule does not alter the use of IWL-2420(c) which requires the examination to commence no more than 1 year prior to the specified date and to be completed not more than 1 year after the specified date. Additionally, if required by plant operating conditions, portions of examinations of the post-tensioning system may be deferred until the next regularly scheduled plant outage.

Note b: Scope of CPM testing is reduced as described in Section IV.d of this request.

Note c: Scope of the surveillance included tendon wire extraction and testing (L2.20).

Note d: If applicable based on current renewed license end date.

Basis for Use

ANO-1 and ANO-2 will continue to perform the general visual and detailed visual examinations as required by Examination Category L-A, Item No. L1.11 and L1.12, respectively, as conditioned by 10 CFR 50.55a(b)(2)(viii)(E). These examinations ensure that unexpected degradation of containment surfaces and post-tensioning hardware are identified in a timely manner for evaluation by the RE.

The acceptance criteria of IWL-3210 for both the general visual (Item No. L1.11) and the detailed Visual (Item L1.12) require the RE to make a determination of acceptance or to require further evaluation in accordance with IWL-3300.

The examinations performed to meet Examination Category L-A provide ample opportunities to identify any unexpected degradation of concrete at tendon anchorage areas, tendon anchorage hardware or CPM leakage well before integrity of the post-tensioning system would be challenged.

The proposed alternatives identified in Section IV.a through IV.d are based on an evaluation documented in the attachment to this enclosure. The results of the 21 post-tensioning system surveillances conducted on ANO-1 and ANO-2 between 1974 and 2020 demonstrate that the post-tensioning systems of both units will continue to perform their intended function well beyond the current operating license end dates.

Tendon Force

As demonstrated in the attachment, the mean force in each of the Unit 1 and Unit 2 tendon groups is projected by log-linear regression, by 95% lower confidence limit computations and, for the vertical and dome groups, by common tendon trends to remain above the specified minima until well beyond the current operating license end dates.

Condition of End Anchorage Hardware / Concrete and Extracted Wires

Enclosed end anchorage hardware and tendon wires extracted for tensile testing have shown no signs of active corrosion. The minor (acceptable) rusting that has been observed is concluded to have occurred prior to filling of the tensioned tendon duct with CPM. Corrosion on the exposed surface of bearing plates is also minor and meets acceptance criteria.

Broken wires and missing / protruding button heads represent only a miniscule fraction of the number of installed tendon wires.

Free water was present in only a few surveillance tendon anchorage areas and only in small quantities (a maximum of 0.2 liters; otherwise less than 0.1 liter).

Only 2 anchorage area concrete cracks (both at the same Unit 1 anchorage) wider than 0.01 inches were reported. Both cracks were short (13 inches or less) and concluded to be limited to surface concrete. These cracks were caulked prior to the 45-year surveillance and have not resurfaced through the caulking material.

Tendon Wire Strength and Ductility

Tensile tests on samples cut from extracted wires show, with a unique exception, that ultimate strength and ductility (quantified by the measured elongation at failure) remain above specified minimum values. Test results also show that strength and ductility are not decreasing over time.

Corrosion Protection Medium Characteristics

Results of CPM tests to determine absorbed water content, corrosive ion concentrations and neutralization number confirm that acceptance criteria have been met. There are no discernible trends to these parameters and no indication that the protective characteristics of the CPM are degrading over time.

Conclusion

Based on the evaluation provided in the attachment to this enclosure, and the information provided above, it is concluded that implementation of the alternatives as proposed in IV.a through IV.d of this request, will ensure that the ANO-1 and ANO-2 post-tensioning systems will continue to perform their design function well beyond the current license end dates to provide an acceptable level of quality and safety.

V. DURATION OF PROPOSED ALTERNATIVE

This request for alternative will remain in effect for the remainder of the current Fifth CISI interval and subsequent CISI intervals for ANO-1 and ANO-2 and will continue until the end of the current renewed operating license. The renewed operating license for ANO-1 expires on May 20, 2034, and on July 17, 2038, for ANO-2.

If similar examination scheduling is implemented in later Edition of ASME Section XI that is approved and incorporated by reference into 10 CFR 50.55a, this request will be retired when that later Edition is adopted as part of a scheduled interval update.

VI. PRECEDENCE

1 NRC letter to Dominion Energy Nuclear Connecticut, Inc., "Millstone Power Station, Unit 2, Proposed Alternative RR-05-05 to the Requirements of the ASME Code Re: Containment Unbonded Post-Tensioning System Inservice Inspection Requirements", (ML20287A471), October 20, 2020.

2 NRC letter to Southern Nuclear Operating Company, Inc., "Vogtle Electric Generating Plant, Units 1 and 2, Inservice Inspection Alternative VEGP-ISI-ALT-19-01 for Containment Tendon Inservice Inspection Extension", (ML19182A077), dated July 11, 2019.

3 NRC letter to Exelon Generation Company, LLC, "Three Mile Island Nuclear Station, Unit 1, Relief From the Requirements of the American Society of Mechanical Engineers Code RE: Examination and Testing for Containment Unbonded Post-Tensioning System", (ML19226A023), dated September 19, 2019.

4 NRC letter to Arizona Public Service Company, "Palo Verde Nuclear Generating Station Units 1, 2, and 3 - Relief Request 67 for an Alternative Frequency to Containment Unbonded Post-Tensioning System Inservice Inspection", (ML22124A241), dated May 12, 2022.

5 NRC letter to Exelon Generation Company, LLC, "Braidwood Station, Units 1 and 2 and Byron Station, Unit Nos. 1 and 2 – Proposed Alternative to the Requirements of the American Society of Mechanical Engineers Boiler & Pressure Vessel Code", (ML21134A006), dated August 3, 2021.

6 NRC letter to Exelon Generation Company, LLC, "Calvert Cliffs Nuclear Power Plant, Units 1 and 2 – Alternative to the Requirements of the ASME Section XI, Subsection IWL Concerning Unbound Post-Tensioning Systems", (ML21190A004), dated September 9, 2021.

The following is referenced as a precedent that requested relief for the remainder of the current renewed operating licenses.

7 NRC letter to Duke Energy Carolinas, LLC, "Oconee Nuclear Station, Units 1, 2, and 3 – Proposed Alternative to ASME Code RE: Containment Unbonded Post-Tensioning System Inservice Inspection Requirements", (ML21335A106), dated December 7, 2021.

VII. <u>REFERENCES</u>

1 NRC Letter to Entergy Operations, Inc., "Arkansas Nuclear One, Unit 2 Request for Alternative ANO2-ISI-021 to Permit Continued Application of the 2007 Edition through the 2008 Addenda of ASME Code", (ML19156A400), dated June 11, 2019.

2 NRC letter to Entergy Operations, Inc., "Arkansas Nuclear One, Units 1 and 2 – Relief Request ANO-CISI-001 RE: Alternative for Containment Inservice Inspection Interval", (ML082490728), dated September 25, 2008.

Enclosure, Attachment

0CAN112201

Containment Post-Tension System Inservice Inspection

Basis for Proposed Extension of Examination Interval Technical Report

ARKANSAS NUCLEAR 1

UNITS 1 & 2

CONTAINMENT POST-TENSIONING SYSTEM INSERVICE INSPECTION

BASIS FOR PROPOSED EXTENSION OF EXAMINATION INTERVAL

TECHNICAL REPORT

Report Prepared by:
Howard T. Hill, PhD, P.E. (California Civil Certificate C 22265)
Revision 1 / 18 October 2022

LIST OF ABREVIATIONS

ACI	American Concrete Institute
ANS	American Nuclear Society
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
CPM	Corrosion protection medium
EF	Elongation at failure
FSAR	Final Safety Analysis Report
kip	Kilo-pound (1,000 pounds)
ksi	Kips per square inch
LCL	Lower confidence limit
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
ppm	Parts per million
RE	Responsible Engineer
SIT	Structural Integrity Test
USNRC	United States Nuclear Regulatory Commission
UTS	Ultimate tensile strength

ARKANSAS NUCLEAR 1
UNITS 1 & 2
CONTAINMENT POST-TENSIONING SYSTEM INSERVICE INSPECTION
BASIS FOR PROPOSED EXTENSION OF EXAMINATION INTERVAL
TECHNICAL REPORT

Report Prepared by:
Howard T. Hill, PhD, P.E. (California Civil Certificate C 22265)
Revision 1 / 18 October 2022

1. PURPOSE, CONTAINMENT / ISI PROGRAM DESCRIPTION AND ORGANIZATION

This report provides the technical evaluation / justification supporting a request for relief to allow alternatives to certain containment inservice inspection (ISI) requirements specified in USNRC Regulation 10CFR50.55a (Reference 7.1) and, by reference therein, ASME Section XI, Subsection IWL (Reference 7.2). The current Arkansas Nuclear One (ANO) containment ISI program conforms to these regulatory and code requirements with modifications as allowed by approved relief requests.

1.1 Containment Description

The ANO containments are dimensionally identical reinforced and post-tensioned concrete pressure vessels that serve as the final barriers (after fuel cladding and the reactor coolant system pressure boundary) against release of radioactive material from the reactor core to the outside environment. The design basis internal pressure for both containments is 59 psig (Unit 1 and Unit 2 Safety Analysis Reports, References 7.3 and 7.4).

Each containment consists of a conventionally reinforced concrete flat base mat, a pre-stressed concrete three-buttress cylinder and a prestressed concrete shallow dome. The dome consists of an outer toroidal section and a central spherical cap. A massive ring girder serves as a transition between the cylinder wall and dome. The interior surface is lined with a ¼ inch steel plate for leak tightness. Principal containment dimensions are, as shown in Reference 7.4:

- Cylinder inside radius (to the inside face of the steel liner) – 58 ft.
- Cylinder height base mat to spring line – 171 ft. 6 in.
- Inside height base mat to dome soffit – 208 ft. 6 in.
- Dome spherical cap inside radius – 87 ft. 6 in.
- Spherical cap to cylinder transition inside radius – 34 ft. 6 $^1/_8$ in.
- Cylinder wall concrete thickness (exclusive of the steel liner) – 3 ft. 9 in.
- Dome thickness (increases at the transition to the ring girder) - 3 ft. 3 in.
- Base mat thickness – 9 ft.

- Equipment opening (the largest wall penetration) diameter – 15 ft.

The cylinder wall and dome are post-tensioned with 186 wire BBRV (wires anchored by cold formed button heads) tendons. The wires, which conform to ASTM A421 (Reference 7.5), have a diameter of 0.250 inches and a specified minimum ultimate tensile strength of 240 ksi.

The cylindrical wall is pre-stressed with both circumferential (hoop) and vertical direction tendons.

Wall circumferential pre-stressing consists of 3 overlapping sub-groups, each spanning 240 degrees plus the width of a buttress. Vertically adjacent sub-groups are offset by 120 degrees to provide continuous overlap of pre-stressing force. Circumferential tendons anchor at the buttress faces.

Wall vertical pre-stressing consists of tendons anchor at the top of the ring girder and the bottom of the base mat. A tunnel (the tendon access gallery) below the base mat provides access to the lower anchorages.

Dome pre-stressing consists of 3 layered sub-groups, each consisting of equally spaced and parallel (in plain view) tendons. The layers intersect at 60 degrees. Dome tendons anchor at the vertical face of the ring girder.

As the Unit 1 and Unit 2 design basis loads are different, the numbers of tendons in the units differ as shown in the following table.

Number of Tendons in Each Group			
Unit	Tendon Group		
	Hoop	Vertical	Dome
Unit 1	169[a]	102	90
Unit 2	159	115	84

Note a: The original design specified 171 tendons, 57 in each sub-group. Due to blocked ductwork, two tendons, 31H12 and 32H8, could not be installed (Reference 7.3).

To accommodate temporary wall openings for steam generator replacement in 2000 (Unit 2) and 2004 (Unit 1), designated tendons were either removed and replaced or de-tensioned and subsequently re-tensioned. These are listed in table below (References 7.3 and 7.6).

Tendons Removed / Replaced or De-tensioned / Re-tensioned During Steam Generator Replacement				
Unit	Removed / Replaced		De-tensioned / Re-tensioned	
	Hoop	Vertical	Hoop	Vertical
Unit 1	12H21 – 21H28 31H21 – 31H28	V75 – V80	12H16 – 21H20 12H29 – 21H32 31H17 – 31H20 31H29 – 31H33	V60 - V74 V81 – V95
Unit 2	12H20 – 12H28 32H21 – 32H29	V82 – V87	12H17 – 12H19 12H29 – 12H31 32H18 – 32H20 32H30 – 32H32	V72 – V81 V88 – V97

Tendon forces decrease with time as a result of elastic shortening (the effect of sequential tensioning operations), concrete shrinkage, concrete creep and pre-stressing strand relaxation losses. Mean tendon forces must remain above specified minima to ensure that concrete remains in a state of membrane compression under postulated accident pressure and temperature conditions. Minimum required mean forces are tabulated below.

Minimum Required Group Mean Tendon Force (kip)			
Unit	Tendon Group		
	Hoop	Vertical	Dome
Unit 1[a]	1,164	1,275	1,251
Unit 2	1,205[b]	1,265[c]	1,235[b]

Note a: Values from Calculation CALC-99-E-0015-01 (Reference 7.32)
Note b: Values from Calculation CALC-97-E-0009-24 (Reference 7.33)
Note c: Values from Calculation CALC-97-E-0009-05 (Reference 7.34)

1.2 Containment ISI Program Summary Description

Continuing structural[2] integrity of the ANO containments is verified through regular examinations and tests (also referred to as surveillance) performed in accordance with the requirements of USNRC Regulation 10CFR50.55a (Reference 7.1) and, by reference therein, ASME Section XI, Subsection IWL (Reference 7.2) as modified by approved relief requests. The ISI program requires visual examination of the containment concrete surface not exempt under IWL-1220 and examination and testing of random samples selected from the tendon population. Surface

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[2] Containment liner ISI, performed to assess leak tight integrity, is covered by Subsection IWE and is not addressed in this technical report.

visual examinations follow the applicable guidelines given in the ACI reports referenced in Subsection IWL and are not addressed further in this report.

Examination and testing (also referred to herein as surveillance) of the post-tensioning system currently follows ASME B & PV Code (2007 Edition with 2008 Addenda) Section XI, Subsection IWL requirements. Examinations and tests, performed on a random sampling of tendons[3], are described below.

- Visual Examination

  Anchorage area concrete and post-tensioning system hardware are visually examined for the following indications of damage or degradation.
    - Cracking or spalling at the surface of concrete within 2 feet of bearing plate edges.
    - Accumulation of water in end caps.
    - Lack of corrosion protection medium (CPM) coverage on anchor heads, shims and buttonheads.
    - Corrosion on bearing plates, anchor heads, shims and tendon buttonheads.
    - Protruding or missing buttonheads.
    - End anchorage component cracking or distortion.
- Tendon Force Measurement

  The force at each end of hoop and dome sample tendons and at the upper end of vertical tendons is measured by applying jacking force just sufficient to loosen the shim stack (thus ensuring that all tendon load is carried by the calibrated jacks).
- CPM Sampling and Testing

  Samples of CPM are collected at each end and analyzed for water content, concentration of corrosive ions and reserve alkalinity.
- Free Water Collection and Testing

  Free water, if found in sufficient quantity for sampling, is collected and tested to determine pH.
- Tendon Wire Sampling and Testing

  A single wire is removed from one tendon in each group, examined for damage and corrosion and tested to determine yield strength, ultimate strength and elongation at failure.

1.3 Report Organization

The remainder of this report consists of the following 7 parts.

Part 2 – Summary of Proposed Alternatives and Conclusions

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[3] One tendon in each group is designated as a common tendon and examined / tested during each surveillance. The common tendon is not de-tensioned.

Part 3 - Background of Current ISI Requirements and Basis for Proposed Deviations

Part 4 – ANO Examination History and Results Analysis / Evaluation

Part 5 – Overall Summary, Conclusions and Recommendations

Part 6 - Future Examinations

Part 7 – References

Part 8 – Tables and Figures

Appendix – Force Trend Plot Parameter Data

2. SUMMARY OF PROPOSED ALTENRATIVES, AND CONCLUSIONS

The following alternatives to ASME Section XI, Subsection IWL, 2007 Edition with the 2008 Addenda are proposed and evaluated in this report.

- Extend the interval for visual examination of end anchorage areas and collection / testing CPM and free water samples (Table IWL-2500-1 Examination Category L-B, Item Nos. L2.30, L2.40 and L2.50) from 5 years to 10 years.
- Extend the interval for complete post-tensioning system examinations that include tendon force measurements (Item No. L2.10) from 10 years to 20 years.
- Align IWL-2420 surveillance schedules to allow concurrent Unit 1 and Unit 2 examinations as shown in the following table.

Proposed Tendon Surveillance Schedule (includes the two most recent Unit 1 and Unit 2 surveillance years for reference)[a]

Year	Unit 1		Unit 2	
	Visual Examination (L2.30) and CPM / Free Water Testing (L2.40[b], L2.50)	Tendon Force Measurement (L2.10)	Visual Examination (L2.30) and CPM / Free Water Testing (L2.40[b], L2.50)	Tendon Force Measurement (L2.10)
2013	Performed	Performed[c]	N/A	N/A
2014	N/A	N/A	Performed	Performed[c]
2018	Performed	N/A	N/A	N/A
2020	N/A	N/A	Performed	Performed[c]
2028	Perform	Perform	Perform	N/A
2038	Perform[d]	N/A	Perform[d]	Perform[d]
2048	Perform[d]	Perform[d]	Perform[d]	N/A
2058	Perform[d]	N/A	Perform[d]	Perform[d]

Note a: The proposed schedule does not alter the use of IWL-2420(c) which requires the examination to commence no more than 1 year prior to the specified date and to be completed not more than 1 year after the specified date.

Note b: Scope of CPM testing to be reduced per the following text.

Note c: Scope of the surveillance included tendon wire extraction and testing (L2.20).

Note d: If applicable.

- Eliminate the requirement for de-tensioning / re-tensioning of tendons, wire removal and wire sample testing (Item No. L2.20).
- Limit initial corrosion protection medium laboratory tests (Item No. L2.40) to that which determines absorbed water content; perform the corrosive ion and reserve alkalinity tests only on those samples that have a water content above the acceptance limit and / or are collected at an anchorage where free water and / or corrosion is found.

The above proposed departures relate only to pre-stressing tendon tests and the associated examinations that require close-in access to tendon end anchorage areas. Examination Category L-A, visual examination of accessible surfaces including concrete surfaces at tendon anchorage areas not selected by IWL-2521 or exempt by IWL-1220(a), will continue to be performed at 5-year intervals in accordance with IWL-2410.

This report and the Relief Request that it supports address only proposed alternatives to the requirements covered by ASME Section XI, Subsection IWL Table IWL-2500-1 Examination Category L-B. Containment liner and penetration assembly inservice inspection requirements specified in Subsection IWE are not addressed in this report.

Based on the evaluation of past examination results as discussed in subsequent sections of this report, it is concluded that implementation of the alternative containment in-service inspection program recommended herein will provide an equivalent level of assurance that the structural integrity of the Unit 1 and Unit 2 containments is maintained at the highest level.

3. BACKGROUND OF CURRENT ISI REQUIREMENTS AND BASIS FOR PROPOSED DEVIATIONS

Containment inservice inspection (also referred to herein as surveillance and inservice examination) requirements originated with the issuance of Regulatory Guide 1.35 (Reference 7.7) in the early 1970's and are currently mandated by ASME Section XI, Subsection IWL, which is incorporated by reference into USNRC regulation 10CFR50.55a. A brief history of current requirement development is summarized in 3.1, 3.2 and 3.3 below. The basis for the proposed departure from the current requirement is discussed in 3.4.

3.1 Regulatory Guide 1.35

In February 1973 the U. S. Atomic Energy Commission issued the initial version of Regulatory Guide 1.35, *Inservice Surveillance of Ungrouted Tendons in Prestressed Concrete Containment Structures*. This document, drafted prior to the completion of the first pre-stressed concrete containment structures and well before the accumulation of prototype containment pre-stressing system performance data, described the following as an acceptable basis for system examinations.

- Examination schedule - 1, 3 and 5 years after the pre-operational structural integrity test and every 5 years thereafter.
- Examination sample size – 6 dome, 5 vertical and 10 hoop tendons.
- Wire / strand extraction – one wire / strand from a tendon in each group (dome, vertical, hoop); extraction requires de-tensioning.
- Visual examinations for damage, deterioration and corrosion – corrosion protection medium, end anchorage hardware, anchorage area concrete and extracted wires / strands.
- Physical tests – tendon liftoff force and extracted wire / strand strength and elongation at failure.

The regulatory guide does not discuss the basis for the examination interval, the sample size or the various tests and examinations to be included in an acceptable program (these represent consensus opinions reached among the individuals involved in guide development). Also, it does not address the possible need for changes as future operating experience accumulates.

Subsequent revisions to Regulatory Guide 1.35 added procedures for corrosion protection medium chemical analyses (added in Revision 3), substantially changed the sampling process and included numerous other additions and clarifications but retained the examination interval and wire / strand testing program as described in the original 1973 issue. The final revision, Revision 3, was issued in July 1990.

Regulatory Guide 1.35 was withdrawn in August 2015 following the incorporation, by reference, of ASME Section XI, Subsection IWL into NRC regulation 10CFR50.55a.

3.2 ASME Section XI / Subsection IWL

The 1989 edition of the ASME Boiler and Pressure Vessel Code included in Section XI, for the first time, Subsection IWL which provided comprehensive and detailed requirements for a concrete containment inservice inspection program. During the development of IWL[4], which commenced in the 1970's, it was concluded that NRC acceptance and endorsement (by reference in 10CFR50.55a) of the document would be expedited if departures from the program described in Regulatory Guide 1.35 were minimized. For this reason, the examination interval, strength / elongation testing of wire / strand samples and relatively extensive chemical testing of corrosion protection medium samples mandated in IWL are unchanged from those identified in Regulatory Guide 1.35, Rev. 3.

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[4] The author of this technical report has been a member of the IWL working group since the 1970's (when it was still being developed as an addition, CC-9000, to ASME Section III, Division 2) and served as chair of the working group during its later development and much of the period leading up to its incorporation into Section XI in 1989.

Subsection IWL has been revised numerous times since its initial incorporation into Section XI in 1989. None of these revisions have altered the examination interval or the basic requirement to test wire / strand and corrosion protection medium samples.

3.3 USNRC Regulation 10CFR50.55a

The 1996 amendment to 10CFR50.55a incorporated, by reference and with specified exceptions and additions, the ISI requirements given in the 1992 edition, with 1992 addenda, of ASME Section XI, Subsection IWL. Subsequent amendments have referenced later editions / addenda of IWL but none have addressed changes to either the examination interval or the requirements for testing wire / strand and corrosion protection medium samples.

3.4 Basis for Proposed Deviations / Relief from 10CFR50.55a and IWL Requirements

[Note: This section of the technical report includes a generalized summary of post-tensioning system performance observed during 4 decades of periodic examinations conducted at 24 U. S. nuclear plant sites with 41 pre-stressed concrete containments. It is intended to show that most containment post-tensioning systems are continuing to perform well and that, in general, system examination intervals could be significantly increased without compromising safe operation of the plant.]

The material covered in this section is based on the report author's experience as described below.

- Participation in containment post-tensioning system examinations at U. S. and foreign sites.
- USNRC funded research, performed under contract to ORNL, on age-related decrease in pre-stressing force and other age-related effects at ~20 U. S. containments.
- Four decades of interacting with fellow members of the IWL working group.
- Review of USNRC informational bulletins and generic letters.
- Review of system performance history in connection with preparation of program basis documents for license renewal applications.
- Forecasting tendon forces in connection with the preparation of minimum required pre-stressing force calculations.
- Work on a USNRC-funded project to review and recommend updates to Regulatory Guides 1.35, 1.35.1 and 1.90, which address inservice inspection of pre-stressed containments.
- A three-year association with the Crystal River 3 containment repair project; assignments included evaluating the condition of tendons not affected by the repair work.

The following summary is qualitative; specific references are not cited as the bases for the generalized statements regarding post-tensioning performance.

As noted in 3.1, 3.2 and 3.3 above, the examination intervals and wire / strand testing addressed in the 1973 original issue of Regulatory Guide 1.35 are now, almost 50 years later, still incorporated effectively unchanged into the current edition of ASME Section XI, Subsection IWL.

In addition, the current edition of ASME Section XI, Subsection IWL specifies corrosion protection medium chemical testing procedures that are effectively unchanged from those described in Regulatory Guide 1.35, Revision 3 (issued in July 1990).

The results of unbonded post-tensioning system examinations performed over the last 4 decades at 24 domestic sites with a total of 41 pre-stressed containments (listed in Table 1) provide ample evidence, as discussed below, that prescriptive requirements currently in IWL are, in many cases, overly conservative. These industry results as well as ANO plant-specific operating experience as subsequently discussed, support the implementation of alternative programs with fewer prescriptive requirements.

Reducing prescriptive requirements, as addressed in this report and the associated Relief Request that it supports, has the following advantages.

- It reduces personnel and equipment safety hazards associated with working at heights, handling of heavy loads, working with high-pressure hydraulic equipment, working close to tendon end anchorages that can suddenly release stored mechanical energy, working with hot (>150 °F) corrosion protection medium that is under pressure and working in proximity to high-energy plant systems.
- It reduces the potentially deleterious cycling of tendon loads that occurs during de-tensioning / re-tensioning for wire removal and to a lesser extent during the measurement of lift-off forces.

The technical justification for the proposed deviations is based on operating experience accumulated over the past 4 decades at the 24 domestic plants with containments having unbonded post-tensioning systems and, in particular, the operating experience documented during the post-tensioning system examinations performed at ANO. The general conclusions regarding post-tensioning system performance are listed below. Conclusions specific to ANO are addressed in detail in subsequent sections of this report.

3.4.1 Pre-Stressing Force Trend

Containment design criteria typically require that the post-tensioning system provide sufficient pre-stressing force at the end of 40 years (period of initial licensure considered to be the plant operating lifetime when design work on existing plants commenced) to maintain membrane compression in the walls and dome under specified accident conditions.

Post-tensioning system design was based on a postulated linear decrease in pre-stressing force with the logarithm of time (log-linear decrease). The log-linear function was selected as this provided a reasonably good fit to the results of relatively short-term creep, shrinkage and relaxation tests and was consistent with expectations based on the calculated response of theoretical models that represent materials as an assemblage of linear springs and dashpots. Concrete creep and shrinkage tests were typically conducted for 180 days and pre-stressing steel relaxation tests for 1000 hours (~40 days). Designing for a 40-year plant operating lifetime required extrapolating concrete test durations by a factor of 80 and steel test durations by a factor of almost 400.

Post-tensioning system examination data have shown, with relative consistency, that the rate of change of pre-stressing force with the logarithm of time tends to decrease with time. Within 20 to 25 years after the completion of pre-stressing operations, the force time trend becomes essentially flat[5]. Given this general trend, it can be stated with a high degree of confidence that the examination interval may be increased beyond 10 years with no compromise of safety function if the following conditions are satisfied.

- The current mean pre-stressing force (hoop, vertical, dome, inverted U) computed using both the trend of individual tendon force data acquired to date and the mean of the most recently acquired data exceed the minimum required level by significant margins. The margin deemed significant is established through an evaluation by the Responsible Engineer. If the trend of the mean is considered to be a log-linear function, data acquired during the year 1, 3 and 5 surveillances may be omitted from the trend computation[6].
- The forecast mean pre-stressing forces (hoop, vertical, dome, inverted U), determined using the data acquired to date and computed, for conservatism, at the 95% lower confidence limit, remain above the minimum required levels until well past the deadline for completion of the subsequent surveillance.

3.4.2 System Hardware Condition History

Industry wide, there have been relatively few significant issues associated with containment post-tensioning system hardware (tendon wire / strand[7], anchor heads, wedges, shims and bearing plates).

Active corrosion is typically found only on the exposed parts of bearing plates. Free water is not often found in end caps and / or on hardware.
Instances of deformation / damage / degradation are rare and almost always associated with singular construction events.

Most exceptions to the above are the result of unique situations that are plant specific and not indicative of an industry wide problem. Two widely reported exceptions, one involving wire corrosion and the other, anchor head material, are described below. Occurrences have been limited to the plants where these were first observed.

- Debris blocked the drains at the perimeter of a shallow dome resulting in flooding that submerged the caps at the upper end of the vertical tendons. The hold down bolt holes in the tops of the caps were not well sealed. Storm water entered the caps through these holes and submerged the short lengths of uncoated wire just below the anchor heads. A number of wires were severely corroded and found to be no longer effective as pre-stressing elements.

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[5] As discussed in Section 4 of this report, scatter of measured tendon forces tends to obscure the true trend of the mean. The conclusion regarding flattening of the trend is based on statistical analysis rather than an observed characteristic of the plotted data.

[6] Industry wide data tend to show that mean force (vs. log time) decreases significantly more rapidly during the first 10 years following completion of pre-stressing operations than it does during subsequent years. In addition, measurements made during the early years of plant life are often known to be less accurate than those made later using improved technology.

[7] The only U. S. containments with strand tendons, anchored with hardened wedges rather than cold formed button heads, are Rancho Seco, San Onofre (2 & 3) and Vogtle (1 & 2). Of these plants, only the Vogtle units are currently operating.

New maintenance procedures to prevent future flooding above the ring girder were implemented. The condition has not recurred.

- A unique combination of steel chemistry and high hardness led to the failure of anchor heads in both units of a two-unit plant. Several failures have occurred at these same units at random times over the past 4 decades. Industry wide evaluations established that anchor heads of this type are not in use elsewhere.

  The problem has been addressed by implementing an enhanced examination program. Corrective action consists of replacing failed or cracked anchor heads as these are found.

3.4.3 Wire / Strand Test Results

Wire sample tests, performed by certified laboratories using appropriate equipment and procedures as specified in the applicable ASTM standards, show that strength and elongation at failure do not degrade with time. While past industry data often show reported strength and elongation to vary significantly from examination to examination, close evaluation of the data suggests that such fluctuations can generally be attributed to variations in the testing, specifically:

- Many of the earlier tests were performed using vendor procedures that differ from those specified by the applicable ASTM standards.
- Testing equipment was often vendor-fabricated and did not meet ASTM specifications
- Personnel assigned to the testing work did not always have the necessary experience.

In general, tests that conform to ASTM specifications and that are performed by experienced technicians show that both strength and elongation are close to, but exceed, the minima (240 ksi and 4.0%, respectively) specified for ASTM A421 (Reference 7.5) wire.

As there is no evidence that either strength or elongation (at failure) decrease with time under load, it is concluded that there is no benefit to ongoing tests for these parameters. And, it is to be noted that there is no precedent across the broader (beyond nuclear power plants) industry to periodically evaluate the continuing mechanical properties of pre-stressing system hardware and other steel structural members.

Relaxing the requirement for wire / strand tests, when justified by evaluation of specific plant operating experience, reduces the deleterious cycling of tendon force resulting from the de-tensioning and re-tensioning needed to allow wire removal. It also reduces the industrial hazard associated with the de-tensioning and re-tensioning operation.

3.4.4 Corrosion Protection Medium Test Results

Effectively all US containments that have ungrouted tendons use a corrosion protection medium (CPM) product supplied by the Viscosity Oil Company. CPM formulations have changed over time but the basic product remains the same, i.e., a microcrystalline wax that provides the following protective functions.

- An essentially waterproof coating on tendon wires and end anchorage hardware.

- A bulk fill to limit water intrusion into tendon ductwork.
- A chemically built-in alkalinity to neutralize acid conditions that could lead to corrosion.

There is no industry operating experience to indicate that the CPM used in US containments has degraded over time in such a manner as to result in tendon or end anchorage hardware corrosion. Such hardware problems as have been found are attributable to either gross loss of medium from the ductwork, end anchorage design features that prevent full coverage of metallic components at the time of CPM injection or, metallurgical characteristics of certain anchor-head production batches.

Current CPM testing requirements mandate relatively complex procedures, as described or referenced in ASME Section XI (Reference 7.2) Table IWL-2525-1, to determine absorbed water content, corrosive ion concentration and residual reserve alkalinity. As corrosive ions cannot enter the ductwork in the absence of water intrusion and reserve alkalinity cannot be brought into play in the absence of acid ion presence in the bulk CPM, there is little or no benefit gained by testing CPM samples for ion concentrations and reserve alkalinity unless there is evidence of free or absorbed water.

Consequently, industry experience would suggest that CPM samples collected during end anchorage examinations should be initially tested only to determine absorbed water content and that additional tests should be conducted only if there is evidence of sufficient water to establish potentially corrosive conditions or, if specific unit / plant test data indicate a history of problems with the CPM. Modifying testing programs accordingly would reduce the environmental problems associated with disposal of the reagents used in these processes (the procedure for determining water content does not require use of reagents).

4. ANO EXAMINATION HISTORY AND RESULTS ANALYSIS / EVALUATION

The visual examination results and test data used in the development of Sections 4.1 through 4.4 are those documented in ANO inservice inspection reports, References 7.8 through 7.27.

ANO has completed, to date, 11 surveillances of the Unit 1 post-tensioning system and 10 surveillances of the Unit 2 system. These were performed in the years as shown in the following table. The SIT year (References 7.28 and 7.29) is also shown for reference. The examinations were conducted in accordance with Regulatory Guide 1.35 or 10CFR50.55a / ASME Section XI Subsection IWL as noted. The transition to 10CFR50.55a / ASME Section XI Subsection is addressed in the 20 December 2000 containment inservice inspection program plan (Reference 7.30).

SIT and Surveillance Number / Year	Year Performed Unit 1	Year Performed Unit 2	Governing Document(s)
SIT	1973	1977	ASME III / Div. 2 / CC-6000
1 / 1	1975	1978	Reg Guide 1.35
2 / 3	1977	1980	Reg Guide 1.35

SIT and Surveillance Number / Year	**Year Performed Unit 1**	**Year Performed Unit 2**	**Governing Document(s)**
3 / 5	1979	1983	Reg Guide 1.35
4 / 10	1983	1988	Reg Guide 1.35
5 / 15	1988	1993 - 1994	Reg Guide 1.35
6 / 20	1993	1999	Reg Guide 1.35
7 / 25	1999	2005	(Unit 1) Reg Guide 1.35 (Unit 2) 10CFR50.55a / IWL
8 / 30	2004	2010	10CFR50.55a / IWL
9 / 35	2008	2014	10CFR50.55a / IWL
10 / 40	2013	2020	10CFR50.55a / IWL
11 / 45	2018	N/A	10CFR50.55a / IWL

The following sections, 4.1 through 4.4, of this report provide a comprehensive evaluation of ANO post-tensioning system examination results documented in the applicable surveillance reports.

Section 4.1 – Tendon force trends and forecasts

- Unit 1 and Unit 2 hoop tendon force trends and forecasts
- Unit 1 and Unit 2 vertical tendon force trends and forecasts
- Unit 1 and Unit 2 dome tendon force trends and forecasts
- Unit 1 and 2 common tendon-based trends and forecasts

Section 4.2 –End anchorage condition

Section 4.3 – Extracted wire condition and mechanical properties

Section 4.4 – Corrosion protection medium chemical properties and free water analysis

The examination schedule proposed in Part 2 of this report is justified if the proposed schedule is supported by an evaluation of each of the 4 post-tensioning system performance categories listed above.

In this report surveillances are generally referred to by calendar year and / or time, T, since the SIT date. Plots of time-dependent parameters use T for the time axis. Tables listing time dependent parameters show both the calendar year of the surveillance and the applicable value of T.

T is calculated as the difference between the surveillance mid-point date and the SIT mid-point date, each expressed as decimal years. Mid-points are determined as decimal years midway between the event (SIT or surveillance) starting and ending dates as noted in the applicable reports. To simplify computations, starting and ending dates are treated as the middle of the month during which the surveillance (or SIT) begins and ends. Values of T computed for Units 1 and 2 are shown in the following tables.

ANO SIT & Surveillance Dates and Times, T, Since SIT - Unit 1						
Event	Start		End		T', Mid-Point	T,
	Year	Month	Year	Month	Year & Fraction	Years Since SIT
SIT	1973	11	1973	11	1973.875	0.0
1	1975	3	1975	6	1975.333	1.5
3	1977	2	1977	5	1977.250	3.4
5	1979	1	1979	4	1979.167	5.3
10	1983	2	1983	3	1983.167	9.3
15	1988	2	1988	4	1988.208	14.3
20	1993	8	1993	12	1993.792	19.9
25	1999	8	1999	12	1999.792	25.9
30	2004	1	2004	5	2004.208	30.3
35	2008	10	2008	11	2008.833	35.0
40	2013	4	2013	6	2013.375	39.5
45	2018	3	2018	5	2018.292	44.4

ANO SIT & Surveillance Dates and Times, T, Since SIT - Unit 2						
Event	Start		End		T', Mid-Point	T,
	Year	Month	Year	Month	Year & Fraction	Years Since SIT
SIT	1977	10	1977	10	1977.792	0.0
1	1978	11	1978	12	1978.917	1.1
3	1980	12	1980	12	1980.958	3.2
5	1983	3	1983	3	1983.208	5.4
10	1988	2	1988	2	1988.125	10.3
15	1993	12	1994	3	1994.083	16.3
20	1999	12	2000	1	2000.000	22.2
25	2005	3	2005	8	2005.417	27.6
30	2010	5	2010	6	2010.417	32.6
35	2014	5	2014	6	2014.417	36.6
40	2020	6	2020	7	2020.500	42.7

4.1 Tendon Force Trends and Forecasts

Force (lift-off force or the force required to separate the anchor head from the shim stack) in designated sample tendons, and additional tendons as mandated by procedure or specified by the Responsible Engineer, is measured during each examination. Measured force trends and forecasts provide ample evidence that mean pre-stressing in the containment wall and dome will remain at or above the lower limits shown in report Section 1.1 above until at least T = 100 years and, well beyond the currently expected 80-year maximum operating lifetime of the units.

The purpose of a lift-off force measurement is to determine how the initial seating force in a tendon (used as a measure of the pre-stressing force contributed by the tendon) has been reduced by elastic shortening and time dependent losses. Reported tendon force is the single lift-off force measured at the upper end of a vertical tendon or the average of the lift-off forces measured at the two anchorages of a hoop or dome tendon. The mean of a number of tendon forces then serves as a reasonable estimate of the overall mean pre-stressing force provided by the applicable tendon group (i.e., hoop, vertical or dome).

Forces measured at tendon anchorages reflect the losses due to elastic shortening[8], concrete creep, concrete shrinkage and tendon wire stress relaxation.

Units 1 and 2 hoop, vertical and dome force trends are addressed separately in sub-sections 4.1.1 through 4.1.3 below. The following characteristics of the trends are evaluated in each of these sub-sections.

- Log-Linear Trends and LCL's

  Concrete creep strain, concrete shrinkage strain and pre-stressing steel stress relaxation are shown by relatively short-term tests[9] to vary more or less linearly with the logarithm of time. The log-linear characteristics established by these tests are used in containment design. For this reason, mean pre-stressing force trends are treated in this report as log-linear functions.

  A log-linear mean force trend and 95% lower confidence limit (LCL) on trend line values are computed for the Unit 1 tendon groups using all applicable lift-off force data acquired during the 1-year through 40-year surveillances. In addition, trend and LCL are computed using only the 10-year through 40-year data to address the generally observed tendency for the downward slope of the force vs log time trend to flatten over time. As previously noted, Unit 2 tendon forces were not measured until the 25-year surveillance.

  The log-linear trend slope and intercept as well as LCL values are computed using the methods developed in *Probability and Statistics for Engineers* by Irwin Miller and John E. Freund (Reference 7.31).

- Common Tendon Trend Based Forecast

  As can be seen on Figures 1 through 9, and as discussed below, surveillance data exhibits a significant degree of scatter. Reasons for the scatter, which is typical regardless of the containment, are not well understood. A lower confidence limit is constructed and used to account for, in a statistical sense, this scatter. The use of a 95% confidence limit is based on a precedent set in the standard (ANSI / ANS 56.8, Reference 7.20) that governs the conduct of another safety related activity, the containment integrated leakage rate test.

  Figures 10 through 15 are plots of common tendon lift-off forces. These plots exhibit relatively little scatter (the Figures 11b, 12 and 15 incorporate only 2 points and, by default,

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[8] Elastic shortening loss is the loss in tendon force resulting from the strain induced in the concrete by subsequent tendon tensioning. It is generally greatest for the first tendon tensioned and zero for the last tendon tensioned.

[9] Creep and shrinkage tests are typically conducted for 6 months and relaxation tests for 1,000 hours (just under 42 days). These time frames are short relative to the expected service life of a containment (40, 60 or possibly even 80 years if a second license extension is granted).

cannot exhibit scatter). Since the scatter of the common tendon force data is small, it is reasonable to postulate that the true trend of group mean force is relatively close to the common tendon force trend (it is assumed, without accounting for tendon geometry, that all tendons in a group tend to lose force at about the same rate). This postulate leads to the following alternative approach to determining the trend of group mean force.

- A logarithmic mean of times, T_M, associated with each plotted lift-off force is computed as:

$$T_M = \mathrm{Exp}\left[(1 / n) * \sum_{i=1}^{n} \mathrm{Log}_{10}(T_i)\right]$$

- It is postulated that there is sufficient data such that the true mean force, F_{MTrue}, at T_M is equal to the mean of the measured lift-off forces, F_M. Then the alternative mean force, F_{MAlt}, is defined as:

$$F_{MAlt} = F_{MTrue} - b_c * [\mathrm{Log}_{10}(T) - \mathrm{Log}_{10}(T_M)]$$

where b_c is the slope (kip per unit logarithmic interval) of the common tendon trend line

Common tendon trends and alternative mean force trend are addressed in 4.1.4.

In the following discussions and evaluations, all computed mean forces and LCL's are rounded to a whole kip value. Computed values ending in (.5) are rounded to the nearest even number.

Units 1 and 2 tendon forces were measured during the surveillances noted in the table below.

Unit	Surveillance Year – Tendon Force Measurement Yes / No										
	1	3	5	10	15	20	25	30	35	40	45
1	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No
2	No	No	No	No	No	No	Yes	No	Yes	Yes[a]	N/A

Note a: Vertical tendon forces only.

Prior to the issue of Revision 3 to Regulatory 1.35 in 1990, the containment tendon surveillance program conformed to the guidance provided in Revisions 1 and 2. These earlier revisions stated that forces in Unit 1 (the first unit constructed at the site) tendons were to be measured during each surveillance and only visual examination of tendon end anchorages and testing of CPM were needed for the second unit (Unit 2).

The alternating schedule for tendon force measurements was introduced in Revision 3 to the Regulatory Guide. The periodic update of the ANO containment ISI program was implemented after the 15-year Unit 2 surveillance had been completed. Therefore, in accordance with the guidance in Revision 3, measurement of forces in Unit 2 tendons commenced with the 25-year surveillance in 2005. Note that in September, 2008, the NRC approved Request for Alternative ANO-CISI-001, for Units 1 and 2, permitting use of IWL-2421 for a 10-year frequency for Examination Category L-B, Item No. L2.10 and L2.20.

Trends and forecasts based on lift-off forces documented in surveillance reports (References 7.8 through 7.27 provide ample evidence that mean tendon force in the containment cylinder and dome will remain above the lower limits, shown in Section 1.1 above, beyond the maximum expected 80-year operating lifetime of the units. Hoop, vertical and dome mean tendon force trends and forecasts are presented and discussed in 4.2.1, 4.2.2 and 4.2.3 below. Common tendon[10] trends are addressed in 4.2.4.

Forces documented for each surveillance are listed in Tables 2 through 8. Tables 2 through 7 include standard sample tendons; i.e., those that were not de-tensioned to support the removal of concrete for steam generator replacement openings in the containment cylinder walls. Table 8 includes only the samples selected from the population of tendons de-tensioned / re-tensioned or replaced to support the steam generator replacement activity. Standard sample tendon force / log T data are plotted in Figures 1 through 15. Steam generator replacement sample tendon data are not plotted (as explained in 4.1.5). Plots are categorized as follows.

- Those including all data from surveillance year 1 (Unit 1 only)
- Those including only data from surveillance year 10 (year 25 for Unit 2)
- Those showing only common tendon (one tendon in each group that is included in consecutive surveillance samples and is not de-tensioned) forces and trends

Each of the plots includes measured lift-off forces (the force required to just separate tendon anchor head / shim stack from the bearing plate and ensure that the anchorage force is carried entirely by the calibrated ram) and log linear mean force trend lines fitted to the force / log time data sets by the method of least squares (as developed in Reference 7.31).

The Unit 1 plots, other than the 3 common tendon plots, include a curve representing the lower 95% confidence limit, or LCL (computed using the methods developed in Reference 7.31) on the trends. The LCL serves as a statistical lower bound on true mean force which has a statistically computed probability (in the present case, 95%) of lying above the computed LCL value. Precedent for applying a 95% confidence limit to a safety related parameter is established in Appendix J to 10CFR50 which, by reference, requires that containment integrated leakage rate be reported at the 95% upper confidence limit.

The Unit 2 hoop and dome tendon force plots, which incorporate only data from surveillance years 25 and 35 (as discussed above) omit the LCL curves which, as these include only data for 2 values of T, would be relatively meaningless. The Unit 2 vertical tendon force plot, which incorporates data from the 40-year surveillance, does include the LCL curve.

Both the trend lines and LCL curves are extrapolated to T = 100 years, a major grid line on the plot abscissa.

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[10] One tendon in each group that is not de-tensioned and is examined during each consecutive surveillance.

4.1.1 Hoop Tendon Force Trends

Unit 1 and Unit 2 hoop tendon mean force trends are addressed separately in 4.1.1.1 and 4.1.1.2 below. A comparison between forecast future Unit 1 and Unit 2 mean tendon force is addressed in 4.1.1.3.

4.1.1.1 Unit 1

Unit 1 hoop tendon mean force trends and LCL's are illustrated by the plots in Figures 1 and 2. The first of these uses all data from surveillance year 1 onward to develop the trend and LCL. The second uses only data from surveillance year 10 onward.

While the data exhibit a high degree of scatter (which is typical for lift-off force data) , the statistically derived characteristics (the fitted line and the LCL curve), illustrate a trend that is typical for pre-stressed concrete containments; linearized mean force and LCL values at T = 100 years are generally greater when the results of the 1, 3 and 5-year surveillances are omitted from the computations. This supports earlier conclusions that concrete creep, concrete shrinkage and pre-stressing steel relaxation may not all follow log-linear characteristics in the long term; i.e., the rate of change with the logarithm of time may decrease over time.

As shown in Figures 1 and 2, the trend and LCL derived using lift-off forces measured during all surveillances conducted to date as well as those derived using only the 10th year through 40th year data remain above the 1,164-kip minimum required mean force through T = 100 years.

The T = 100 trended mean force and LCL computed using data acquired during the 10-year and later surveillances are, as shown in Figure 2, both greater than those computed using all data from surveillance year 1. Trended mean force and LCL at T = 100 years are 1,325-kip and 1,279-kip, respectively; both values are above the 1,164-kip lower acceptance limit. However, as the mean force trend line has a positive slope, a probable consequence of data scatter, the value at T = 100 years cannot be considered realistic. Therefore, the LCL should be used in lieu of the trended mean force when assessing containment performance.

The vertical tendon mean force trend and LCL, as discussed in 4.1.2 below, have characteristics similar to those of the corresponding hoop tendon parameters.

Mean force trend, LCL and associated margins at T = 100 years are summarized in the table below.

	Computed Using 1 – 40 Year Surveillance Data		Computed Using 10 – 40 Year Surveillance Data	
	Mean Force	LCL	Mean Force	LCL
Computed Value, kip	1,243	1,220	1,325[a]	1,279
Margin, kip	79	56	161[a]	115

Note a: Value based on rising mean force trend; use LCL.

The data, trend and LCL shown on Figure 2 support the conclusion that the Unit 1 mean hoop tendon force will remain above the 1,164-kip lower acceptance limit through T = 100 years.

4.1.1.2 Unit 2

Unit 2 hoop tendon lift-off force data and the fitted trend line are plotted on Figure 3. As noted above, lift-off forces were measured only during the 25-year (T = 27.6) and 35-year (T = 36.6) surveillances. With the data incorporating only two closely spaced (relative to the plot time span) values of T, the LCL curve cannot be considered meaningful and is not included on the plot.

The Unit 2 data show much less scatter than those for Unit 1. Therefore, the trend line is considered to be a reasonably close representation of the true mean hoop tendon force trend. Both the data and trend line plotted on Figure 3 support the conclusion that mean hoop tendon force will remain above the 1,205-kip (Unit 2) lower acceptance limit through T = 100 years.

4.1.1.3 Comparison of Forecast Unit 1 and Unit 2 Hoop Tendon Mean Force

The Unit 1 LCL (Figure 2) crosses T = 100 at about 1,279 kips. The Unit 2 trend line crosses T = 100 at almost the same level. As the Unit 1 LCL is relatively flat from T = 30 years, it's intercept at T = 100 cannot be compared directly to that of the sloped Unit 2 trend line and, trend and LCL cannot be compared directly. Still, the close agreement between these two parameters at T = 100 years does support the expectation that both units behave in a similar manner.

4.1.2 Vertical Tendon Force Trends

Unit 1 and Unit 2 vertical tendon mean force trends are addressed separately in 4.1.2.1 and 4.1.2.2 below. A comparison between forecast future Unit 1 and Unit 2 mean tendon force is addressed in 4.1.2.3.

4.1.2.1 Unit 1

Unit 1 vertical tendon mean force trends and LCL's are illustrated by the plots in Figures 4 and 5. The first of these uses all data from surveillance year 1 onward to develop the trend and LCL. The second uses only data from surveillance year 10 onward.

The vertical tendon lift-off force data exhibit a degree of scatter similar to that exhibited by the hoop tendon forces. The statistically derived characteristics (the fitted line and the LCL curve) are also similar, with the linearized mean force and LCL values at T = 100 years both greater when the results of the 1, 3 and 5-year surveillances are omitted from the computations. This again supports earlier conclusions that concrete creep, concrete shrinkage and pre-stressing steel relaxation may not all follow log-linear characteristics in the long term; i.e., the rate of change with the logarithm of time may decrease over time.

As shown in Figure 4, the trended mean force and LCL derived using lift-off forces measured during all surveillances conducted to date fall above the 1,275-kip lower acceptance limit. Trended mean force and LCL at T = 100 years are 1,354-kip and-1,330 kip; both values are above the 1,275-kip lower acceptance limit.

The T = 100 trended mean force and LCL computed using data acquired during the 10-year and later surveillances are, as shown in Figure 5, both greater than those computed using all data from surveillance year 1. Trended mean force and LCL at T = 100 years are 1,406-kip and 1,368-kip; both values are above the 1,275-kip lower acceptance limit.

However, as the mean force trend line has a positive slope, a probable consequence of data scatter, the value at T = 100 years cannot be considered realistic. Therefore, the LCL should be used in lieu of the trended mean force when assessing containment performance.

Mean force trend, LCL and associated margins at T = 100 years are summarized in the table below.

	Computed Using 1 – 40 Year Surveillance Data		Computed Using 10 – 40 Year Surveillance Data	
	Mean Force	LCL	Mean Force	LCL
Computed Value, kip	1,354	1,330	1,406[a]	1,368
Margin, kip	79	55	131[a]	93

Note a: Value based on rising mean force trend; use LCL.

The data, mean force trend and LCL shown on both Figure 4 and 5 support the conclusion that the Unit 1 mean vertical tendon force will remain above the 1,275-kip lower acceptance limit through T = 100 years.

4.1.2.2 Unit 2

Unit 2 vertical tendon lift-off force data and mean force trend are illustrated by the Figure 6 plot. As the span of time associated with the lift-off forces is narrow, LCL values would be relatively meaningless and are not shown. Data scatter is significantly greater than that shown on Figure 3 for the Unit 2 hoop tendon lift-off forces. However, the trended mean tendon force remains above the 1,265-kip lower acceptance limit at T = 100 years.

The slope of the trend line, while slightly positive (a probable consequence of data scatter), is, at +7.5-kip per unit logarithmic interval, quite small. This suggests that loss of vertical tendon mean force following the 25-year surveillance is essentially negligible. The calculated mean force at T = 100 years is 1,383-kip. Corresponding margin above the 1,265-kip lower acceptance limit is 118-kip.

The data and trend line plotted on Figure 6 support the conclusion that Unit 2 mean vertical tendon force will remain above the 1,205-kip (Unit 2) lower acceptance limit through T = 100 years.

4.1.2.3 Comparison of Forecast Unit 1 and Unit 2 Vertical Tendon Mean Force

Due to the difference in data time spans and quantity, a direct comparison of the Unit 1 and Unit 2 vertical tendon mean force expected at T = 100 years is not possible. However, as the trend line slopes shown on Figures 5 and 6 are both small, the associated intercepts are considered to provide a reasonable alternative to the parameters that would be used in a rigorous comparison. The 1,354-kip Unit 1 intercept and the 1,368-kip Unit 2 intercept are close. If the true trend line slopes are treated as having a negligible effect over the time intervals involved, the close agreement between the intercepts leads to the conclusion that, as expected, the two units are behaving in a similar manner.

4.1.3 Dome Tendon Force Trends

Unit 1 and Unit 2 dome tendon mean force trends are addressed separately in 4.1.2.1 and 4.1.2.2 below. A comparison between forecast future Unit 1 and Unit 2 mean tendon force is addressed in 4.1.2.3.

4.1.3.1 Unit 1

Unit 1 dome tendon mean force trends and LCL's are illustrated by the plots in Figures 7 and 8. The first of these uses all data from surveillance year 1 onward to develop the trend and LCL. The second uses only data from surveillance year 10 onward. The trend and LCL at T = 100 years, as shown on both figures, are above the 1,250-kip lower acceptance limit on mean dome prestressing force.

The dome tendon lift-off force data exhibit a degree of scatter similar to that exhibited by the hoop and vertical tendon forces. However. The trends of the statistically derived characteristics differ from those computed for the hoop and vertical tendon groups. The T = 100 year mean force values shown on Figures 7 and 8 are the same (1,330-kip); the T = 100 LCL computed using all data from surveillance years 1 through 40 (Figure 7) is 1,304-kip while that computed using only the data from surveillance years 10 through 40 (Figure 8) is.30-kip less at 1,274-kip. While this behavior is not expected (omitting the 1, 3 and 5-year data from the computations almost always results in a greater mean force and LCL at T = 100), it is explained in part by the effect of the 15-year data point which can be considered an outlier[11].

Mean force trend, LCL and associated margins at T = 100 years are summarized in the table below.

	Computed Using 1 – 40 Year Surveillance Data		Computed Using 10 – 40 Year Surveillance Data	
	Mean Force	LCL	Mean Force	LCL
Computed Value, kip	1,330	1,304	1,330	1,274
Margin, kip	80	54	80	24

The data, mean force trend and LCL shown on both Figure 7 and 8 support the conclusion that the Unit 1 mean vertical tendon force will remain at or above the 1,250-kip lower acceptance limit until T = 100 years and well beyond the currently expected 80-year limit on unit operating lifetime.

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[11] Omitting the 15-year data point from the calculations increases the T = 100 trended mean force and LCL to 1,342-kip and 1,293-kip, respectively.

4.1.3.2 Unit 2

Unit 2 dome tendon lift-off force data and mean force trend are illustrated by the Figure 9 plot. The LCL is not shown, as previously discussed, since the plot includes only two closely spaced (relative to the abscissa range) values of T. Overall, data scatter is less than that shown for the Unit 1 lift-off forces on Figures 7 and 8. significantly greater than that shown on Figure 3 for the Unit 2 hoop tendon lift-off forces. The mean force trend line has a relatively flat slope, 49.0-kip per unit logarithmic interval. Mean force extrapolated to T = 100 years is 1,342-kip which is 107-kip above the 1,235-kip lower acceptance limit.

Based on the trend line calculations and the relatively low degree of data scatter, it is concluded that Unit 2 dome tendon mean force will remain above the 1,235-kip lower acceptance limit through T = 100 years and well beyond the currently expected 80-year limit on unit operating lifetime.

4.1.3.3 Comparison of Forecast Unit 1 and Unit 2 Dome Tendon Mean Force

Due to the difference in data time spans and quantity, a direct comparison of the Unit 1 and Unit 2 dome tendon mean force expected at T = 100 years is not possible. However, since the slope of the log-linear trend lines shown on Figures 8 and 9 are close (-46.45 and -49.0-kip per unit logarithmic interval, respectively), it is reasonable to conclude that both units are, as expected, behaving in a similar manner with respect to loss of dome tendon mean force.

4.1.4 Common Tendon Trends and Alternative Analysis

Common tendon force trends are plotted on Figures 10 through 15. The Unit 1 plots and the Unit 2 vertical tendon force plot exhibit relatively little scatter about the fitted trend lines. As the Unit 2 hoop and dome tendon force plots consist of only 2 points, these provide no basis to assess scatter; the fitted lines pass through both points.

As discussed at the beginning of Part 4 above, the trend of common tendon lift-off forces provides an alternative method for computing group mean force. If common tendon force scatter is small and if the mean, F_m, of all group lift-off forces is close to the true mean force at the mean value of Log T (a basic postulate in linear regression analysis), then the following expression can be considered to provide a reasonably close approximation of true group mean tendon force, F_{mt}.

$$F_{mt} = F_m + b_c * [\text{Log } T - (\text{Log } T_i)_m] \qquad (4\text{-}1)$$

where (with all values of T in years)

b_c is the slope (kip per unit logarithmic interval) of the common tendon trend line

T is any time of interest

$(\text{Log } T_i)_{mean}$ is the mean of the values of Log T associated with each lift-off

The table below lists the values of b_c, F_m and $(\text{Log } T_i)_m$ computed for the Unit 1 and Unit 2 tendon groups. These values are computed and displayed on the spread sheets used in the generation of the plots shown on Figures 1 through 15. The spread sheets are reproduced in the Appendix.

Two values are shown for the Unit 1 common hoop tendon trend line slope. The first is computed using all three lift-off force data points as plotted on Figure 10. The second, or alternative, slope is computed using only the first two data points, treating the third (40-year surveillance) data point as a possibly erroneous. The alternative slope is considered to be a more reasonable estimate of true trend line slope as it is more in line with the remaining values listed in the table below.

Alternative Mean Force Trend Analysis Parameters				
Tendon Group	Unit	b_c	F_m	$(\text{Log } T_i)_m$
Hoop	Unit 1	-205.9	1,283	1.293
	Unit 1, alt[a]	-44.0[a]	1,283	1.293
	Unit 2	+24.5	1,328	1.493
Vertical	Unit 1	-111.65	1,386	1.332
	Unit 2	-29.21	1.596	1,380
Dome	Unit 1	-65.89	1,359	1.365
	Unit 2	-32.6	1,365	1.493

Note a: Alternate value of b_c as discussed above.

Using the above parameters in Expression (4-1) gives the following values for group mean force, F_{mt}, at T = 100 years as well as at the deadline date for completion of the next surveillance during which lift-off forces will be measured. Values of T corresponding to the deadline dates are 55.6 years for Unit 1 and 61.7 years for Unit 2. The margins (in kip) between forecast tendon group mean force and the lower acceptance limit (LAL) is shown in parenthesis after the forecast mean. LAL values (in kip) as listed in Section 1.1 above are show in the second column.

Computed Alternative Mean Force and (Margin), kip, for Times, T, Listed Below				
Tendon Group	Unit / LAL	T = 55.6 (Unit 1)	T = 61.7 (Unit 2)	T = 100
Hoop	Unit 1 / 1,164	1,190 (26)	N/A	1,138 (-26)
	Unit 1, alt[a] / 1,164	1,263 (99)	N/A	1,252 (88)
	Unit 2 / 1,205	N/A	1,336 (131)	1,341 (136)
Vertical	Unit 1 / 1,275	1,340 (65)	N/A	1,312 (37)
	Unit 2 / 1,265	N/A	1.375 (110)	1,369 (104)
Dome	Unit 1 / 1,250	1,334(84)	N/A	1,317 (67)
	Unit 2 / 1,235	N/A	1,356 (121)	1,349 (114)

Note a: Forecast mean computed using the alternative trend line slope of -44.0 kip per unit logarithmic interval.

In all cases except that for the Unit 1 hoop tendon group with the common tendon trend line slope, b_c, set equal to -205.9 kip per unit logarithmic interval, F_{mt} at T = 100 years is at or above the associated lower acceptance limit. This supports the conclusion that Unit 1 and Unit 2 group mean tendon forces will remain at or above that limit until T = 100 years and, well beyond the currently expected 80-year maximum unit operating lifetime.

4.1.5 Tendons Affected by Steam Generator Replacement Activities

As previously discussed, a number of tendons were de-tensioned / re-tensioned or replaced to support the Unit 1 and Unit 2 steam generator replacement (SGR) opening in the containment cylinder wall. As required by ASME Section XI, Sub-section IWL, forces in tendons randomly selected from this population were measured. The random samples included both originally installed tendons that were de-tensioned and re-tensioned and replaced tendons. Measured lift-off forces are listed in Table 8.

Unit 1 The steam generators were replaced in 2004 and Unit 2 generators in 2000, in both cases after most of the ultimate creep and shrinkage losses had occurred. Consequently, SGR tendon force loss is due principally to steel relaxation; ongoing creep and shrinkage losses are expected to be minimal. Therefore, SGR tendons are expected to maintain higher levels of force than the remaining tendons that were not de-tensioned to accommodate the containment cylinder wall opening.

Unit 1 SGR tendon lift-off forces were measured during the 40-year surveillance in 2013, approximately 9 years after the SGR tendons were tensioned. To date there have been no other Unit 1 SGR tendon force measurements. The following table provides a comparison between the SGR tendon forces measured in 2013 and those measured during the 5-year surveillance in 1979. In each case the time intervals between tensioning and measurement are roughly the same.

Unit 1 Tendon Force Comparison

Group	Parameter	1979 Surveillance Tendon Force, kip	2013 Surveillance SGR Tendon Force, kip
Hoop	Maximum	1,356	1,516
	Average	1,324	1,514
	Minimum	1,286	1,509
Vertical	Maximum	1,407	1,550
	Average	1,368	1,545
	Minimum	1,332	1,550

The table confirms the expectation that SGR tendon force loss over a given time period will be substantially less than that experienced by the tendons tensioned in the early 1970’s. For both the hoop and vertical tendon groups, SGR tendon maximum, average and minimum force levels are more than 100 kips above the corresponding levels documented for the 1979 surveillance.

Unit 2 SGR tendon lift-off forces were measured during the 25-year surveillance in 2005 and the 35-year surveillance in 2014, approximately 5 years and 14 years, respectively, after the SGR tendons were tensioned. As measurement of Unit 2 lift-off forces did not commence until the 25-year surveillance in 2005, the SGR tendon forces cannot be compared to those measured 5 and 14 years after initial tensioning. As an alternative, the table below provides a comparison between the Unit 2 SGR tendon forces measured in 2005 / 2014 and the Unit 1 forces measured during the 3-year and 10-year surveillances in 1977 and 1983, respectively. In the first case the time intervals between tensioning and measurement are roughly the same. In the second case, the interval between tensioning and measurement is somewhat greater for the SGR tendons which gives a conservative comparison.

Unit 2 Tendon Force Comparison

Group	Parameter	1977 Unit 1 Surveillance Tendon Force, kip	2005 Unit 2 Surveillance SGR Tendon Force, kip	1983 Unit 1 Surveillance Tendon Force, kip	2014 Unit 2 Surveillance SGR Tendon Force, kip
Hoop	Maximum	1,406	1,444[a]	1,320	1,502
	Average	1,345		1,274	1,452
	Minimum	1,303		1,216	1,403
Vertical	Maximum	1,460	1,532[a]	1,398	1,562
	Average	1,428		1,382	1,530
	Minimum	1,380		1,354	1,497

Note a: The 2005 surveillance SGR tendon sample consisted of a single hoop and a single vertical.

Again, the table confirms (subject to the expectation that Unit 1 and Unit 2 tendon forces follow similar trends) that SGR tendon force loss over a given time period will be substantially less than that experienced by the tendons tensioned in the mid-1970's.

The numbers in the above tables support the conclusion that forces in SGR tendons will always remain above those in the remaining tendon population.

4.1.6 Conclusion Relating to Pre-Stressing Force

The tendon force trend and comparative data evaluated in 4.1.1 through 4.1.5 above lead to the conclusion that Unit 1 and Unit 2 mean tendon forces levels will remain above the lower acceptance limits beyond the currently postulated 80-year maximum unit operating lifetime. And, further, that mean tendon force levels will remain at or above the lower acceptance limits until T = 100 years (after the applicable unit SIT).

This conclusion supports the proposed extension of the interval between containment post-tensioning system examinations as presented in Part 2 of this technical report.

4.2 End Anchorage Condition

During each of the surveillances, end anchorage areas were visually examined for evidence of corrosion, presence of free water, broken wires or missing button heads, damage to / distortion of load bearing components and cracks in concrete adjacent to bearing plates. Results of these examinations are summarized in 4.3.1 through 4.3.5.

4.2.1 Corrosion

Levels of corrosion are defined in this report by number or letter categories[12] as shown below.

CORROSION CATEGORIES	
Level	Category Definition
1 or A	Bright metal
2 or B	Light rust removable with a few passes of fine grit emery cloth
3 or C	Patches of red oxide with pitting depth not exceeding 0.003 in.
4 or D	Red oxide; noticeable pits with depth 0.003 to 0.006 in.
5 or E	Heavy rusting; noticeable pits with depth 0.006 to 0.010 in.

No active corrosion was observed on bearing plates, anchor heads, button heads, shims or extracted wires. With the exceptions noted below, observed corrosion was limited to Level 2 or, alternatively, Category B, generally defined as light rust removable with a few passes of fine grit emery cloth. Level 2 corrosion is considered acceptable.

- Some Level 3 corrosion, defined as patches of red oxide with pitting not exceeding 0.003 inches in depth was observed on some bearing plate areas. Level 3 corrosion on bearing plates is considered acceptable.
- During the Unit 1 20-year surveillance, Level 5 corrosion was found on a 3-inch shim at the shop (top) end of vertical tendon V65. The shim was replaced.

As corrosion is not active, it is concluded that rust observed on items other than the exposed areas of bearing plates occurred during fabrication, transport or storage or otherwise prior to the time that the tendon duct and end anchorage areas were filled with CPM.

Based on the results of surveillances conducted to date, it is concluded that corrosion of post-tensioning system hardware is minor in nature and will not impact the structural integrity of the Unit 1 or Unit 2 containment during the foreseeable future. This conclusion supports the extension of system examinations as presented in Part 2 of this technical report.

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[12] Corrosion Categories 1 through 5 (or A through E) were defined, without an identified basis or other justification, in early INRYCO surveillance procedures. These definitions are still in use.

4.2.2 Free Water

Free water found at tendon end anchorages during surveillances performed to date is documented in the table below.

Free Water Observations[a]		
Surveillance Year	Unit 1	Unit 2
1	Report not available	Water not mentioned in report
3	Water not mentioned in report	Water not mentioned in report
5	Water not mentioned in report	Water not mentioned in report[b]
10	Water not mentioned in report	31H36 field end - <0.1 l
15	V70[c] - <0.1 l V72[c] - <0.1 l V98[c] - <0.1 l	V74 field (bottom) end - drops
20	V101 field (bottom) end - <0.1 l	None found
25	V80 shop (top) end – drops	12H07 shop end - <0.1 l
30	None found	31H38 field end – 0.2 l pH per test – 9.1
35	None found	V50 field (bottom) end - drops
40	None found	None found
45	21H55 shop end - drops	N/A, 45-year surveillance not yet performed

Note a: Water quantities shown in surveillance reports as ounces are converted to the nearest 0.1 liter for consistency. Quantities less than 0.1 liter are shown as <0.1 l.

Note b: Procedure summary in the surveillance report states that examination scope covers free water.

Note c: Tendon end not identified in surveillance report.

In no case was the presence of water associated with corrosion. Since relatively few of the anchorages examined showed evidence of free water, since the quantities of free water found did not exceed 0.2 liters and since the free water observed was determined not to have caused corrosion, it is concluded that free water in tendon anchorages and ductwork is not a cause for concern.

Based on the results of surveillances conducted to date, it is concluded that accumulations of free water in post-tensioning system anchorage areas and ductwork are minor in nature and will not adversely affect system hardware during the foreseeable future. This conclusion supports the extension of system examinations as presented in Part 2 of this technical report.

4.2.3 Broken / Protruding Wires and Missing Button Heads

Broken / protruding (beyond the anchor head face) wires and missing button heads found at tendon end anchorages during surveillances performed to date are identified in the table below. This listing does not include conditions that were previously documented.

Broken / Protruding Wires and Missing Button Heads		
Surveillance Year	Unit 1	Unit 2
1	Report not available	Missing button heads: 1 at 2D21 field end 2 at 3D20 field end 1 at 12H02 field end
3	Report notes 13 ineffective wires with breakage or other not service related; no further details	No ineffective wires not previously documented
5	Report notes 12 ineffective wires with breakage or other not service related; no further details	Missing button heads: 1 at V78 shop end 1 at V78 field end 1 at D04 field end
10	Missing button heads: 1 at 32H14 field end 1 at 32H15 field end	No ineffective wires not previously documented
15	No ineffective wires not previously documented	Missing button head at V20 field end
20	No ineffective wires not previously documented	No ineffective wires not previously documented
25	Missing button head at 21H08 field end; one broken wire found during de-tensioning	No ineffective wires not previously documented
30	No ineffective wires not previously documented	No ineffective wires not previously documented
35	No ineffective wires not previously documented	No ineffective wires not previously documented
40	Missing button head at 31H05 Buttress 3 end	No ineffective wires not previously documented
45	No ineffective wires not previously documented	N/A, 45-year surveillance not yet performed

The numbers of Unit 1 wires identified as ineffective in the 3 and 5-year surveillance reports suggest that the designation is based on observed button head splits and diameter measurements. Neither splits nor button head size render a wire ineffective. As the condition of the wires was stated to be ‘not service related’, it is concluded that no missing / protruding button heads or broken wires were found during these surveillances. Omitting these wires from the count, a total of 5 ineffective wires, all in hoop tendons, were reported for Unit 1. This represents an insignificant fraction (0.048 %) of the 56 tendons examined * 186 wires per tendon ~ 10,400 Unit 1 hoop tendon wires examined.

A total of 8 missing wires were reported for Unit 2, 1 hoop tendon wire, 4 dome tendon wires and 3 vertical tendon wires. Corresponding fractions of ineffective wires are:

- Hoop tendons – 100 % * 1 / (63 tendons examined * 186) = 0.009 %
- Vertical tendons - 100 % * 3 / (53 tendons examined * 186) = 0.030 %

- Dome tendons – 100 % * 4 / (40 tendons examined * 186) = 0.054 %

The above fractions are considered to be structurally insignificant.

Also, the above table provides reasonably solid evidence that the number of ineffective wires is not increasing with time.

Therefore, based on the results of surveillances conducted to date, it is concluded that the fraction of ineffective wires in the Unit 1 and Unit 2 containment tendons has, and will continue to have, no structural significance. This conclusion supports the extension of system examinations as presented in Part 2 of this technical report.

4.2.4 Load Bearing Components Damage / Distortion

No damaged, cracked or distorted load bearing components (bearing plates, anchor heads, wedges, shims) have been found.

4.2.5 Concrete Cracking Adjacent to Bearing Plates

Concrete extending out 24 inches from the edges of tendon bearing plates was visually examined for cracking. Cracks exceeding 0.01 inches in width were recorded and require evaluation for structural significance.

- Unit 1

  The Unit 1 anchorage area concrete examinations were covered in separate surveillance reports through year 20. Of these, only the 1-year concrete examination report is available.

  Only two cracks, both extending out from the edge of the 31H08 shop end bearing plate, having widths greater than 0.01 inches were identified in the 25-year through 40-year surveillance reports. Both were patched prior to the 45-year surveillance which shows a 14" and an 8" patch, but no cracks, on the shop end data sheet. It is concluded that the reported cracks were surface anomalies resulting from concrete shrinkage and are of no structural significance.

- Unit 2

  The Unit 2 anchorage area concrete examinations were covered in separate surveillance reports through year 15. These concrete examination reports are not available.

  During the 25-year surveillance, concrete cracks > 0.01 inches in width were found at the field ends of Tendon 3D128 and Tendon 12H-26. These were determined to be contained entirely within the surface layers of concrete and were considered purely cosmetic in nature.

  No other anchorage area concrete cracks wide than 0.010 inches are documented in the 20-year through 40-year surveillance reports.

Based on the results of surveillances conducted to date and as documented above, it is concluded that there is no structurally significant cracking in the concrete adjacent to the tendon end anchorage areas and no indication that this condition will change in the foreseeable future.

This conclusion supports the extension of system examinations as presented in Part 2 of this technical report.

4.2.6 Anchorage Condition Summary and Conclusions

Tendon end anchorage hardware and adjacent concrete have performed well throughout the life of the plant (through the most recent surveillance in 2020) and show no trends of deteriorating condition.

There have been no findings of active corrosion on bearing plates, anchor heads, shims or button heads. Inactive corrosion is limited to Level 2 (minor light rust) on hardware enclosed by the anchorage end caps and Level 3 (acceptable) on exposed areas of bearing plates.

Only minor amounts of free water have been found in anchorage areas and no corrosion has been associated with such water as has been found. The sample of free water tested for pH was alkaline (pH > 7) and therefore noncorrosive.

Only a small fraction (less than 0.1 % of any group) of examined wires were found to be ineffective and there was no indication that the incidence of ineffective wires was increasing with time.

No damage, cracking or distortion has been found during visual examinations of bearing plates, anchor heads, wedges and shims.

Concrete cracks observed adjacent to bearing plates were either less than 0.01 inches in width or were concluded to be confined to surface concrete. No cracks deemed structurally significant were found.

End anchorage visual examination trends, as discussed above, show that the condition of both post-tensioning system hardware and concrete adjacent to tendon end anchorage bearing plates is stable and unlikely to experience significant change over the operating lifetime of the plant.

The results of the tendon end anchorage examinations (and free water pH test) support the extension of system examinations as presented in Part 2 of this technical report.

4.3 Wire Examination and Test Results Evaluation

Wires were extracted from designated surveillance tenons and tested to verify continuing strength and ductility. Testing, test results and conclusions are addressed in 4.3.1 through 4.3.2 below.

4.3.1 Unit 1 Wire Examination and Testing

During each of the Unit 1 surveillances other than those performed at years 35 and 45, one or more test wires were extracted from one tendon in each group. In addition, broken wires were extracted whenever found. Each of the extracted wires was examined for corrosion. Three test specimens were cut from each wire, two near the ends and one close to the center (or, in the case of broken wires, near the break). These specimens were tested to determine yield strength, ultimate tensile strength and elongation at failure. Test results were compared to the ASTM A421 acceptance criteria for ultimate strength (240 ksi minimum) and elongation (4 % minimum).

Unit 1 test results are shown in tables 9a and 9b. These tables do not show results for the 1-year surveillance (report not available) and 3-year surveillance. The report covering the latter surveillance lists three sets of tests, one performed in the field using 100-inch specimens and the other two in separate laboratories using ASTM standard 10-inch specimens. As, the results are inconsistent suggesting procedural errors on the part of one or more of the testing organizations, these are omitted from the tables in the interest of clarity.

Unit 1 test results, with the exceptions noted below, met the ASTM A421 acceptance criteria.

- All nine of the test specimens cut from wires extracted from dome tendon 3D20 during the 20-year surveillance failed below the 240 ksi minimum. In addition, 4 specimens failed to meet the 4 % minimum elongation criterion. A metallurgical analysis determined that this resulted from low carbon and manganese content in those wires. As this represented the as installed composition of the wires, the failures were not considered service related. In addition, the low carbon and manganese content was concluded to be an isolated condition and not structurally significant.

  The condition is addressed in NCR No. FN465-003.
- One specimen cut from a broken wire extracted from hoop tendon 21H08 during the 25-year surveillance failed at a 2.8% elongation (tensile strength was acceptable at 247 ksi). The low elongation was attributed to possible yielding of the wire in the break region. The evaluation is covered in condition report CR#1-99-0352.

Samples cut from SGR replacement tendon wires are listed separately in the tables. These have higher tensile strength and somewhat greater elongation at failure than samples cut from originally installed tendon wires. Greater strength and ductility are considered to be the result of improvements in wire metallurgy.

4.3.2 Unit 2 Wire Examination and Testing

Measurement of Unit 2 tendon lift-of forces and the associated extraction of wires test wires commenced with the 25-year surveillance. As a consequence of the alternating schedule for lift-off measurements, only the 25-year and 35-year surveillances required lift-off measurements and test wire extraction. Results of tests on wires extracted during these surveillances are shown in Tables 10a and 10b. All results are acceptable. As is the case for Unit 1, SGR replacement tendon wires have higher tensile strength than those in originally installed tendons. SGR replacement tendon elongations are not, however, greater.

4.3.3 Wire Test Evaluation, Conclusions and Recommendations

The results of tests performed on Unit 1 and Unit 2 tendon wire specimens do not give any indication that tensile strength and ductility are decreasing over time. And, with the limited exceptions discussed above, the results show that strength and ductility meet the ASTM A421 acceptance criteria. Finally, visual examination results show that tendon wires are not corroding over time.

Therefore, it is concluded that there is no need to continue extracting and testing wires. And, further, it is recommended that requirements for de-tensioning of tendons for the purpose of extracting of test wires and subsequent testing be eliminated from the post-tensioning system surveillance program.

However, wire extraction, examination and testing could be specified by the Responsible Engineer if conditions indicative of wire degradation are found during future end anchorage visual examinations and / or force measurements.

4.4 Corrosion Protection Medium Testing

Corrosion protection medium (CPM) was collected at the ends of sample tendons during each surveillance. Each CPM sample was tested for the presence of three corrosive ions (chlorides, nitrates and sulfides), absorbed water content and reserve alkalinity[13] (expressed as neutralization number or base number).

Results of many of the earlier tests, other than those that determine water content, are inconsistent and erratic. This probably results from sample preparation procedures being relatively unique to the Visconorust 2090P CPM product, defined only in ASME Section XI, Subsection IWL and consequently, unfamiliar to laboratory testing personnel. Later results are consistent, reflecting the increase, over the years, in laboratory experience with these relatively unique tests. Therefore, to promote clarity of presentation, early CPM test results are not included in this report.

Absorbed water content and base number are determined for bulk samples of CPM. The laboratory procedure used to determine water content is standardized and easily performed. It should yield reasonably accurate results. That used to determine base number is fairly complex; results tend to exhibit more variability than would be expected for the material being analyzed.

Corrosive ion concentrations are not determined for bulk samples of CPM but, rather, for water maintained in contact with a defined CPM surface area under specified conditions. More recently conducted tests tend to yield the expected results; i.e., that corrosive ions are essentially absent from the CPM samples. Earlier tests gave erratic results, particularly for nitrate ion concentrations. The erratic results may have resulted from errors in specimen preparation or application of the procedures used to quantify concentrations in the water samples, or both.

4.4.1 Unit 1 CPM Test Results

Unit 1 CPM test results are summarized in the tables which follow. These list for surveillance year starting with year 30, the number of samples tested and the maximum, mean and minimum values determined for each test category. Two sets of maxima, means and minima are shown

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[13] Unit 1 CPM samples were analyzed for reserve alkalinity beginning with the 10-year surveillance in 1983.

for base number. The lower values are for what is concluded to be the earlier Visconorust 2090P formulation and the higher values for the later 2090P-4 formulation. Both formulations were used for Unit 1.

4.4.1.1 Corrosive Ion Concentrations

The results of tests for corrosive ions are summarized below.

Unit 1 CPM Sample Corrosive Ion Concentrations – 10 ppm Acceptance Limit										
Surveillance Year	Samples Tested	Chloride Ion, ppm			Sulfide Ion, ppm			Nitrate Ion, ppm		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
30	21	0.5[a]	0.5	1.0	0.5[a]	0.5	0.5	0.5[a]	0.5	0.5
35	35	0.5[a]	0.5	1.0	0.5[a]	0.5	0.5	0.5[a]	0.5	0.5
40	33	0.5[a]	0.5	0.5	0.5[a]	0.5	0.5	0.5[a]	0.5	0.5
45	26	0.5[a]	0.5	0.5	0.5[a]	0.5	0.5	1.0[a]	1.0	1.0

Note a: Lower limit of resolution for the analytical procedure used. No explanation was provided for the doubling of the resolution limit between the 40-year and 45-year surveillances.

With the exception of two chloride ion concentration values listed in the above table, both shown in the 30-year and 35-year surveillance reports as 1.0 ppm, all concentrations listed are at the lower limit of resolution for the analytical technique used. The 1.0 ppm values listed are only 10% of the 10-ppm acceptance limit. There is no trend illustrated by either the minimum, mean or maximum values.

4.4.1.2 Absorbed Water Content

Results of tests for absorbed water content are summarized below.

Unit 1 CPM Sample Absorbed Water Content – 10% Acceptance Limit				
Surveillance Year	Samples Tested	Water Content, %		
		Min	Mean	Max
30	21	0.1[a]	1.0	8.2
35	35	0.1[a]	0.8	6.5
40	33	0.1[a]	0.7	4.9
45	26	0.1[a]	0.6	4.9

Note a: Lower limit of resolution.

All of the absorbed water contents shown in the above table are below the 10% acceptance limit. In addition, the greatest sample mean is, at 1.0% only one tenth of the limit. Trends, if any can be ascribed to the parameters listed, show maxima and means decreasing with time.

4.4.1.3 Neutralization Number

Results of tests to determine neutralization (base) number are summarized below.

Unit 1 CPM Sample Neutralization Number - Acceptance Limit per Row Below								
Surveillance Year	2090P Samples Tested	2090P-4 Samples Tested	2090P Test Results Lower Limit 0.0			2090P-4 Test Results Lower Limit 17.5		
			Min	Mean	Max	Min	Mean	Max
30	3		0.5[a]	0.5	0.5			
		18				14.8	39.7	61.8
35	12		1.6	4.0	8.5			
		23				14.3	54.9	81.7
40	15		1.0	2.8	5.1			
		18				28.5	45.6	61.4
45	10		0.5[a]	2.6	4.7			
		16				22.5	47.5	69.6

Note a: Lower limit of resolution. Samples with numbers below the lower limit are tested for acid number.

Tests on 5 of the 2090P samples, 3 in year 30 and 2 in year 45, yielded base numbers below the indicated limit of resolution (0.5) for the analytical procedure used. Additional specimens from these samples were checked for acid numbers. The greatest value was somewhat under 4, which is considered effectively neutral and was treated as acceptable by evaluation (an acid number acceptance limit is not stated in the referenced editions of ASME Section XI).

All other neutralization number test results were above the Unit 1 acceptance limit of zero. In addition, the minima, means and maxima shown in the above table do not exhibit noticeable trends.

4.4.2 Unit 2 CPM Test Results

Unit 2 CPM test results are summarized in the tables which follow. For consistency with the Unit 1 presentation, these are shown for 4 surveillance years, 25, 30, 35 and 40. It is presumed that only Visconorust 2090P-4 CPM was used for Unit 2. Possible exceptions are addressed in 4.5.2.3 below.

4.4.2.1 Corrosive Ion Concentrations

The results of tests for corrosive ions are summarized below.

Unit 2 CPM Sample Corrosive Ion Concentrations – 10 ppm Acceptance Limit										
Surveillance Year	Samples Tested	Chloride Ion, ppm			Sulfide Ion, ppm			Nitrate Ion, ppm		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
25	28	0.5[a]	0.5	0.5	0.5[a]	0.5	0.5	0.5[a]	0.5	0.5
30	22	0.5[a]	0.5	0.5	0.5[a]	0.5	0.5	0.5[a]	0.5	0.5
35	26	0.5[a]	0.5	1.0	0.5[a]	0.5	0.5	0.5[a]	0.5	0.6
40	34	0.5[a]	0.5	1.0	0.5[a]	0.5	0.5	1.0[a]	1.0	2.0

Note a: Lower limit of resolution for the analytical procedure used. No explanation was provided for the doubling of the resolution limit between the 35-year and 40-year surveillances.

With the exception of two chloride ion and two nitrate ion concentration values listed in the above table, all concentrations listed are at the lower limit of resolution for the analytical technique used. The 1.0 ppm chloride ion concentrations and the 2.0 ppm nitrate ion concentration are only 10% and 20%, respectively, of the 10-ppm acceptance limit. There is no meaningful trend illustrated by either the minimum, mean or maximum values.

4.4.2.2 Absorbed Water Content

Results of tests for absorbed water content are summarized below.

Unit 2 CPM Sample Absorbed Water Content – 10% Acceptance Limit				
Surveillance Year	Samples Tested	Water Content, %		
		Min	Mean	Max
25	28	0.1[a]	0.3	2.5
30	22	0.1[a]	0.3	1.9
35	26	0.1[a]	0.3	3.2
40	34	0.1[a]	0.3	2.2

Note a: Lower limit of resolution.

All of the absorbed water contents shown in the above table are below the 10% acceptance limit. In addition, the greatest sample mean is, at 0.3%, only one thirtieth of the limit. No trends are evident.

4.4.2.3 Neutralization Number

Results of tests to determine neutralization (base) number are summarized below.

Unit 2 CPM Sample Neutralization Number - Lower Acceptance Limit 17.5				
Surveillance Year	Samples Tested	Neutralization Number		
		Min	Mean	Max
25	28	8.1	45.6	69.7
30	22	38.6	55.8	80.6
35	26	9.0	39.1	56.3
40	34	0.5 / 13.0[a]	34.6	64.3

Note a: The 0.5 minimum is an extreme outlier and is not included in the mean computation. The next lower number is 13.0.

All neutralization number test results were above the Unit 2 acceptance limit of zero. In addition, the minima, means and maxima shown in the above table do not exhibit consistent trends.

4.4.3 CPM Test Evaluation, Conclusions and Recommendations

The results of Unit 1 and Unit 2 CPM tests show that concentrations of corrosive ions and absorbed water content have remained well below the specified acceptance (upper) limits and, in addition, exhibit no adverse trends over time. Neutralization numbers remained well above the specified acceptance (lower) limits and exhibited no consistent trends over time. When evaluated in conjunction with the tendon end anchorage and wire examination finding, these results demonstrate that the CPM is continuing to perform its corrosion protection function. In addition, the test results give no indication that the protective properties of the CPM have degraded since initial installation in the 1970's.

An evaluation of the CPM test results, as summarized above, leads to the conclusion that the interval between collecting samples and performing tests can be extended as proposed in Part 2 of this report with no adverse consequences. And further, unless evidence of active corrosion is found during visual examinations of end anchorage hardware, free water in quantities deemed significant by the RE is found or there is evidence that the quantity of absorbed water has increased over time, there should be no need to perform the tests for corrosive ions and neutralization number. It is concluded that these tests need be done only if corrosion or moisture conditions favoring corrosion are found. If free water is found, it will be collected and analyzed to determine pH.

Therefore, it is recommended that future CPM testing be limited to determining absorbed water content, unless the Responsible Engineer specifies otherwise based on evaluation of surveillance findings or industry operating experience.

5. OVERALL SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A summary of surveillance results, conclusions based thereon and recommendations for future changes to the surveillance program are outlined Sections 5.1, 5.2 and 5.3 which follow.

5.1 Surveillance Results Overall Summary

The results of the 21 post-tensioning system surveillances conducted at ANO between 1974 and 2020 show that the systems are continuing to perform the intended functions and can be expected to do so until well beyond the maximum expected 80-year operating lifetime of the units. Performance of the Unit 1 and Unit 2 systems, determined by evaluations of the visual examination findings / test results as detailed in Part 4 of this technical report, is summarized below.

5.1.1 Tendon Force

The mean force in each of the Unit 1 and Unit 2 tendon groups is projected by log-linear regression, by 95% lower confidence limit computations and, for the vertical and dome groups, by common tendon trends to remain above the specified minima until well beyond the maximum expected 80-year operating lifetime of the units.

5.1.2 Condition of End Anchorage Hardware / Concrete and Extracted Wires

Enclosed end anchorage hardware and tendon wires extracted for tensile testing show no signs of active corrosion. The minor (acceptable) rusting that has been observed is concluded to have occurred prior to filling of the tensioned tendon duct with corrosion protection medium. Corrosion on the exposed surface of bearing plates is also minor and meets acceptance criteria

Broken wires and missing / protruding button heads represent only a miniscule fraction of the number of installed tendon wires.

Free water was present in only a few surveillance tendon anchorage areas and only in small quantities (a maximum of 0.2 liters; otherwise less than 0.1 liter).

Only 2 anchorage area concrete cracks (both at the same Unit 1 anchorage) wider than 0.01 inches were reported. Both cracks were short (13 inches or less) and concluded to be limited to surface concrete. These cracks were caulked prior to the 45-year surveillance and have not resurfaced through the caulking material.

5.1.3 Tendon Wire Strength and Ductility

Tensile tests on samples cut from extracted wires show, with a unique exception, that ultimate strength and ductility (quantified by the measured elongation at failure) remain above specified minimum values. Test results also show that strength and ductility are not decreasing over time.

5.1.4 Corrosion Protection Medium Characteristics

Results of corrosion protection medium (CPM) tests to determine absorbed water content, corrosive ion concentrations and neutralization number confirm that acceptance criteria have been met. There are no discernible trends to these parameters and no indication that the protective characteristics of the CPM are degrading over time.

5.2 Conclusions

Based on the evaluations detailed in Part 4 of this technical report and summarized above, it is concluded that the ANO post-tensioning system will continue to perform its design function until well beyond the maximum expected operating lifetime of the units. And, specifically that:

- Tendon group mean forces will remain above the specified minima;
- End anchorage hardware and tendon wire will remain free of active corrosion. Corrosion on exposed surfaces of bearing plates will remain minor (condition will be verified during IWL mandated concrete surface visual examinations);
- Tendon wire strength and ductility will not change over time and will remain acceptable throughout the operating lifetime of the plant;
- Corrosion protection medium will retain its protective properties with no unacceptable degradation over time;
- And, free water will not be a concern.

5.3 Recommendations

On the basis of the above conclusions, it is recommended that the intervals between post-tensioning system surveillances, which include examinations identified in Reference 7.2, Table IWL-2500-1, Examination Category L-B, be increased in accordance with the schedule presented in Part 2 of this report.

Implementing this change will provide the following safety and related benefits.

- Reducing personnel exposure to a number of industrial safety hazards associated with system examination / testing. These include:
    - Working at heights;
    - Working on open platforms with no ready means of egress in the event of sudden changes in weather;
    - Working in a de facto confined space (the tendon gallery).
    - Working with high-pressure hydraulic systems;
    - Working around high-energy plant systems;
    - Working around solvent and hot petroleum product fumes.
    - Working around containers and lines filled with hot petroleum products.

  - Close in exposure to high levels of stored elastic energy in tendons (sudden rotation during force measurement has resulted in rapid shim ejection);
  - Handling heavy loads, often in the vicinity of critical plant components.
- Reducing potentially damaging repetitive loading on tendons during de-tensioning / re-tensioning as well as during implementation of force measurement procedures.
- Reducing end anchorage exposure to the elements during periods when end caps are removed for examination, force measurement and wire extraction.

It is also recommended that removal and testing of tendon wires be done only when specified by the Responsible Engineer. This will eliminate the routine need to de-tension and re-tension tendons and the consequent possible damage to the remaining wires.

In addition, it is recommended that routine CPM testing be limited to determination of absorbed water content and that additional tests for corrosive ion concentration and neutralization number be performed only if:

- Active corrosion is found on anchorage components and / or tendon wires;
- Free water is found at anchorages;
- CPM absorbed water content exceeds the Table IWL-2525-1 acceptance limit;
- And, otherwise if specified by the Responsible Engineer.

Eliminating routine ion concentration and neutralization number testing has the benefit of reducing the quantity of hazardous reagents to be disposed of by the testing laboratory.

6. FUTURE EXAMINATIONS

It is proposed that future examinations be performed per the schedule shown in Part 2 of this report. The proposed examination schedule for the remainder of the current operating license is to align the two units in the event both units enter into a second extended operating period. For the second extended operating period, additional relief will be required to continue with the extended frequencies. That relief would include the results of the examinations and tests that are scheduled based on this report.

7. REFERENCES

7.1 USNRC Regulation 10CFR50.55a, *Codes and standards*.

7.2 ASME Boiler and Pressure Vessel Code, Section XI, Subsection IWL, *Requirements for Class CC Concrete Components of Light-Water-Cooled Plants*, (editions / addenda as noted).

7.3 ANO Unit 1 SAR

7.4 ANO Unit 2 SAR

7.5 ASTM A421, *Specification for Uncoated Stress Relieved Wire for Prestressed Concrete*, Published by the American Society for Testing and Materials.

7.6 ER980642D202 *(ANO-2 SGRP – Containment Construction Opening)*

7.7 USNRC Regulatory Guide 1.35, *Inservice Inspection of Ungrouted Tendons in Prestressed Concrete Containments*, Revisions 1, 2 and 3.

7.8 *Reactor Building Tendon Surveillance / Three-Year Surveillance / Arkansas Nuclear One – Unit No. 1 / Arkansas Power and Light Company,* Report prepared by Bechtel Corporation, Job No. 11406-014, October 1977.

7.9 *Reactor Building Tendon Surveillance / Five-Year Surveillance / Arkansas Nuclear One – Unit No. 1 / Arkansas Power and Light Company,* Report prepared by Bechtel National, Inc., Job No. 11406-243, Revision 1, September 1979.

7.10 *10 Year Physical Surveillance of the Arkansas Nuclear One – Unit 1 Primary Reactor Containment Building*, Report prepared by Inryco, Revision 1, 01 August 1983*.*

7.11 *Fifteenth Year Physical surveillance of the Arkansas Nuclear One – Unit 1 Primary Reactor Containment Building*, Report prepared by Precision Surveillance Corporation, Revision 0, 01 July 1988.

7.12 *7.12 Twentieth Year Physical Surveillance of Arkansas Nuclear One Unit 1 – Containment Building,* Report prepared by Precision Surveillance Corp., Revision 0, 08 February 1994.

7.13 *Twenty Fifth Year Physical Surveillance of ANO Unit 1 Reactor Building*, Report prepared by Precision Surveillance Corp., Revision 0, 08 May 2000*.*

7.14 *30th Year Unit 1 Containment Building Tendon Surveillance and Concrete Inspection at Arkansas Nuclear One / Post tensioning Surveillance Report*, Report prepared by Precision Surveillance Corporation, Revision 1, 30 October 2004*.*

7.15 *Final Report for the 35th Year Tendon Surveillance at ANO Unit 1 / Document No AN-N1029-501*, Report prepared by Precision Surveillance Corporation, Revision 0, 18 May 2009*.*

7.16 *Final Report for the 40th Year (10th Period) Tendon Surveillance at Arkansas Nuclear One Unit 1 / Document No REP-1086-510*, Report prepared by Precision Surveillance Corporation, Revision 1, 24 October 2013*.*

7.17 *Final Report for the 45th Year Containment Structure Tendon Surveillance at Arkansas Nuclear One Unit 1 / Document No REP-1138-510*, Report prepared by Precision Surveillance Corporation, Revision 0, 14 October 2018.

7.18 Reactor Building Surveillance / One-Year Visual Surveillance / Arkansas Nuclear One – Unit No. 2, Report prepared by Bechtel National Corp., January 1979.

7.19 *Primary Reactor Containment Building / Three-Year Visual Tendon Surveillance / Arkansas Nuclear One – Unit No.* 2, Report prepared by Bechtel Power Corporation, December 1980.

7.20 *Five Year Visual Tendon Surveillance of the Arkansas Nuclear One – Unit 2 Primary Reactor Containment Building / Surveillance Report,* Report prepared by Inryco, Revision 1, 14 June 1983.

7.21 *Ten Year Visual Tendon Surveillance of the Arkansas Nuclear One – Unit 2 Primary Reactor Containment Building / Surveillance Report*, Report prepared by Precision Surveillance Corporation, Revision 0, 01 July 1980.

7.22 *Fifteenth Year Visual Surveillance of Arkansas Nuclear One Unit 2 – Containment Building*, Report prepared by Precision Surveillance Corporation, Revision 0, 27 April 1994.

7.23 *Twentieth Year Visual Surveillance of Unit 2 at the Arkansas Nuclear One Plant*, Report prepared by Precision Surveillance Corporation, Revision 0, 08 June 2000.

7.24 *25th Year Unit 2 Containment Building Tendon Surveillance and Concrete Inspection at Arkansas Nuclear One / Post Tensioning Surveillance*, Report prepared by Precision Surveillance Corporation, Revision 1, 26 January 2006.

7.25 *Final Report for the ANO Unit 2 30th Year (8th Period) Tendon Surveillance*, Report prepared by Precision Surveillance Corporation, Revision 0, 15 September 2010.

7.26 *Final Report for the 35th Year Unit 2 Tendon Surveillance at Arkansas Nuclear One Power Plant*, Report prepared by Precision Surveillance Corporation, Revision 0, 16 October 2014.

7.27 *Final Report for the 40th Year Containment Structure Tendon Surveillance at Arkansas Nuclear One Unit 2,* Report prepared by Precision Surveillance Corporation, Revision 0, 24 September 2020.

7.28 18 January 1974 letter BL-6194 from George Katanics, Bechtel Power Corporation to William Cavanaugh III, Arkansas Power & Light Company, transmitting the Arkansas Nuclear One Unit 1 Structural Integrity Test Report.

7.29 *Arkansas Power & Light Company / Arkansas Nuclear One / Unit 2 / Reactor Building Structural Integrity Test Report,* prepared by Bechtel National Incorporated, January 1978 (Approved 02 March 1978).

7.30 *Arkansas Nuclear One, Units 1 and 2 / Containment Inservice Inspection (CII) / Program Plan*, Program Section No. CEP-CII-007, Revision 0, 21 December 2000.

7.31 Miller, Irwin and John E. Freund, *Probability and Statistics for Engineers*, Prentice-Hall, Englewood Cliffs, NJ, 1965.

7.32 ANO Calculation CALC-99-E-0015-01, *Predicted Tendon Prestress Forces for 20 Year License Extension*, Revision 0, November 2013.

7.33 ANO Calculation CALC-97-E-0009-24, *Unit 2 Tendon Surveillance Wire Force Curves*, Revision 1, December 1997.

7.34 ANO (Unit 2) Calculation CALC-97-E-0009-05, *Containment Side Shell Design Report*, Revision 2, June.

8. TABLES AND FIGURES

Tables and figures cited in the above text follow.

Table 1 – List of US Containments[1] with Ungrouted Pre-stressing Systems

Plant / Unit	Containment Type[2] / Notation[3]
Millstone 2	Shallow dome w / hoop, vertical & dome tendon groups; B
Ginna	Vertical tendons only; anchored in rock; B
TMI 1	Shallow dome w / hoop, vertical & dome tendon groups; B; N
Calvert Cliffs 1 & 2	Shallow dome w / hoop, vertical & dome tendon groups; B
V. C Summer	Shallow dome w / hoop, vertical & dome tendon groups; B
Oconee 1, 2 & 3	Shallow dome w / hoop, vertical & dome tendon groups; B
Vogtle 1 & 2	Hemispherical dome w / hoop & inverted U tendon groups; S
Crystal River 3	Shallow dome w / hoop, vertical & dome tendon groups; B; N
Turkey Point 3 & 4	Shallow dome w / hoop, vertical & dome tendon groups; B
Farley 1 & 2	Shallow dome w / hoop, vertical & dome tendon groups; B
Palisades	Shallow dome w / hoop, vertical & dome tendon groups; B; N
Zion 1 & 2	Shallow dome w / hoop, vertical & dome tendon groups; B: N
Braidwood 1 & 2	Shallow dome w / hoop, vertical & dome tendon groups; B
Byron 1 & 2	Shallow dome w / hoop, vertical & dome tendon groups; B
LaSalle 1 & 2	BWR Mark II (cylinder – cone) containment w / hoop & vertical tendon groups; B
Point Beach 1 & 2	Shallow dome w / hoop, vertical & dome tendon groups; B
Callaway	Hemispherical dome w / hoop & inverted U tendon groups; B
ANO 1 & 2	Shallow dome w / hoop, vertical & dome tendon groups; B
South Texas 1 & 2	Hemispherical dome w / hoop & inverted U tendon groups; B
Wolf Creek	Hemispherical dome w / hoop & inverted U tendon groups; B
Ft. Calhoun	Shallow dome with spiral and dome tendon groups; B; N
Palo Verde 1, 2 & 3	Hemispherical dome w / hoop & inverted U tendon groups; B
San Onofre 1 & 2	Hemispherical dome w / hoop & inverted U tendon groups; S; N
Rancho Seco	Shallow dome w / hoop, vertical & dome tendon groups; S; N
Trojan	Hemispherical dome w / hoop & inverted U tendon groups; B; N

Note 1: Bellefonte 1 & 2, which are still under construction, Midland 1 & 2, which were terminated prior to fuel load and Robinson & TMI 2, which have grouted tendon systems, are not listed.

Note 2: All units are PWR's except LaSalle (BWR).

Note 3: B – BBRV system with button headed wires; S – strand system with wedge anchors; N – unit(s) are no longer in operation.

Table 2 - Summary of Unit 1 Hoop Tendon[a] Forces, Sh. 1			
Surveillance / Calendar Year	T, Time Since SIT, Years	Tendon	F_M, Measured Force, kip
1 / 1975	1.5	21H24	1,338
		21H30	1,390
		21H36	1,348
		31H27	1,370
		31H28	1,376
		31H29	1,372
		31H40	1,367
		31H52	1,360
		32H10	1,416
		32H20	1,396
		32H32	1,322
		32H44	1,388
3 / 1977	3.4	21H42	1,370
		21H45	1,406
		21H53	1,390
		31H38	1,342
		31H39	1,345
		31H40[b]	1,223
		31H41	1,309
		31H50	1,318
		32H14	1,347
		32H24	1,321
		32H40	1,303
		32H48	1,348
5 / 1979	5.3	21H16	1,328
		21H42[b]	1,329
		21H50	1,354
		31H11	1,346
		31H35	1,286
		31H47	1,330
		32H14[b]	1,303
		32H26	1,314
		32H40[b]	1,292
		32H46	1,356

Table 2 - Summary of Unit 1 Hoop Tendon[a] Forces, Sh. 2

Surveillance / Calendar Year	T, Time Since SIT, Years	Tendon	F_M, Measured Force, kip
10 / 1983	9.3	21H41	1,284
		31H15	1,320
		32H13	1,282
		32H14[b]	1,220
		32H15	1,268
		32H43	1,216
		32H44[b]	1,206
15 / 1988	14.3	21H12	1,256
		31H42	1,262
		31H52[b]	1,234
		32H28	1,212
20 / 1993	19.9	21H30[b]	1,292
		31H23	1,296
		32H50	1,264
25 / 1999	25.9	21H08	1,290
		31H08[c]	1,317
		31H36[d]	1,197
		32H44	1,260
30 / 2004	30.3	21H43	1,316
		21H52	1,363
		31H08[c]	1,314
		32H18	1,288
35 / 2008	35.0	N/A, Visual Only	
40 / 2013	39.5	31H08[c]	1,281
		31H09	1,334
		32H35	1,238
45 / 2018	44.4	N/A, Visual Only	

Note a: Excluding tendons de-tensioned during steam generator replacement.
Note b: Tendon previously de-tensioned; force excluded from trend.
Note c: Common tendon.
Note d: Single end force measurement excluded from trend.

Table 3 - Summary of Unit 1 Vertical Tendon[a] Forces, Sh. 1

Surveillance / Calendar Year	T, Time Since SIT, Years	Tendon	F_M, Measured Force, kip
1 / 1975	1.5	V19	1,509
		V40	1,466
		V60	1,433
		V80	1,469
		V100	1,450
3 / 1977	3.4	V15	1,452
		V40[b]	1,438
		V55	1,422
		V75	1,460
		V95	1,380
5 / 1979	5.3	V26	1,368
		V3	1,367
		V102	1,332
		V84	1,407
		V68	1,367
10 / 1983	9.3	V12	1,398
		V25	1,354
		V73	1,395
15 / 1988	14.3	V42	1,347
		V71	1,377
		V98	1,369
20 / 1993	19.9	V34	1,392
		V65	1,396
		V101	1,382
25 / 1999	25.9	V13[c]	1,417
		V20	1,432
		V30	1,350
		V40[b]	1,449
		V50	1,456
		V60[b]	1,370
		V70	1,347
		V80[b]	1,458
		V90	1,346
		V101	1,431

Table 3 - Summary of Unit 1 Vertical Tendon[a] Forces, Sh. 2

Surveillance / Calendar Year	T, Time Since SIT, Years	Tendon	F_M, Measured Force, kip
30 / 2004	30.3	V10	1,399
		V13[c]	1,406
		V89	1,384
35 / 2008	35.0	N/A, Visual Only	
40 / 2013	39.5	V13[c]	1,396
		V27	1,392
		V39	1,378
45 / 2018	44.4	N/A, Visual Only	

Note a: Excluding tendons de-tensioned during steam generator replacement.
Note b: Tendon previously de-tensioned; force excluded from trend.
Note c: Common tendon.

Table 4 - Summary of Unit 1 Dome[a] Tendon Forces, Sh. 1			
Surveillance / Calendar Year	**T, Time Since SIT, Years**	**Tendon**	**F_M, Measured Force, kip**
1 / 1975	1.5	1D20	1,409
		1D28	1,443
		2D07	1,450
		2D10	1,428
		3D10	1,361
		3D20	1,404
3 / 1977	3.4	1D20[b]	1,378
		1D26	1,398
		2D08	1,355
		2D11	1,382
		3D08	1,316
		3D21	1,390
5 / 1979	5.3	1D07	1,391
		1D12	1,364
		2D22	1,338
		2D29	1,409
		3D02	1,361
		3D24	1,341
10 / 1983	9.3	1D03	1,376
		2D28	1,352
		3D02[b]	1,369
15 / 1988	14.3	1D30	1,434
		2D08[b]	1,328
		3D20[b]	1,331
20 / 1993	19.9	1D02	1,390
		2D22[b]	1,347
		3D11	1,336
25 / 1999	25.9	1D20[b]	1,382
		2D13[c]	1,352
		2D29[b]	1,437
		3D18	1,281

Table 4 - Summary of Unit 1 Dome Tendon Forces, Sh. 2			
Surveillance / Calendar Year	**T, Time Since SIT, Years**	**Tendon**	**F_M, Measured Force, kip**
30 / 2004	30.3	1D11	1,381
		2D13[c]	1,348
		2D18	1,358
35 / 2008	35.0	N/A, Visual Only	
40 / 2013	39.5	2D09	1,346
		2D13[c]	1,340
		3D04	1,376
45 / 2018	44.4	N/A, Visual Only	

Note b: Tendon previously de-tensioned; force excluded from trend.
Note c: Common tendon.

Table 5 - Summary of Unit 2 Hoop Tendon[a] Forces			
Surveillance / Calendar Year	**T, Time Since SIT, Years**	**Tendon**	**F_M, Measured Force, kip**
25 / 2005	27.6	12H07	1,348
		12H26	1,444[e]
		31H13	1,330
		31H45[c]	1,315
		31H48	1,345
30 / 2010	32.6	N/A, Visual Only	
35 / 2014	36.6	12H13	1,313
		12H14	1,329
		31H45[c]	1,318
40 / 2020	42.7	N/A, Visual Only	

Note c: Common Tendon.
Note: SGR tendon replaced in 2000; excluded from trend.

Table 6 - Summary of Unit 2 Vertical[a] Tendon Forces

Surveillance / Calendar Year	T, Time Since SIT, Years	Tendon	F_M, Measured Force, kip
25 / 2005	27.6	V003	1,547
		V083	1,532[e]
		V101[c]	1,375
		V109	1,366
30 / 2010	32.6	N/A, Visual Only	
35 / 2014	36.6	V050	1,427
		V101[c]	1,392
		V110	1,371
40 / 2020	42.7	V001	1,414
		V014	1,596
		V021	1,365
		V027	1,373
		V032	1,426
		V040	1,438
		V047	1,377
		V058	1,410
		V067	1,369
		V100	1,325
		V101[c]	1,365
		V102	1,313
		V103	1,361

Note c: Common Tendon.

Note e: SGR tendon replaced in 2004; excluded from trend

Table 7 - Summary of Unit 2 Dome Tendon[a] Forces			
Surveillance / Calendar Year	**T, Time Since SIT, Years**	**Tendon**	**F_M, Measured Force, kip**
25 / 2005	27.6	1D13	1,360
		1D15	1,373[d]
		3D09[c]	1,346
		3D28	1,393
30 / 2010	32.6	N/A, Visual Only	
35 / 2014	36.6	2D13	1,359
		2D18	1,385
		3D09[c]	1,342
40 / 2020	42.7	N/A, Visual Only	

Note c: Common Tendon.
Note d: Single end force measurement;00 excluded from trend.

	Table 8 - Summary of Unit 1 & Unit 2 SGR[a] Tendon Forces				
Unit	**Surveillance / Calendar Year**	**T, Time Since SIT, Years**	**Tendon Group**	**Tendon**	**F_M, Measured Force, kip**
1	40 / 2013	39.5	Hoop	21H31	1,516
				31H19	1,518
				31H21 (R)[b]	1,506
			Vertical	V62	1,540
				V64	1,550
2	25 / 2005	27.6	Hoop	12H26 (R)	1,444
			Vertical	V83 (R)	1,532
	35 / 2014	36.6	Hoop	12H18	1,502
				32H29 (R)	1,403
			Vertical	V84 (R)	1,497
				V93	1,562

Note a: SGR tendons de-tensioned / re-tensioned or replaced to support the steam generator replacement project.

Note b: (R) denotes a replacement tendon.

Table 9a - Unit 1 Wire Test Results / Ultimate Tensile Strength

Exam Year	Tendon	Ultimate Tensile Strength, ksi				Wire Mean, ksi	Exam Mean, ksi
		Specimen 1	Specimen 2	Specimen 3	Specimen 4		
5	32H14	245	249	249	N/A	248	245
	31H47	243	241	242	N/A	242	
	3D24	243	245	245	N/A	244	
	V102	244	247	243	N/A	245	
10	3D02	268	266	270	N/A	268	265
	3D02	261	265	262	N/A	263	
	32H44	260	261	258	N/A	260	
	V73	268	267	268	N/A	268	
15	V42	254	256	257	N/A	256	260
	1D30	271	270	274	N/A	272	
	32H28	251	252	252	N/A	252	
20	V101	243	244	243	N/A	243	242
	32H50	245	248	247	N/A	247	
	1D02	251	252	251	252	252	
	3D20[a]	237	235	236	N/A	236	
	3D20[a]	238	239	237	N/A	238	
	3D20[a]	238	230	237	N/A	235	
25	V80	270	269	279	N/A	273	258
	3D18	252	251	252	N/A	252	
	21H08	256	258	257	N/A	257	
	21H08	252	254	253	N/A	253	
	21H08	257	247	259	N/A	254	
30	V89	261	260	256	N/A	259	263
	2D18	270	268	268	N/A	269	
	21H43	260	260	261	N/A	260	
40	3D04	248	242	246	N/A	245	251
	32H35	246	247	247	N/A	247	
	V39	274	274	248	N/A	265	
	31H19	247	246	246	N/A	246	
	V64	254	253	254	N/A	254	
40[b]	31H21	274	274	275	N/A	274	271
	31H28	276	250	275	N/A	267	

Note a: Low tensile strength atributed to low carbon and manganese contents of wire.

Note b: Wire from SGR replacement tendon.

Table 9b - Unit 1 Wire Test Results / Elongation at Failure

Exam Year	Tendon	Elongation at Failure, %				Wire Mean, %	Exam Mean, %
		Specimen 1	Specimen 2	Specimen 3	Specimen 4		
5	32H14	6.0	6.0	6.5	N/A	6.2	6.2
	31H47	5.0	6.6	6.5	N/A	6.0	
	3D24	6.2	7.1	6.5	N/A	6.6	
	V102	6.5	6.0	5.8	N/A	6.1	
10	3D02	4.0	4.6	4.5	N/A	4.4	4.8
	3D02	4.7	4.7	4.5	N/A	4.6	
	32H44	4.5	4.9	5.2	N/A	4.9	
	V73	4.7	5.4	5.7	N/A	5.3	
15	V42	5.2	4.8	5.1	N/A	5.0	5.0
	1D30	4.7	4.5	4.5	N/A	4.6	
	32H28	5.5	5.3	5.6	N/A	5.5	
20	V101	4.1	4.0	4.1	N/A	4.1	4.4
	32H50	5.5	6.2	5.6	N/A	5.8	
	1D02	4.0	4.9	4.4	4.4	4.4	
	3D20[a]	3.5	3.9	4.6	N/A	4.0	
	3D20[a]	4.2	4.4	3.7	N/A	4.1	
	3D20[a]	4.2	4.0	3.6	N/A	3.9	
25	V80	4.8	4.5	4.5	N/A	4.6	4.7
	3D18	4.1	4.1	4.3	N/A	4.2	
	21H08	4.6	5.4	5.4	N/A	5.1	
	21H08	4.9	5.9	5.4	N/A	5.4	
	21H08	4.9	2.8	5.0	N/A	4.2	
30	V89	5.0	5.2	5.0	N/A	5.1	4.7
	2D18	5.0	4.5	4.4	N/A	4.6	
	21H43	4.4	4.2	4.4	N/A	4.3	
40	3D04	4.1	4.8	4.0	N/A	4.3	5.2
	32H35	5.0	4.6	5.2	N/A	4.9	
	V39	5.8	6.2	5.8	N/A	5.9	
	31H19	5.5	5.9	5.3	N/A	5.6	
	V64	5.4	5.0	5.0	N/A	5.1	
40[b]	31H21	5.8	6.0	4.7	N/A	5.5	5.6
	31H28	5.7	5.8	5.5	N/A	5.7	

Note a: Low elongation atributed to low carbon and manganese contents of wire.

Note b: Wire from SGR replacement tendon.

Table 10a - Unit 2 Wire Test Results / Ultimate Tensile Strength							
Exam Year	Tendon	Ultimate Tensile Strength, ksi				Wire Mean, ksi	Exam Mean, ksi
		Specimen 1	Specimen 2	Specimen 3	Specimen 4		
25	V109	255	253	255	N/A	254	255
	3D28	257	256	257	N/A	257	
	31H48	253	257	256	N/A	255	
35	2D18	256	258	258	N/A	257	250
	12H14	250	250	248	N/A	249	
	V110	241	243	244	N/A	243	
35[b]	32H29	265	264	265	N/A	265	266
	V84	266	267	267	N/A	267	

Note b: Wire from SGR replacement tendon.

Table 10b - Unit 2 Wire Test Results / Elongation at Failure							
Exam Year	Tendon	Elongation at Failure, %				Wire Mean, %	Exam Mean, %
		Specimen 1	Specimen 2	Specimen 3	Specimen 4		
25	V109	5.0	4.6	4.7	N/A	4.8	4.6
	3D28	4.2	4.0	4.0	N/A	4.1	
	31H48	4.9	5.1	5.2	N/A	5.1	
35	2D18	4.2	4.7	4.3	N/A	4.4	5.3
	12H14	5.2	6.1	6.1	N/A	5.8	
	V110	5.4	5.8	5.8	N/A	5.7	
35[b]	32H29	5.2	4.5	4.2	N/A	4.6	4.6
	V84	4.5	4.2	5.1	N/A	4.6	

Note b: Wire from SGR replacement tendon.

FIGURE 1 - ANO 1 HOOP TENDON LIFTOFF FORCES, TREND & LCL / 1 - 40

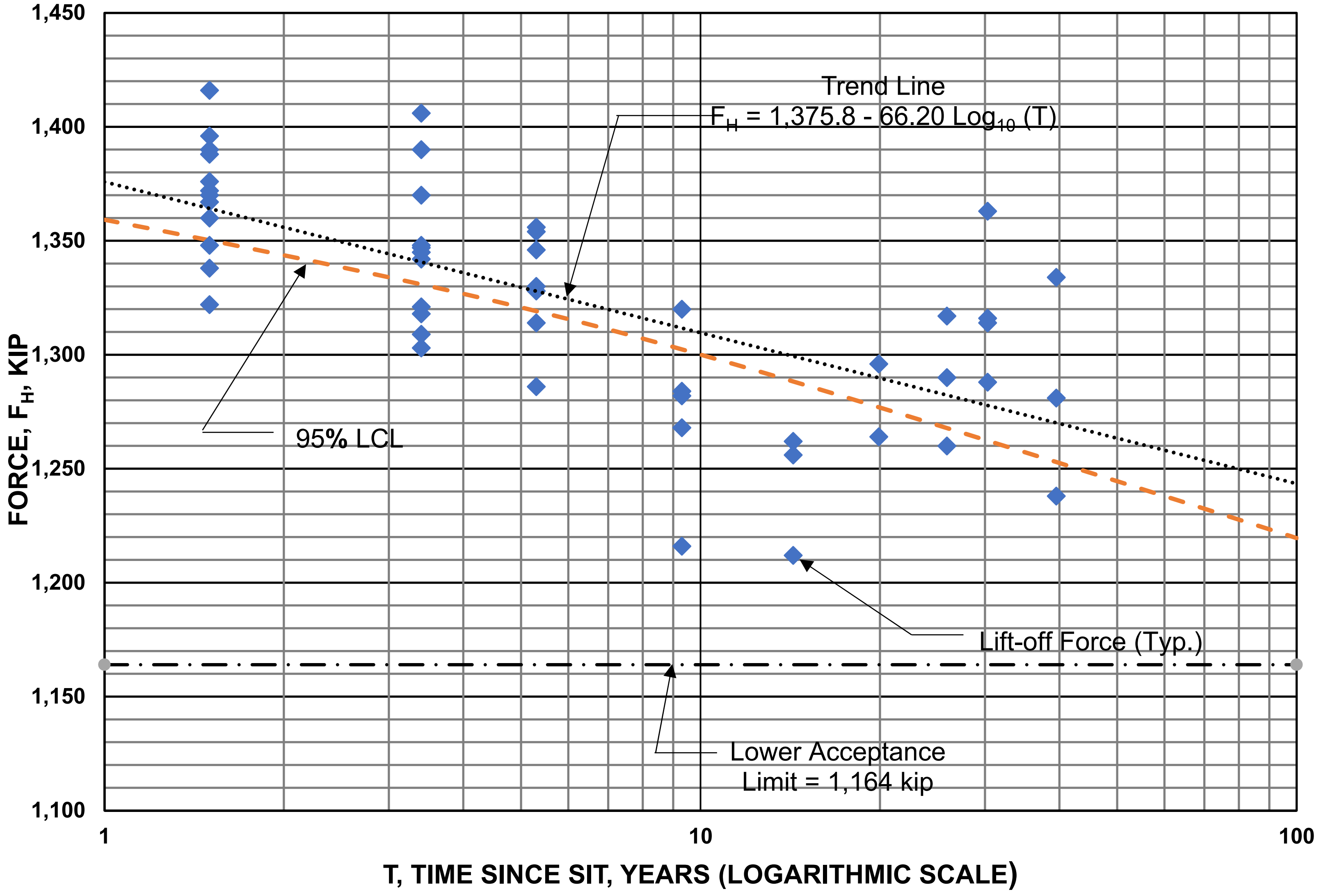


FIGURE 2 - ANO 1 HOOP TENDON LIFTOFF FORCES, TREND & LCL / 10 - 40

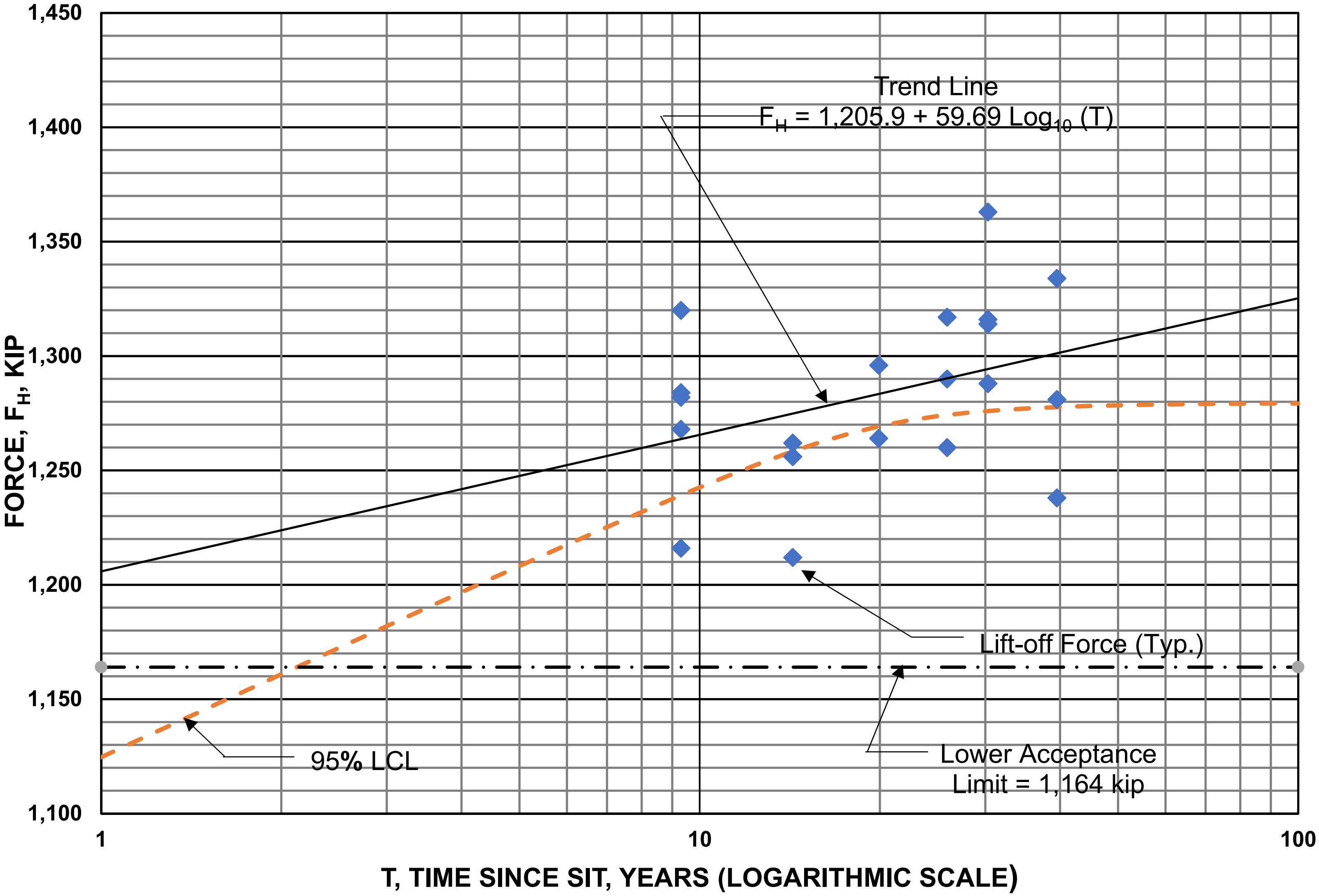


FIGURE 3 - ANO 2 HOOP TENDON LIFTOFF FORCES & TREND

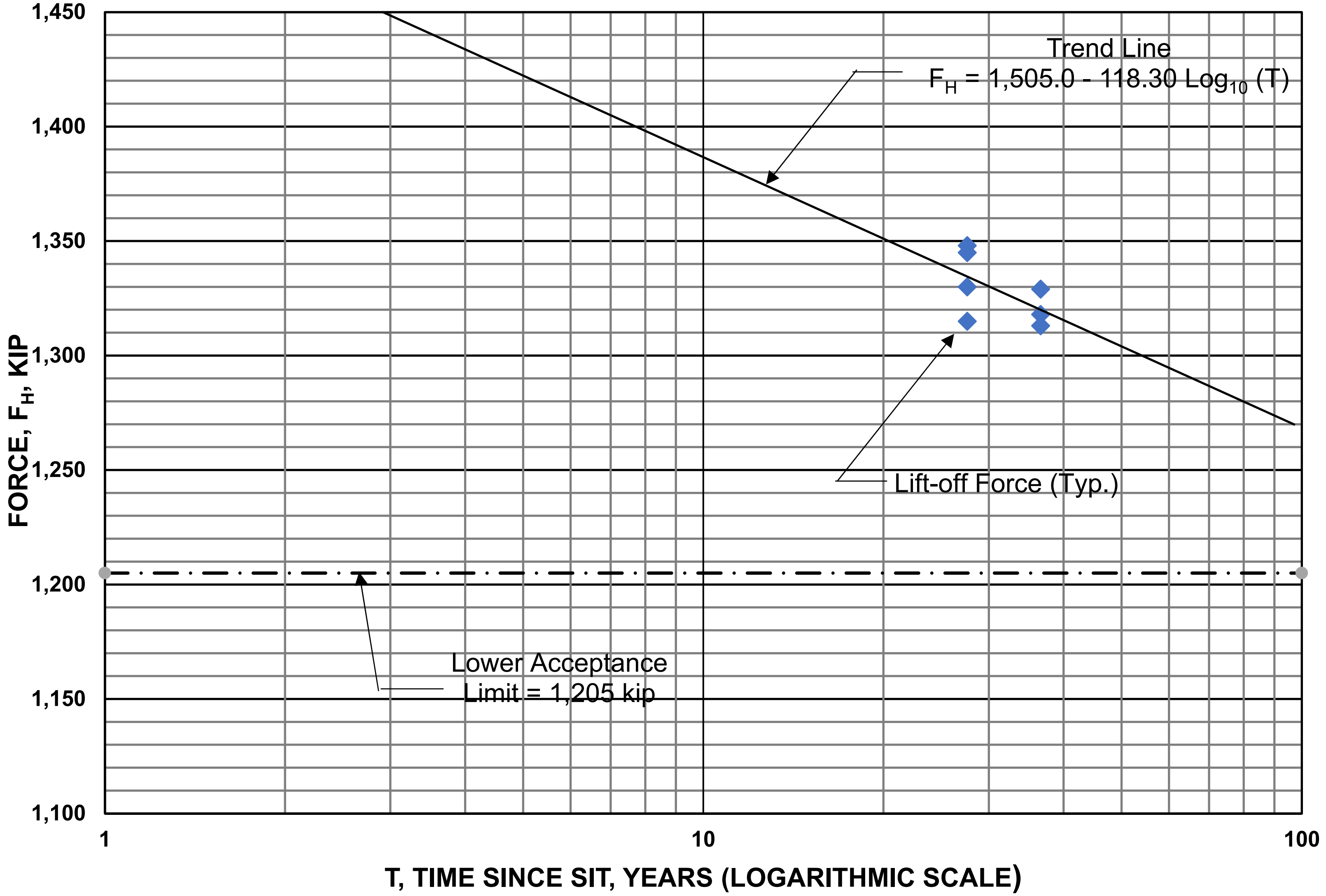


FIGURE 4 - ANO 1 VERTICAL TENDON LIFTOFF FORCES, TREND & LCL / 1 - 40

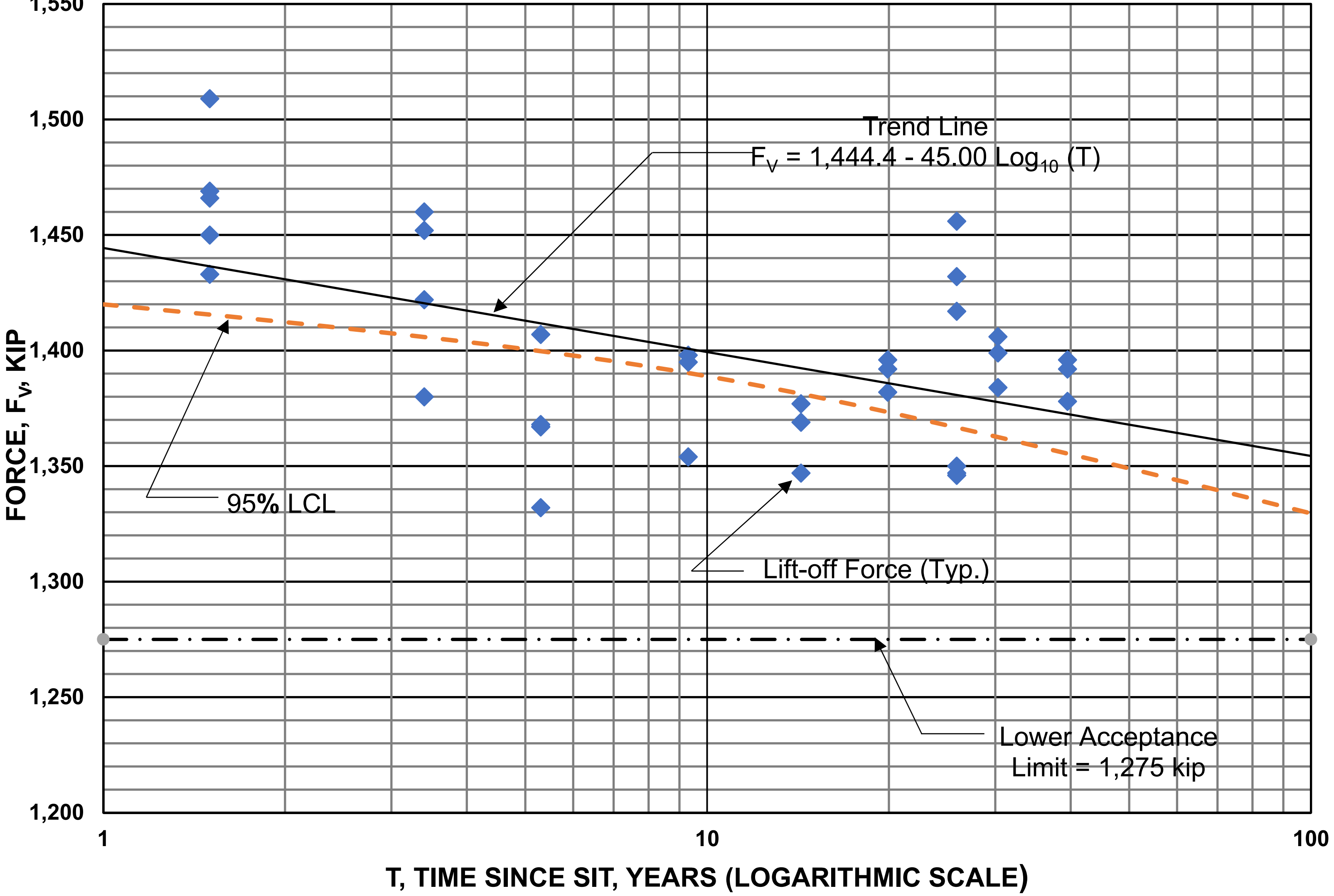


FIGURE 5 - ANO 1 VERTICAL TENDON LIFTOFF FORCES, TREND & LCL / 10 - 40

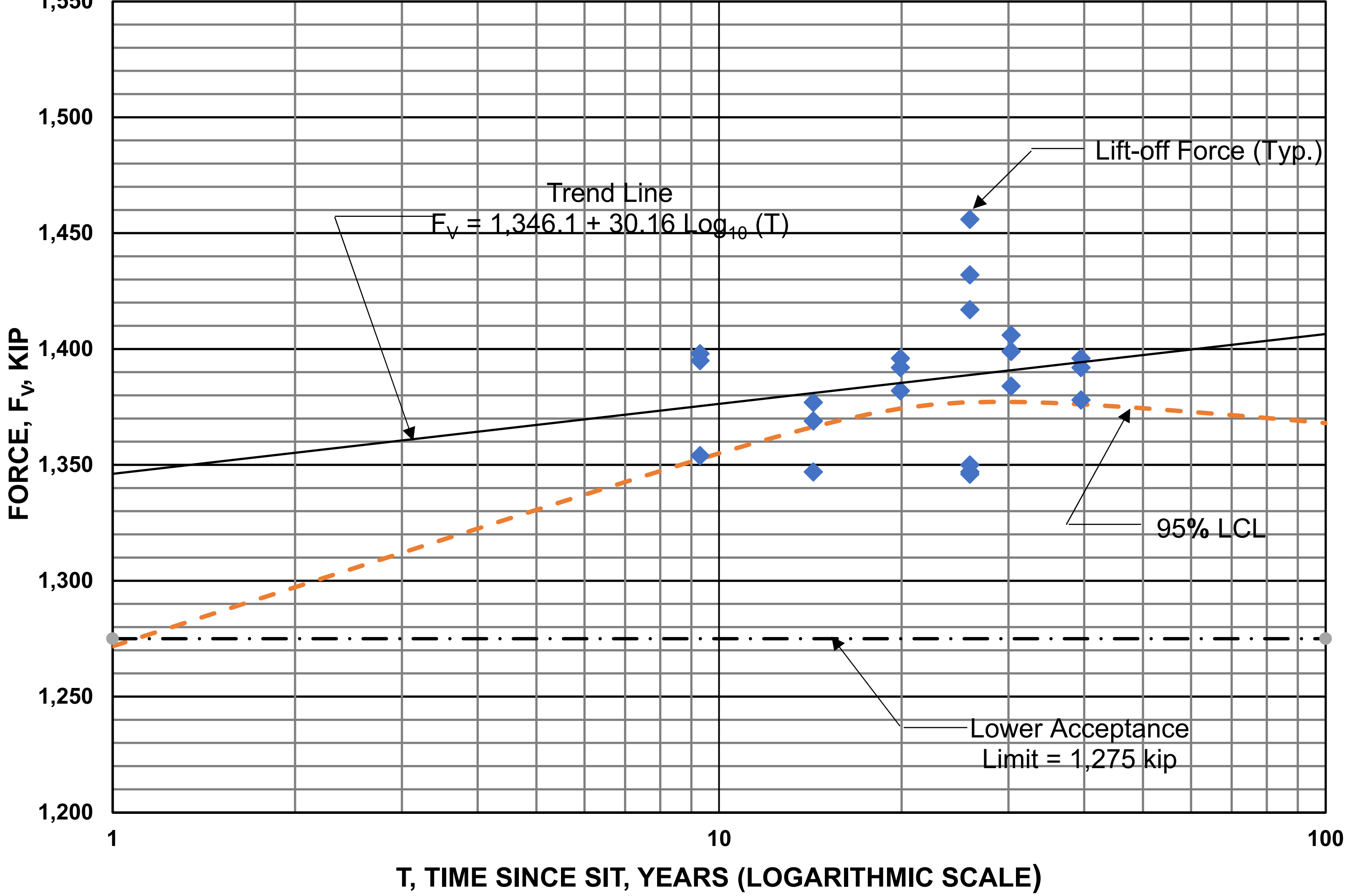


FIGURE 6 - ANO 2 VERTICAL TENDON LIFTOFF FORCES & TREND

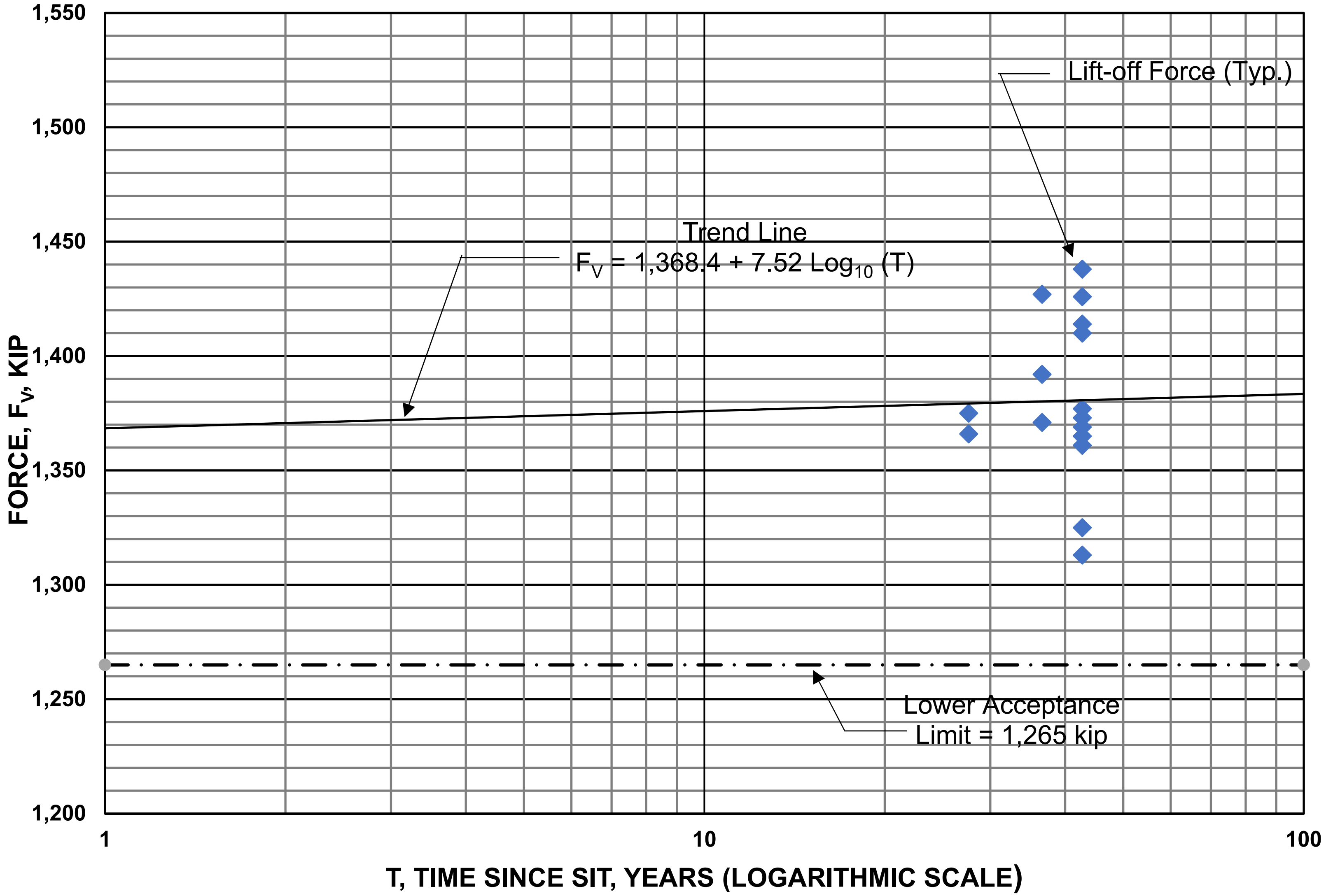


FIGURE 7 - ANO 1 DOME TENDON LIFTOFF FORCES, TREND & LCL / 1 - 40

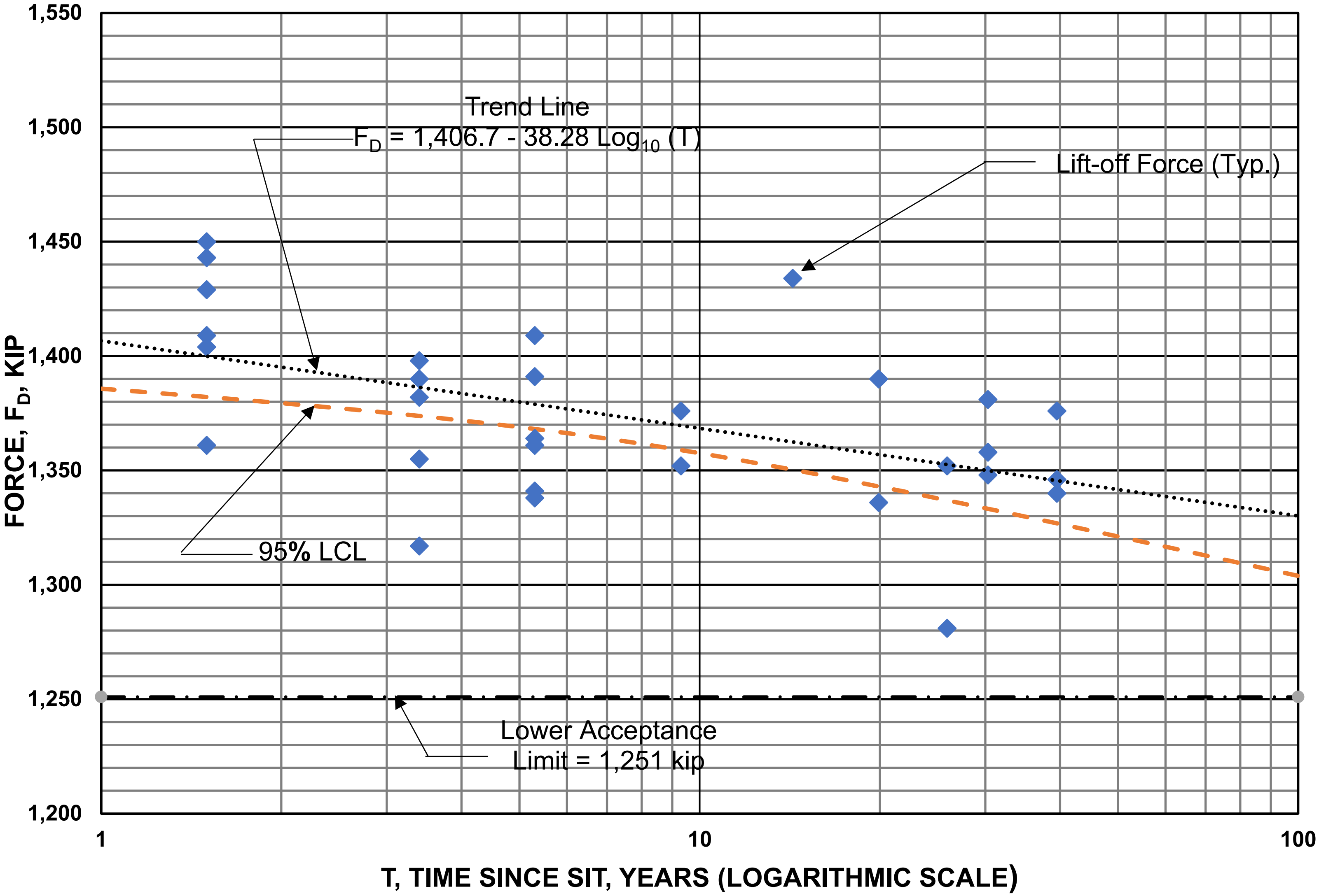


FIGURE 8 - ANO 1 DOME TENDON LIFTOFF FORCES, TREND & LCL / 10 - 40

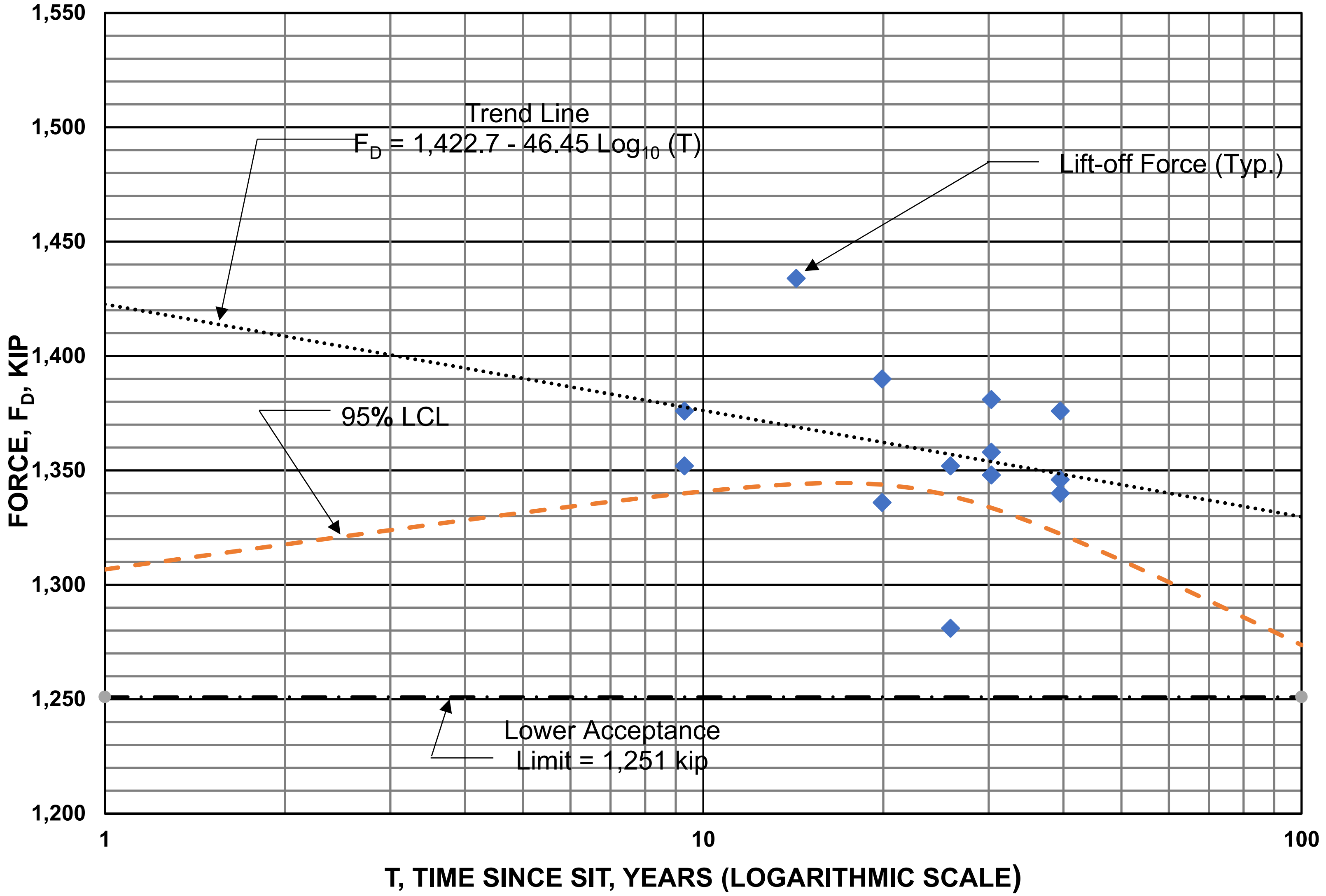


FIGURE 9 - ANO 2 DOME TENDON LIFTOFF FORCES & TREND

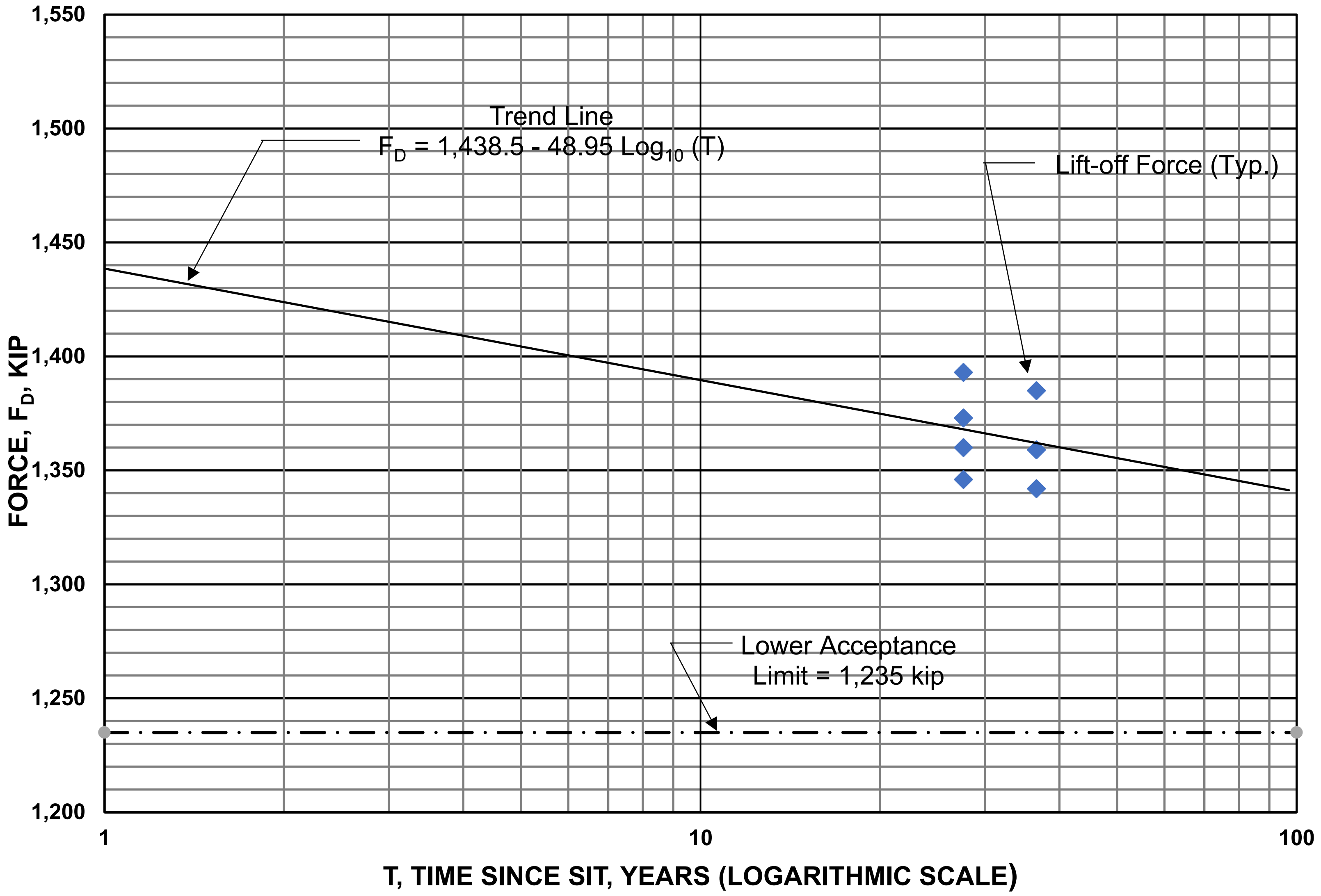


FIGURE 10a - ANO 1 HOOP COMMOM TENDON 31H08 LIFTOFF FORCES & TREND 25 - 40

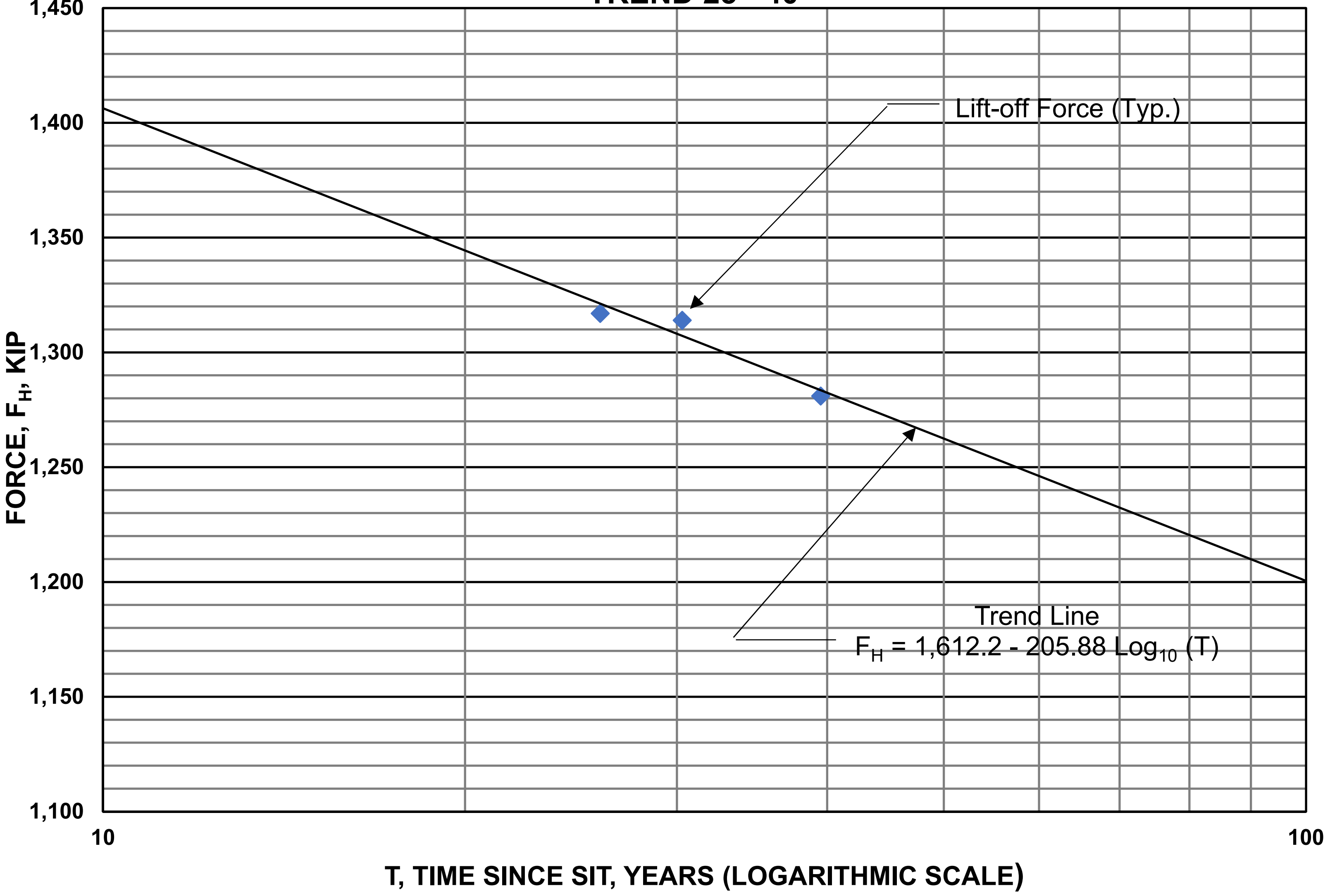


FIGURE 10b - ANO 1 HOOP COMMOM TENDON 31H08 LIFTOFF FORCES & TREND 25 - 30

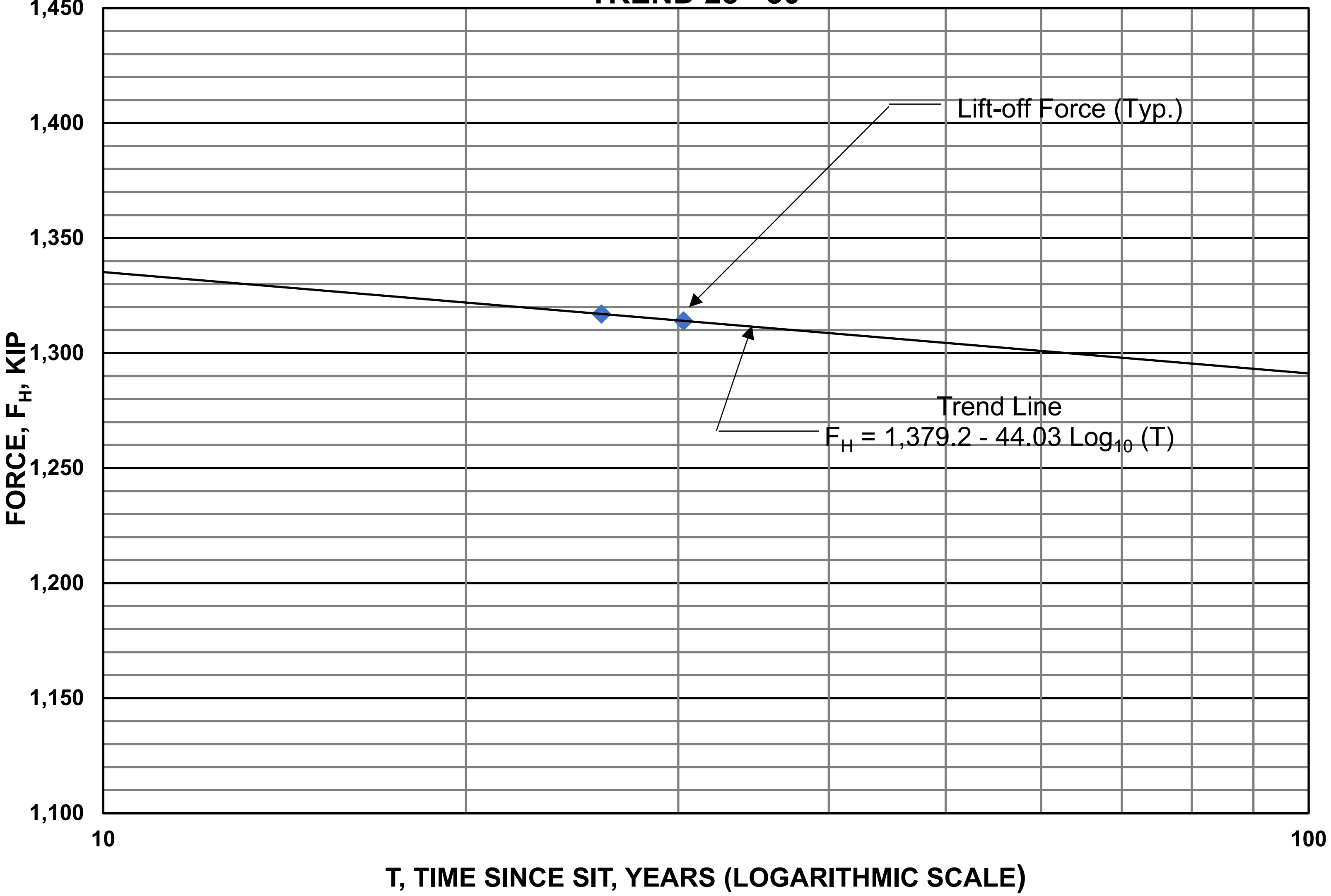


FIGURE 11 - ANO 2 HOOP COMMON TENDON 31H45 LIFTOFF FORCES & TREND

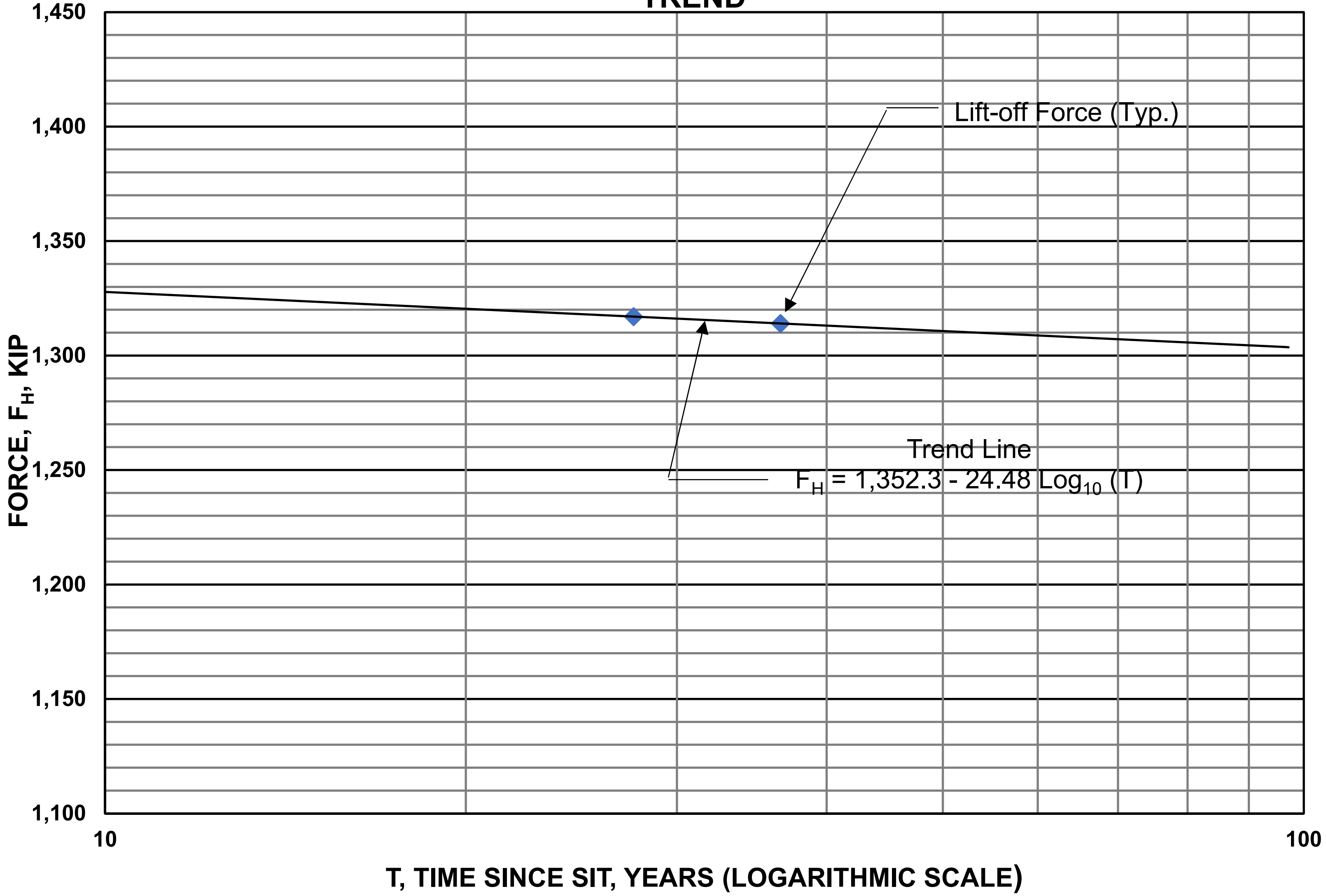


FIGURE 12 - ANO 1 VERTICAL COMMOM TENDON V13 LIFTOFF FORCES & TREND

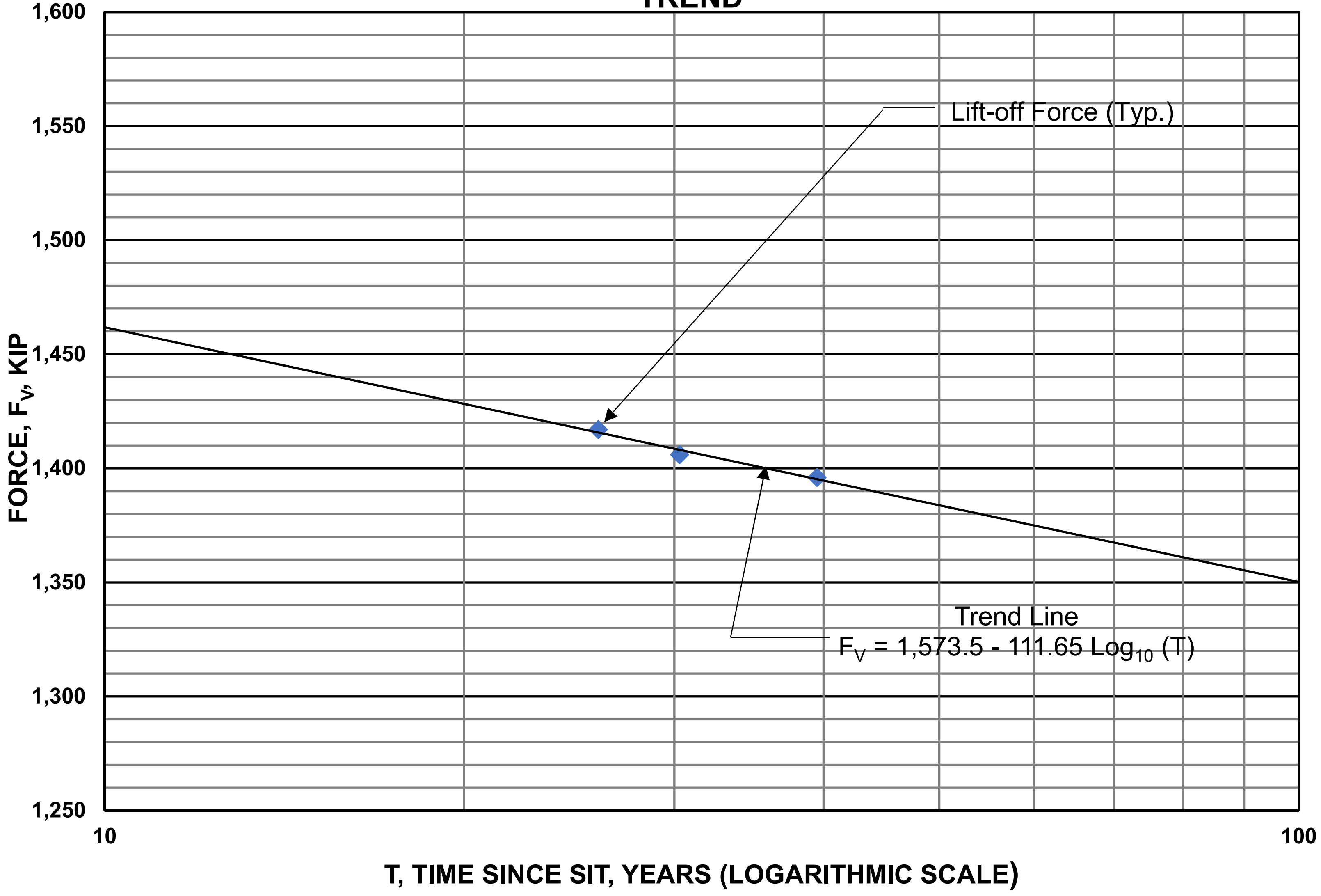


FIGURE 13 - ANO 2 VERTICAL COMMOM TENDON V101 LIFTOFF FORCES & TREND

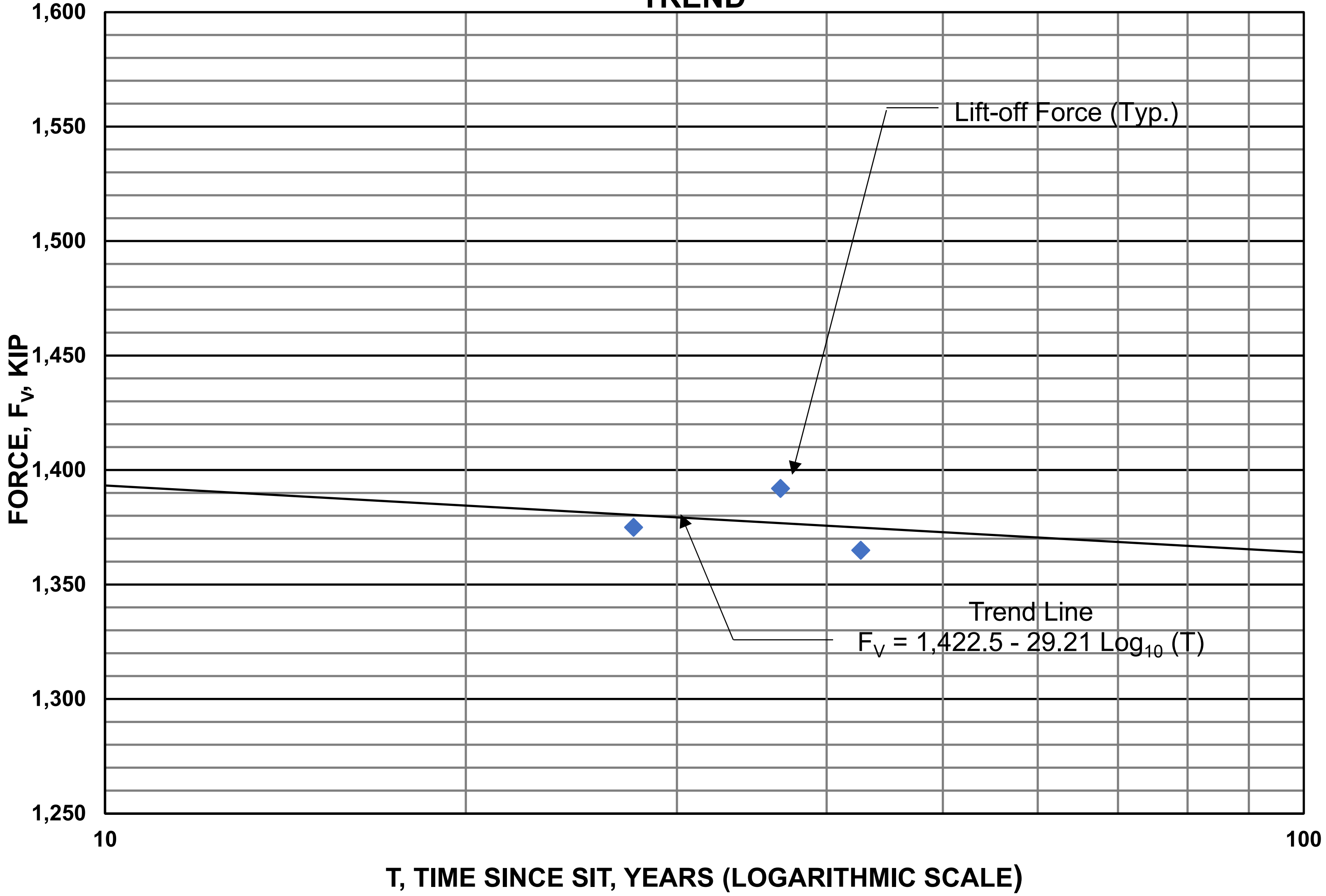


FIGURE 14 - ANO 1 DOME COMMON TENDON 2D13 LIFTOFF FORCES & TREND

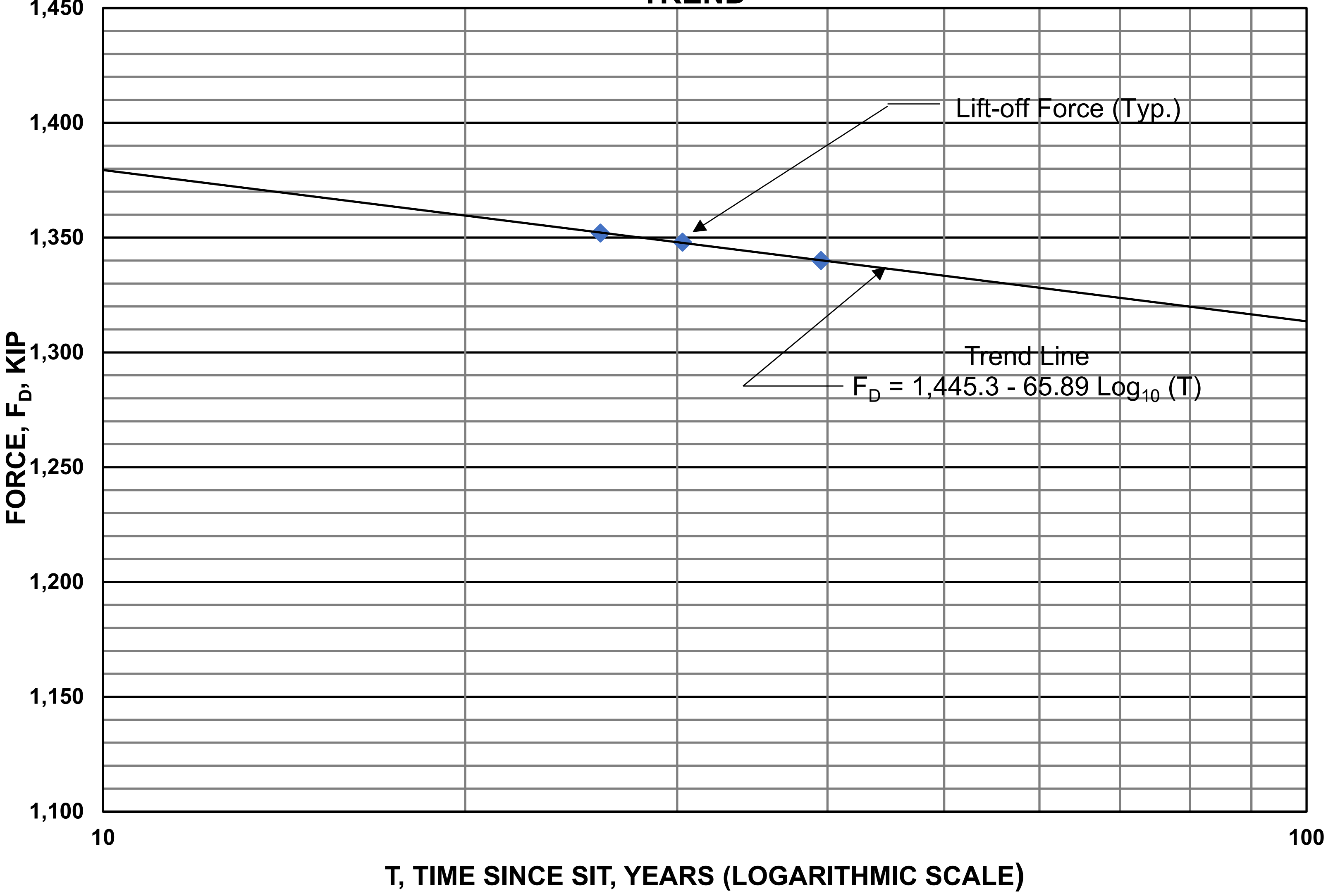
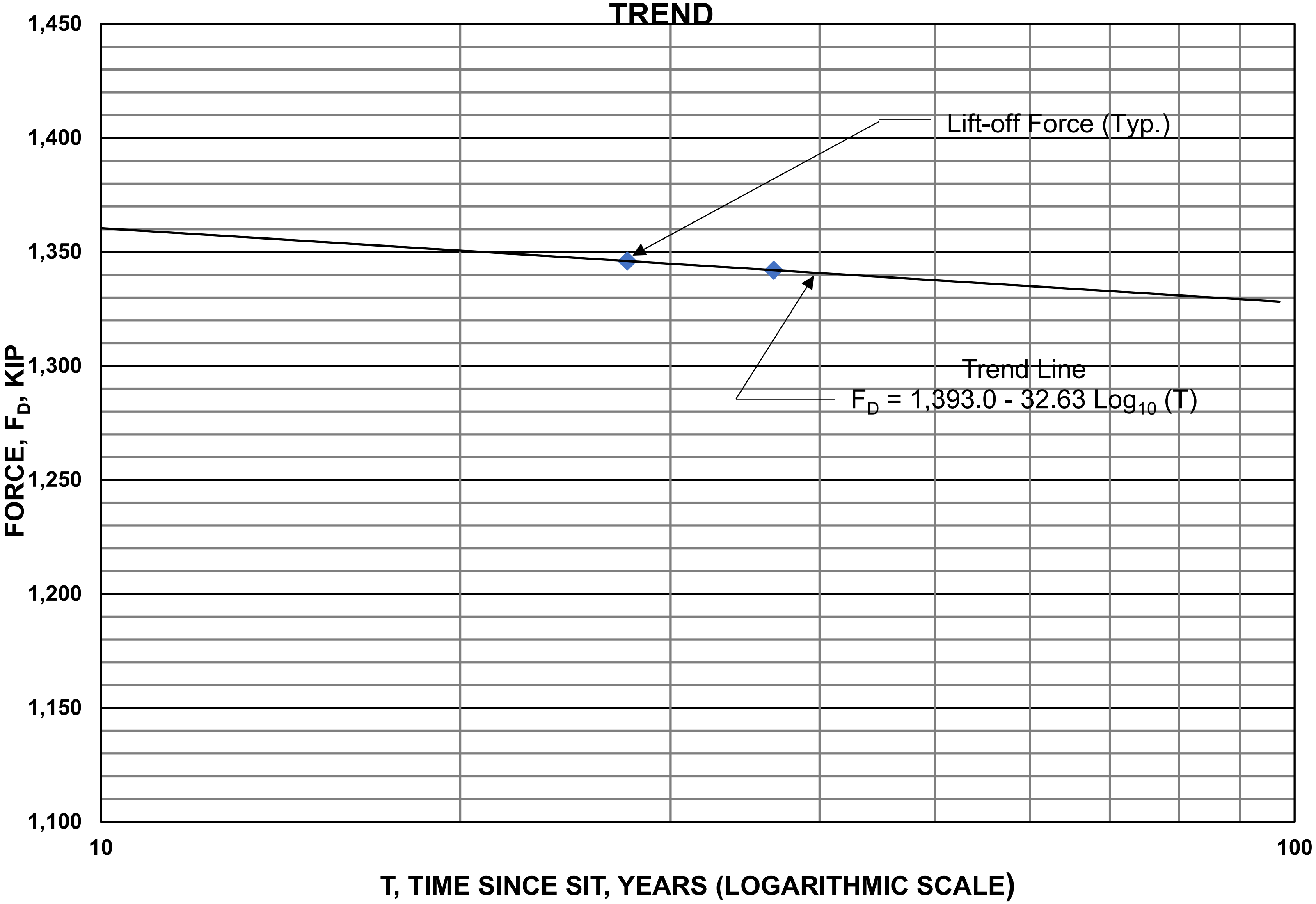


FIGURE 15 - ANO 2 DOME COMMON TENDON 3D09 LIFTOFF FORCES & TREND



Appendix
Figures 1 – 15 Numerical Data and Regression Parameters

Figure 1 Numerical Data and Regression Parameters

Exam	Tendon	T	t = Log T	L/O, kip	t*t	t*F	F*F	tLCL	TLCL	LCL
1	21H24	1.5	0.176	1,338	0.031	235.6	1,790,244	0.00	1.00	1,359.2
1	21H30	1.5	0.176	1,390	0.031	244.8	1,932,100	0.05	1.12	1,356.7
1	21H36	1.5	0.176	1,348	0.031	237.4	1,817,104	0.10	1.26	1,354.1
1	31H27	1.5	0.176	1,370	0.031	241.2	1,876,900	0.15	1.41	1,351.6
1	31H28	1.5	0.176	1,376	0.031	242.3	1,893,376	0.20	1.58	1,349.0
1	31H29	1.5	0.176	1,372	0.031	241.6	1,882,384	0.25	1.78	1,346.3
1	31H40	1.5	0.176	1,367	0.031	240.7	1,868,689	0.30	2.00	1,343.7
1	31H52	1.5	0.176	1,360	0.031	239.5	1,849,600	0.35	2.24	1,341.0
1	32H10	1.5	0.176	1,416	0.031	249.3	2,005,056	0.40	2.51	1,338.3
1	32H20	1.5	0.176	1,396	0.031	245.8	1,948,816	0.45	2.82	1,335.5
1	32H32	1.5	0.176	1,322	0.031	232.8	1,747,684	0.50	3.16	1,332.7
1	32H44	1.5	0.176	1,388	0.031	244.4	1,926,544	0.55	3.55	1,329.8
3	21H42	3.4	0.531	1,370	0.282	728.1	1,876,900	0.60	3.98	1,326.9
3	21H45	3.4	0.531	1,406	0.282	747.3	1,976,836	0.65	4.47	1,323.8
3	21H53	3.4	0.531	1,390	0.282	738.8	1,932,100	0.70	5.01	1,320.7
3	31H38	3.4	0.531	1,342	0.282	713.2	1,800,964	0.75	5.62	1,317.5
3	31H39	3.4	0.531	1,345	0.282	714.8	1,809,025	0.80	6.31	1,314.2
3	31H41	3.4	0.531	1,309	0.282	695.7	1,713,481	0.85	7.08	1,310.8
3	31H50	3.4	0.531	1,318	0.282	700.5	1,737,124	0.90	7.94	1,307.3
3	32H14	3.4	0.531	1,347	0.282	715.9	1,814,409	0.95	8.91	1,303.7
3	32H24	3.4	0.531	1,321	0.282	702.1	1,745,041	1.00	10.00	1,300.1
3	32H40	3.4	0.531	1,303	0.282	692.5	1,697,809	1.05	11.22	1,296.3
3	32H48	3.4	0.531	1,348	0.282	716.4	1,817,104	1.10	12.59	1,292.5
5	21H16	5.3	0.724	1,328	0.525	961.8	1,763,584	1.15	14.13	1,288.7
5	21H50	5.3	0.724	1,354	0.525	980.7	1,833,316	1.20	15.85	1,284.8
5	31H11	5.3	0.724	1,346	0.525	974.9	1,811,716	1.25	17.78	1,280.9
5	31H35	5.3	0.724	1,286	0.525	931.4	1,653,796	1.30	19.95	1,276.9
5	31H47	5.3	0.724	1,330	0.525	963.3	1,768,900	1.35	22.39	1,272.9
5	32H26	5.3	0.724	1,314	0.525	951.7	1,726,596	1.40	25.12	1,268.9
5	32H46	5.3	0.724	1,356	0.525	982.1	1,838,736	1.45	28.18	1,264.9
10	21H41	9.3	0.968	1,284	0.938	1,243.5	1,648,656	1.50	31.62	1,260.8
10	31H15	9.3	0.968	1,320	0.938	1,278.4	1,742,400	1.55	35.48	1,256.7
10	32H13	9.3	0.968	1,282	0.938	1,241.6	1,643,524	1.60	39.81	1,252.6
10	32H15	9.3	0.968	1,268	0.938	1,228.0	1,607,824	1.65	44.67	1,248.5
10	32H43	9.3	0.968	1,216	0.938	1,177.7	1,478,656	1.70	50.12	1,244.4
15	21H12	14.3	1.155	1,256	1.335	1,451.1	1,577,536	1.75	56.23	1,240.3
15	31H42	14.3	1.155	1,262	1.335	1,458.0	1,592,644	1.80	63.10	1,236.2
15	32H28	14.3	1.155	1,212	1.335	1,400.3	1,468,944	1.85	70.79	1,232.0
20	31H23	19.9	1.299	1,296	1.687	1,683.3	1,679,616	1.90	79.43	1,227.9
20	32H50	19.9	1.299	1,264	1.687	1,641.8	1,597,696	1.95	89.13	1,223.7
25	21H08	25.9	1.413	1,290	1.997	1,823.2	1,664,100	2.00	100.00	1,219.6
25	31H08[c]	25.9	1.413	1,317	1.997	1,861.3	1,734,489			
25	32H44	25.9	1.413	1,260	1.997	1,780.8	1,587,600		Lower Limit	
30	21H43	30.3	1.481	1,316	2.195	1,949.6	1,731,856		1	1,164
30	21H52	30.3	1.481	1,363	2.195	2,019.2	1,857,769		100	1,164
30	31H08[c]	30.3	1.481	1,314	2.195	1,946.6	1,726,596			
30	32H18	30.3	1.481	1,288	2.195	1,908.1	1,658,944			
40	31H08[c]	39.5	1.597	1,281	2.549	2,045.2	1,640,961		Sxy	-37,695.1
40	31H09	39.5	1.597	1,334	2.549	2,129.9	1,779,556		Fm	1,324.3
40	32H35	39.5	1.597	1,238	2.549	1,976.6	1,532,644		tm	0.7778
									b	-66.20
	Sums	539.1	38.891	66,217	41.638	50,750.9	87,807,945		a	1,375.8
									se	36.576
n	50		Sum t*t	41.638		Sum F*F	87,807,945		t_{stat}	1.6772
Sum t	38.891		Sum t*F	50,750.9		Sxx	569.39			
Sum F	66,217					Syy	5,706,161			

Figure 2 Numerical Data and Regression Parameters

			t =							
Exam	Tendon	T	Log T	L/O, kip	t*t	t*F	F*F	tLCL	TLCL	LCL
10	21H41	9.3	0.968	1,284	0.938	1,243.5	1,648,656	0.00	1.00	1,124.6
10	31H15	9.3	0.968	1,320	0.938	1,278.4	1,742,400	0.05	1.12	1,130.7
10	32H13	9.3	0.968	1,282	0.938	1,241.6	1,643,524	0.10	1.26	1,136.7
10	32H15	9.3	0.968	1,268	0.938	1,228.0	1,607,824	0.15	1.41	1,142.7
10	32H43	9.3	0.968	1,216	0.938	1,177.7	1,478,656	0.20	1.58	1,148.7
15	21H12	14.3	1.155	1,256	1.335	1,451.1	1,577,536	0.25	1.78	1,154.7
15	31H42	14.3	1.155	1,262	1.335	1,458.0	1,592,644	0.30	2.00	1,160.7
15	32H28	14.3	1.155	1,212	1.335	1,400.3	1,468,944	0.35	2.24	1,166.7
20	31H23	19.9	1.299	1,296	1.687	1,683.3	1,679,616	0.40	2.51	1,172.7
20	32H50	19.9	1.299	1,264	1.687	1,641.8	1,597,696	0.45	2.82	1,178.7
25	21H08	25.9	1.413	1,290	1.997	1,823.2	1,664,100	0.50	3.16	1,184.7
25	31H08[c]	25.9	1.413	1,317	1.997	1,861.3	1,734,489	0.55	3.55	1,190.6
25	32H44	25.9	1.413	1,260	1.997	1,780.8	1,587,600	0.60	3.98	1,196.5
30	21H43	30.3	1.481	1,316	2.195	1,949.6	1,731,856	0.65	4.47	1,202.4
30	21H52	30.3	1.481	1,363	2.195	2,019.2	1,857,769	0.70	5.01	1,208.3
30	31H08[c]	30.3	1.481	1,314	2.195	1,946.6	1,726,596	0.75	5.62	1,214.2
30	32H18	30.3	1.481	1,288	2.195	1,908.1	1,658,944	0.80	6.31	1,220.0
40	31H08[c]	39.5	1.597	1,281	2.549	2,045.2	1,640,961	0.85	7.08	1,225.8
40	31H09	39.5	1.597	1,334	2.549	2,129.9	1,779,556	0.90	7.94	1,231.5
40	32H35	39.5	1.597	1,238	2.549	1,976.6	1,532,644	0.95	8.91	1,237.1
								1.00	10.00	1,242.6
	Sums	446.6	25.862	25,661	34.487	33,244.1	32,952,011	1.05	11.22	1,247.9
								1.10	12.59	1,253.0
n	20		Sum F*F	32,952,011		tm	1.2931	1.15	14.13	1,257.8
Sum t	25.862		Sxx	20.91		b	59.69	1.20	15.85	1,262.2
Sum F	25,661		Syy	553,299		a	1,205.9	1.25	17.78	1,266.1
Sum t*t	34.487		Sxy	1,248.2		se	36.469	1.30	19.95	1,269.3
Sum t*F	33,244.1		Fm	1,283.1		t_{stat}	1.7341	1.35	22.39	1,271.9
								1.40	25.12	1,273.8
								1.45	28.18	1,275.3
								1.50	31.62	1,276.3
			Lower Limit					1.55	35.48	1,277.1
			1	1,164				1.60	39.81	1,277.7
			100	1,164				1.65	44.67	1,278.1
								1.70	50.12	1,278.5
								1.75	56.23	1,278.7
								1.80	63.10	1,278.9
								1.85	70.79	1,279.1
								1.90	79.43	1,279.2
								1.95	89.13	1,279.2
								2.00	100.00	1,279.3

Figure 3 Numerical Data and Regression Parameters

Exam	Tendon	T	t = Log T	L/O, kip	t*t	t*F	F*F
25	12H07	27.6	1.441	1,348	2.076	1,942.3	1,817,104
25	31H13	27.6	1.441	1,330	2.076	1,916.4	1,768,900
25	31H45	27.6	1.441	1,315	2.076	1,894.8	1,729,225
25	31H48	27.6	1.441	1,345	2.076	1,938.0	1,809,025
35	12H13	36.6	1.563	1,313	2.444	2,052.9	1,723,969
35	12H14	36.6	1.563	1,329	2.444	2,077.9	1,766,241
35	31H45	36.6	1.563	1,318	2.444	2,060.7	1,737,124
	Sums	220.2	10.454	9,298	15.638	13,883.0	12,351,588
						n	7
			Lower Limit			Sum t	10.454
			1	1,205		Sum F	9,298
			100	1,205		Sum t*t	15.638
						Sum t*F	13,883.0
						Sum F*F	12,351,588
						Sxx	0.18
						Syy	8,312
						Sxy	-21.3
						Fm	1,328.3
						tm	1.4934
						b	-118.30
						a	1,505.0
						se	12.861
						t_{stat}	2.015

Figure 4 Numerical Data and Regression Parameters

Exam	Tendon	T	t = Log T	L/O, kip	t*t	t*F	F*F	tLCL	TLCL	LCL
1	V19	1.5	0.176	1,509	0.031	265.7	2,277,081	0.00	1.00	1,420.0
1	V40	1.5	0.176	1,466	0.031	258.1	2,149,156	0.05	1.12	1,418.8
1	V60	1.5	0.176	1,433	0.031	252.3	2,053,489	0.10	1.26	1,417.5
1	V80	1.5	0.176	1,469	0.031	258.7	2,157,961	0.15	1.41	1,416.2
1	V100	1.5	0.176	1,450	0.031	255.3	2,102,500	0.20	1.58	1,414.9
3	V15	3.4	0.531	1,452	0.282	771.7	2,108,304	0.25	1.78	1,413.6
3	V55	3.4	0.531	1,422	0.282	755.8	2,022,084	0.30	2.00	1,412.3
3	V75	3.4	0.531	1,460	0.282	776.0	2,131,600	0.35	2.24	1,411.0
3	V95	3.4	0.531	1,380	0.282	733.4	1,904,400	0.40	2.51	1,409.6
5	V3	5.3	0.724	1,367	0.525	990.1	1,868,689	0.45	2.82	1,408.2
5	V26	5.3	0.724	1,368	0.525	990.8	1,871,424	0.50	3.16	1,406.8
5	V68	5.3	0.724	1,367	0.525	990.1	1,868,689	0.55	3.55	1,405.3
5	V84	5.3	0.724	1,407	0.525	1,019.1	1,979,649	0.60	3.98	1,403.8
5	V102	5.3	0.724	1,332	0.525	964.7	1,774,224	0.65	4.47	1,402.2
10	V12	9.3	0.968	1,398	0.938	1,353.9	1,954,404	0.70	5.01	1,400.6
10	V25	9.3	0.968	1,354	0.938	1,311.3	1,833,316	0.75	5.62	1,398.9
10	V73	9.3	0.968	1,395	0.938	1,351.0	1,946,025	0.80	6.31	1,397.1
15	V42	14.3	1.155	1,347	1.335	1,556.2	1,814,409	0.85	7.08	1,395.2
15	V71	14.3	1.155	1,377	1.335	1,590.9	1,896,129	0.90	7.94	1,393.2
15	V98	14.3	1.155	1,369	1.335	1,581.7	1,874,161	0.95	8.91	1,391.1
20	V34	19.9	1.299	1,392	1.687	1,808.0	1,937,664	1.00	10.00	1,388.9
20	V65	19.9	1.299	1,396	1.687	1,813.2	1,948,816	1.05	11.22	1,386.5
20	V101	19.9	1.299	1,382	1.687	1,795.0	1,909,924	1.10	12.59	1,384.1
25	V13	25.9	1.413	1,417	1.997	2,002.6	2,007,889	1.15	14.13	1,381.5
25	V20	25.9	1.413	1,432	1.997	2,023.8	2,050,624	1.20	15.85	1,378.9
25	V30	25.9	1.413	1,350	1.997	1,908.0	1,822,500	1.25	17.78	1,376.1
25	V50	25.9	1.413	1,456	1.997	2,057.8	2,119,936	1.30	19.95	1,373.3
25	V70	25.9	1.413	1,347	1.997	1,903.7	1,814,409	1.35	22.39	1,370.4
25	V90	25.9	1.413	1,346	1.997	1,902.3	1,811,716	1.40	25.12	1,367.5
30	V10	30.3	1.481	1,399	2.195	2,072.5	1,957,201	1.45	28.18	1,364.4
30	V13	30.3	1.481	1,406	2.195	2,082.9	1,976,836	1.50	31.62	1,361.4
30	V89	30.3	1.481	1,384	2.195	2,050.3	1,915,456	1.55	35.48	1,358.3
40	V13	39.5	1.597	1,396	2.549	2,228.8	1,948,816	1.60	39.81	1,355.2
40	V27	39.5	1.597	1,392	2.549	2,222.5	1,937,664	1.65	44.67	1,352.1
40	V39	39.5	1.597	1,378	2.549	2,200.1	1,898,884	1.70	50.12	1,348.9
								1.75	56.23	1,345.7
	Sums	542.9	34.610	48,995	42.003	48,098.6	68,646,029	1.80	63.10	1,342.5
								1.85	70.79	1,339.3
						n	35	1.90	79.43	1,336.1
						Sum t	34.610	1.95	89.13	1,332.8
						Sum F	48,995	2.00	100.00	1,329.6
						Sum t*t	42.003			
						Sum t*F	48,098.6	Lower Limit		
						Sum F*F	68,646,029	1	1,275	
						Sxx	272.28	100	1,275	
						Syy	2,100,990			
						Sxy	-12,251.2			
						Fm	1,399.9			
						tm	0.9888			
						b	-45.00			
						a	1,444.4			
						se	36.630			
						t_{stat}	1.6924			

Figure 5 Numerical Data and Regression Parameters

Exam	Tendon	T	t = Log T	L/O, kip	t*t	t*F	F*F	tLCL	TLCL	LCL
10	V12	9.3	0.968	1,398	0.938	1,353.9	1,954,404	0.00	1.00	1,271.7
10	V25	9.3	0.968	1,354	0.938	1,311.3	1,833,316	0.05	1.12	1,276.0
10	V73	9.3	0.968	1,395	0.938	1,351.0	1,946,025	0.10	1.26	1,280.2
15	V42	14.3	1.155	1,347	1.335	1,556.2	1,814,409	0.15	1.41	1,284.4
15	V71	14.3	1.155	1,377	1.335	1,590.9	1,896,129	0.20	1.58	1,288.7
15	V98	14.3	1.155	1,369	1.335	1,581.7	1,874,161	0.25	1.78	1,292.9
20	V34	19.9	1.299	1,392	1.687	1,808.0	1,937,664	0.30	2.00	1,297.1
20	V65	19.9	1.299	1,396	1.687	1,813.2	1,948,816	0.35	2.24	1,301.3
20	V101	19.9	1.299	1,382	1.687	1,795.0	1,909,924	0.40	2.51	1,305.5
25	V13	25.9	1.413	1,417	1.997	2,002.6	2,007,889	0.45	2.82	1,309.8
25	V20	25.9	1.413	1,432	1.997	2,023.8	2,050,624	0.50	3.16	1,314.0
25	V30	25.9	1.413	1,350	1.997	1,908.0	1,822,500	0.55	3.55	1,318.2
25	V50	25.9	1.413	1,456	1.997	2,057.8	2,119,936	0.60	3.98	1,322.3
25	V70	25.9	1.413	1,347	1.997	1,903.7	1,814,409	0.65	4.47	1,326.5
25	V90	25.9	1.413	1,346	1.997	1,902.3	1,811,716	0.70	5.01	1,330.7
30	V10	30.3	1.481	1,399	2.195	2,072.5	1,957,201	0.75	5.62	1,334.8
30	V13	30.3	1.481	1,406	2.195	2,082.9	1,976,836	0.80	6.31	1,338.9
30	V89	30.3	1.481	1,384	2.195	2,050.3	1,915,456	0.85	7.08	1,343.0
40	V13	39.5	1.597	1,396	2.549	2,228.8	1,948,816	0.90	7.94	1,347.0
40	V27	39.5	1.597	1,392	2.549	2,222.5	1,937,664	0.95	8.91	1,351.0
40	V39	39.5	1.597	1,378	2.549	2,200.1	1,898,884	1.00	10.00	1,355.0
								1.05	11.22	1,358.8
	Sums	495.3	27.982	29,113	38.095	38,816.7	40,376,779	1.10	12.59	1,362.5
								1.15	14.13	1,366.0
						n	21	1.20	15.85	1,369.2
						Sum t	27.982	1.25	17.78	1,372.1
			Lower Limit			Sum F	29,113	1.30	19.95	1,374.4
			1	1,275		Sum t*t	38.095	1.35	22.39	1,376.0
			100	1,275		Sum t*F	38,816.7	1.40	25.12	1,376.9
						Sum F*F	40,376,779	1.45	28.18	1,377.2
						Sxx	17.01	1.50	31.62	1,377.1
						Syy	345,590	1.55	35.48	1,376.7
						Sxy	513.1	1.60	39.81	1,376.1
						Fm	1,386.3	1.65	44.67	1,375.3
						tm	1.3325	1.70	50.12	1,374.4
						b	30.16	1.75	56.23	1,373.4
						a	1,346.1	1.80	63.10	1,372.4
						se	28.764	1.85	70.79	1,371.4
						t_{stat}	1.7291	1.90	79.43	1,370.3
								1.95	89.13	1,369.1
								2.00	100.00	1,368.0

Figure 6 Numerical Data and Regression Parameters

Exam	Tendon	T	t = Log T	L/O, kip	t*t	t*F	F*F
25	V101	27.6	1.441	1,375	2.076	1,981.2	1,890,625
25	V109	27.6	1.441	1,366	2.076	1,968.3	1,865,956
35	V050	36.6	1.563	1,427	2.444	2,231.1	2,036,329
35	V101	36.6	1.563	1,392	2.444	2,176.4	1,937,664
35	V110	36.6	1.563	1,371	2.444	2,143.5	1,879,641
40	V001	42.7	1.630	1,414	2.658	2,305.4	1,999,396
40	V021	42.7	1.630	1,365	2.658	2,225.5	1,863,225
40	V027	42.7	1.630	1,373	2.658	2,238.6	1,885,129
40	V032	42.7	1.630	1,426	2.658	2,325.0	2,033,476
40	V040	42.7	1.630	1,438	2.658	2,344.6	2,067,844
40	V047	42.7	1.630	1,377	2.658	2,245.1	1,896,129
40	V058	42.7	1.630	1,410	2.658	2,298.9	1,988,100
40	V067	42.7	1.630	1,369	2.658	2,232.1	1,874,161
40	V100	42.7	1.630	1,325	2.658	2,160.3	1,755,625
40	V101	42.7	1.630	1,365	2.658	2,225.5	1,863,225
40	V102	42.7	1.630	1,313	2.658	2,140.8	1,723,969
40	V103	42.7	1.630	1,361	2.658	2,219.0	1,852,321
	Sums	677.4	27.137	23,467	43.385	37,461.3	32,412,815
						n	17
						Sum t	27.137
			Lower Limit			Sum F	23,467
			1	1,265		Sum t*t	43.385
			100	1,265		Sum t*F	37,461.3
						Sum F*F	32,412,815
						Sxx	1.11
						Syy	317,766
						Sxy	8.4
						Fm	1,380.4
						tm	1.5963
						b	7.52
						a	1,368.4
						se	35.297
						t_{stat}	1.7531

Figure 7 Numerical Data and Regression Parameters

Exam	Tendon	T	t = Log T	L/O, kip	t*t	t*F	F*F	tLCL	TLCL	LCL
1	1D320	1.5	0.176	1,409	0.031	248.1	1,985,281	0.00	1.00	1,385.7
1	1D328	1.5	0.176	1,443	0.031	254.1	2,082,249	0.05	1.12	1,384.7
1	2D207	1.5	0.176	1,450	0.031	255.3	2,102,500	0.10	1.26	1,383.7
1	2D210	1.5	0.176	1,429	0.031	251.6	2,042,041	0.15	1.41	1,382.7
1	3D110	1.5	0.176	1,361	0.031	239.7	1,852,321	0.20	1.58	1,381.6
1	3D120	1.5	0.176	1,404	0.031	247.2	1,971,216	0.25	1.78	1,380.5
3	1D26	3.4	0.531	1,398	0.282	743.0	1,954,404	0.30	2.00	1,379.4
3	2D08	3.4	0.531	1,355	0.282	720.2	1,836,025	0.35	2.24	1,378.3
3	2D11	3.4	0.531	1,382	0.282	734.5	1,909,924	0.40	2.51	1,377.1
3	3D08	3.4	0.531	1,317	0.282	700.0	1,734,489	0.45	2.82	1,375.9
3	3D21	3.4	0.531	1,390	0.282	738.8	1,932,100	0.50	3.16	1,374.6
5	1D07	5.3	0.724	1,391	0.525	1,007.5	1,934,881	0.55	3.55	1,373.3
5	1D12	5.3	0.724	1,364	0.525	987.9	1,860,496	0.60	3.98	1,371.9
5	2D22	5.3	0.724	1,338	0.525	969.1	1,790,244	0.65	4.47	1,370.4
5	2D29	5.3	0.724	1,409	0.525	1,020.5	1,985,281	0.70	5.01	1,368.9
5	3D02	5.3	0.724	1,361	0.525	985.7	1,852,321	0.75	5.62	1,367.3
5	3D24	5.3	0.724	1,341	0.525	971.3	1,798,281	0.80	6.31	1,365.5
10	1D03	9.3	0.968	1,376	0.938	1,332.6	1,893,376	0.85	7.08	1,363.7
10	2D28	9.3	0.968	1,352	0.938	1,309.4	1,827,904	0.90	7.94	1,361.7
15	1D30	14.3	1.155	1,434	1.335	1,656.8	2,056,356	0.95	8.91	1,359.7
20	1D02	19.9	1.299	1,390	1.687	1,805.4	1,932,100	1.00	10.00	1,357.5
20	3D11	19.9	1.299	1,336	1.687	1,735.3	1,784,896	1.05	11.22	1,355.3
25	2D13	25.9	1.413	1,352	1.997	1,910.8	1,827,904	1.10	12.59	1,353.0
25	3D18	25.9	1.413	1,281	1.997	1,810.4	1,640,961	1.15	14.13	1,350.6
30	1D11	30.3	1.481	1,381	2.195	2,045.9	1,907,161	1.20	15.85	1,348.1
30	2D13	30.3	1.481	1,348	2.195	1,997.0	1,817,104	1.25	17.78	1,345.5
30	2D18	30.3	1.481	1,358	2.195	2,011.8	1,844,164	1.30	19.95	1,342.9
40	2D09	39.5	1.597	1,346	2.549	2,149.0	1,811,716	1.35	22.39	1,340.3
40	2D13	39.5	1.597	1,340	2.549	2,139.4	1,795,600	1.40	25.12	1,337.6
40	3D04	39.5	1.597	1,376	2.549	2,196.9	1,893,376	1.45	28.18	1,334.9
								1.50	31.62	1,332.2
	Sums	391.7	25.810	41,212	29.557	35,175.1	56,656,672	1.55	35.48	1,329.4
								1.60	39.81	1,326.7
						n	30	1.65	44.67	1,323.9
						Sum t	25.810	1.70	50.12	1,321.0
						Sum F	41,212	1.75	56.23	1,318.2
			Lower Limit			Sum t*t	29.557	1.80	63.10	1,315.4
			1	1,251		Sum t*F	35,175.1	1.85	70.79	1,312.5
			100	1,251		Sum F*F	56,656,672	1.90	79.43	1,309.7
						Sxx	220.53	1.95	89.13	1,306.8
						Syy	1,271,216	2.00	100.00	1,303.9
						Sxy	-8,441.8			
						Fm	1,373.7			
						tm	0.8603			
						b	-38.28			
						a	1,406.7			
						se	33.595			
						t_{stat}	1.7011			

Figure 8 Numerical Data and Regression Parameters

Exam	Tendon	T	t = Log T	L/O, kip	t*t	t*F	F*F	tLCL	TLCL	LCL
10	1D03	9.3	0.968	1,376	0.938	1,332.6	1,893,376	0.00	1.00	1,306.7
10	2D28	9.3	0.968	1,352	0.938	1,309.4	1,827,904	0.05	1.12	1,308.5
15	1D30	14.3	1.155	1,434	1.335	1,656.8	2,056,356	0.10	1.26	1,310.4
20	1D02	19.9	1.299	1,390	1.687	1,805.4	1,932,100	0.15	1.41	1,312.2
20	3D11	19.9	1.299	1,336	1.687	1,735.3	1,784,896	0.20	1.58	1,314.0
25	2D13	25.9	1.413	1,352	1.997	1,910.8	1,827,904	0.25	1.78	1,315.8
25	3D18	25.9	1.413	1,281	1.997	1,810.4	1,640,961	0.30	2.00	1,317.6
30	1D11	30.3	1.481	1,381	2.195	2,045.9	1,907,161	0.35	2.24	1,319.4
30	2D13	30.3	1.481	1,348	2.195	1,997.0	1,817,104	0.40	2.51	1,321.2
30	2D18	30.3	1.481	1,358	2.195	2,011.8	1,844,164	0.45	2.82	1,322.9
40	2D09	39.5	1.597	1,346	2.549	2,149.0	1,811,716	0.50	3.16	1,324.7
40	2D13	39.5	1.597	1,340	2.549	2,139.4	1,795,600	0.55	3.55	1,326.4
40	3D04	39.5	1.597	1,376	2.549	2,196.9	1,893,376	0.60	3.98	1,328.2
								0.65	4.47	1,329.9
	Sums	333.9	17.751	17,670	24.811	24,100.7	24,032,618	0.70	5.01	1,331.6
								0.75	5.62	1,333.2
						n	13	0.80	6.31	1,334.9
						Sum t	17.751	0.85	7.08	1,336.5
		Lower Limit				Sum F	17,670	0.90	7.94	1,338.0
		1	1,251			Sum t*t	24.811	0.95	8.91	1,339.5
		100	1,251			Sum t*F	24,100.7	1.00	10.00	1,340.8
						Sum F*F	24,032,618	1.05	11.22	1,342.1
						Sxx	7.45	1.10	12.59	1,343.2
						Syy	195,134	1.15	14.13	1,344.0
						Sxy	-346.3	1.20	15.85	1,344.5
						Fm	1,359.2	1.25	17.78	1,344.5
						tm	1.3654	1.30	19.95	1,343.8
						b	-46.45	1.35	22.39	1,342.3
						a	1,422.7	1.40	25.12	1,339.8
						se	35.385	1.45	28.18	1,336.3
						t_{stat}	1.7959	1.50	31.62	1,332.0
								1.55	35.48	1,327.2
								1.60	39.81	1,321.9
								1.65	44.67	1,316.3
								1.70	50.12	1,310.5
								1.75	56.23	1,304.6
								1.80	63.10	1,298.5
								1.85	70.79	1,292.4
								1.90	79.43	1,286.2
								1.95	89.13	1,280.0
								2.00	100.00	1,273.7

Figure 9 Numerical Data and Regression Parameters

Exam	Tendon	T	t = Log T	L/O, kip	t*t	t*F	F*F
25	1D313	27.6	1.441	1,360	2.076	1,959.6	1,849,600
25	1D315	27.6	1.441	1,373	2.076	1,978.4	1,885,129
25	3D109	27.6	1.441	1,346	2.076	1,939.5	1,811,716
25	3D128	27.6	1.441	1,393	2.076	2,007.2	1,940,449
35	2D213	36.6	1.563	1,359	2.444	2,124.8	1,846,881
35	2D218	36.6	1.563	1,385	2.444	2,165.4	1,918,225
35	3D109	36.6	1.563	1,342	2.444	2,098.2	1,800,964
	Sums	220.2	10.454	9,558	15.638	14,273.0	13,052,964
						n	7
						Sum t	10.454
						Sum F	9,558
			Lower Limit			Sum t*t	15.638
			1	1,235		Sum t*F	14,273.0
			100	1,235		Sum F*F	13,052,964
						Sxx	0.18
						Syy	15,384
						Sxy	-8.8
						Fm	1,365.4
						tm	1.4934
						b	-48.95
						a	1,438.5
						se	20.669
						t_{stat}	2.015

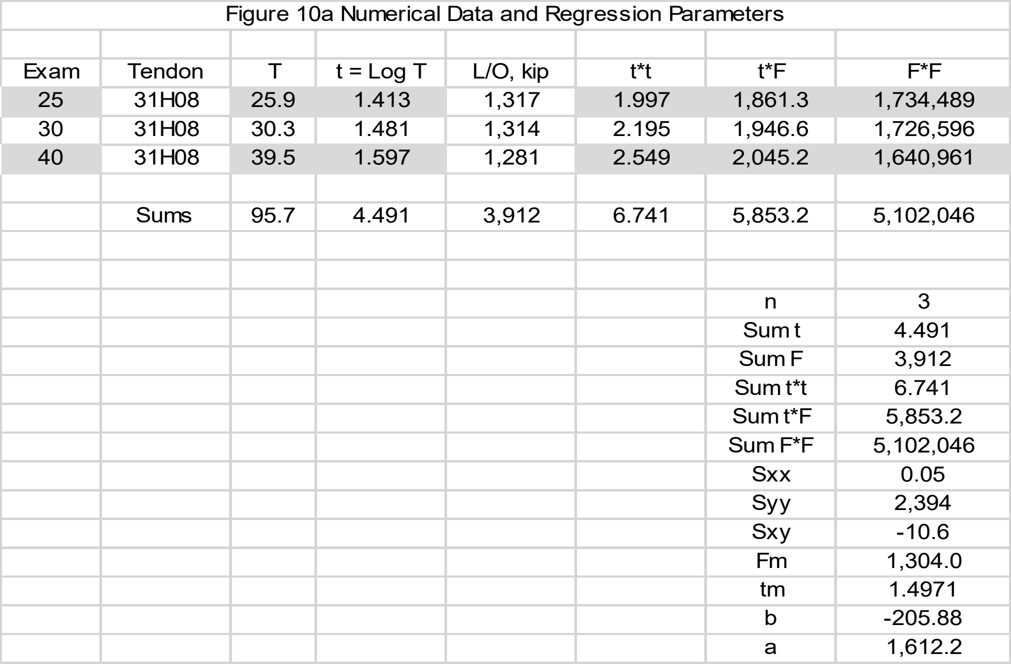


Figure 10a Numerical Data and Regression Parameters

Exam	Tendon	T	t = Log T	L/O, kip	t*t	t*F	F*F
25	31H08	25.9	1.413	1,317	1.997	1,861.3	1,734,489
30	31H08	30.3	1.481	1,314	2.195	1,946.6	1,726,596
40	31H08	39.5	1.597	1,281	2.549	2,045.2	1,640,961
	Sums	95.7	4.491	3,912	6.741	5,853.2	5,102,046
						n	3
						Sum t	4.491
						Sum F	3,912
						Sum t*t	6.741
						Sum t*F	5,853.2
						Sum F*F	5,102,046
						Sxx	0.05
						Syy	2,394
						Sxy	-10.6
						Fm	1,304.0
						tm	1.4971
						b	-205.88
						a	1,612.2

Figure 10b Numerical Data and Regression Parameters

Exam	Tendon	T	t = Log T	L/O, kip	t*t	t*F	F*F
25	31H08	25.9	1.413	1,317	1.997	1,861.3	1,734,489
30	31H08	30.3	1.481	1,314	2.195	1,946.6	1,726,596
	Sums	56.2	2.895	2,631	4.192	3,807.9	3,461,085
						n	2
						Sum t	2.895
						Sum F	2,631
						Sum t*t	4.192
						Sum t*F	3,807.9
						Sum F*F	3,461,085
						Sxx	0.00
						Syy	9
						Sxy	-0.2
						Fm	1,315.5
						tm	1.4474
						b	-44.03
						a	1,379.2

Figure 11 Numerical Data and Regression Parameter

Exam	Tendon	T	t = Log T	L/O, kip	t*t	t*F	F*F
25	31H45	27.6	1.441	1,317	2.076	1,897.7	1,734,489
35	31H45	36.6	1.563	1,314	2.444	2,054.4	1,726,596
	Sums	64.2	3.004	2,631	4.521	3,952.1	3,461,085
						n	2
						Sum t	3.004
						Sum F	2,631
						Sum t*t	4.521
						Sum t*F	3,952.1
						Sum F*F	3,461,085
						Sxx	0.02
						Syy	9
						Sxy	-0.4
						Fm	1,315.5
						tm	1.5022
						b	-24.48
						a	1,352.3

Figure 12 Numerical Data and Regression Partameters

Exam	Tendon	T	t = Log T	L/O, kip	t*t	t*F	F*F
25	V13	25.9	1.413	1,417	1.997	2,002.6	2,007,889
30	V13	30.3	1.481	1,406	2.195	2,082.9	1,976,836
40	V13	39.5	1.597	1,396	2.549	2,228.8	1,948,816
	Sums	95.7	4.491	4,219	6.741	6,314.4	5,933,541
						n	3
						Sum t	4.491
						Sum F	4,219
						Sum t*t	6.741
						Sum t*F	6,314.4
						Sum F*F	5,933,541
						Sxx	0.05
						Syy	662
						Sxy	-5.8
						Fm	1,406.3
						tm	1.4971
						b	-111.65
						a	1,573.5

Figure 13 Numerical Data and RegressionParameters

Exam	Tendon	T	t = Log T	L/O, kip	t*t	t*F	F*F
25	V101	27.6	1.441	1,375	2.076	1,981.2	1,890,625
35	V102	36.6	1.563	1,392	2.444	2,176.4	1,937,664
40	V103	42.7	1.630	1,365	2.658	2,225.5	1,863,225
	Sums	106.9	4.635	4,132	7.179	6,383.1	5,691,514
						n	3
						Sum t	4.635
						Sum F	4,132
						Sum t*t	7.179
						Sum t*F	6,383.1
						Sum F*F	5,691,514
						Sxx	0.06
						Syy	1,118
						Sxy	-1.6
						Fm	1,377.3
						tm	1.5449
						b	-29.21
						a	1,422.5

Figure 14 Numerical Data and Regression Parameters

Exam	Tendon	T	t = Log T	L/O, kip	t*t	t*F	F*F
25	2D213	25.9	1.413	1,352	1.997	1,910.8	1,827,904
30	2D213	30.3	1.481	1,348	2.195	1,997.0	1,817,104
40	2D213	39.5	1.597	1,340	2.549	2,139.4	1,795,600
	Sums	95.7	4.491	4,040	6.741	6,047.2	5,440,608
						n	3
						Sum t	4.491
						Sum F	4,040
						Sum t*t	6.741
						Sum t*F	6,047.2
						Sum F*F	5,440,608
						Sxx	0.05
						Syy	224
						Sxy	-3.4
						Fm	1,346.7
						tm	1.4971
						b	-65.89
						a	1,445.3

Figure 15 Numerical Data and Regression Parameters

Exam	Tendon	T	t = Log T	L/O, kip	t*t	t*F	F*F
25	3D09	27.6	1.441	1,346	2.076	1,939.5	1,811,716
35	3D09	36.6	1.563	1,342	2.444	2,098.2	1,800,964
	Sums	64.2	3.004	2,688	4.521	4,037.7	3,612,680
						n	2
						Sum t	3.004
						Sum F	2,688
						Sum t*t	4.521
						Sum t*F	4,037.7
						Sum F*F	3,612,680
						Sxx	0.02
						Syy	16
						Sxy	-0.5
						Fm	1,344.0
						tm	1.5022
						b	-32.63
						a	1,393.0