Southern Nuclear

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Vogtle Electric Generating Plant – Unit 1 and 2
Proposed ISI Alternative VEGP-ISI-ALT-19-01 for Tendon Inservice Inspection Extension

Ladies and Gentlemen:

Enclosed for your review is proposed Inservice Inspection (ISI) alternative VEGP-ISI-ALT-19-01 associated with the 4th ISI Interval for Vogtle Electric Generating Plant (VEGP), Unit 1 and 2. VEGP-ISI-RR-19-01 concerns requirements associated with the Containment ISI program. The 4th ISI Interval program complies with the 2007 Edition, 2008 Addenda of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code. The 4th ISI Interval began on May 31, 2017 and is currently scheduled to end May 30, 2027. We request your approval by February 19, 2020.

This letter contains no NRC commitments. If you have any questions, please contact Jamie Coleman at 205.992.6611.

Respectfully submitted,

Cheryl A. Gayheart
Regulatory Affairs Director

CAG/kgl/sm

Enclosures: 1. Proposed Alternative VEGP-ISI-ALT-19-01
2. Containment Post-Tensioning System Inservice Inspection Technical Report

Cc: Regional Administrator
NRR Project Manager – Vogtle 1 & 2
Senior Resident Inspector – Vogtle 1 & 2
RType: CVC7000

Vogtle Electric Generating Plant – Unit 1 and 2
Proposed ISI Alternative VEGP ISI-ALT-19-01 for Tendon Inservice Inspection Extension

Enclosure 1

Proposed Alternative VEGP-ISI-ALT-19-01

Proposed Alternative VEGP-ISI-ALT-19-01 for Containment Unbonded Post-Tensioning System Inservice Inspection Requirements in Accordance with 10 CFR 50.55a(z)(1)

1. ASME Code Component(s) Affected

Code Class:	CC
Reference:	IWL-2421, IWL-2520, Table IWL-2500-1
Examination Category:	Table IWL-2500-1, Category L-B
Item Number:	L2.10, L2.20, L2.30, L2.40, and L2.50
Description:	Examination of unbonded post-tensioning system
Component Number:	Unit 1 Vogtle Containment Building Unit 2 Vogtle Containment Building

2. Request Approval Date

February 19, 2020

3. Applicable Code Edition and Addenda

The following table identifies the ASME Section XI Code of Record for performing Inservice Inspection (ISI) activities at Southern Nuclear Plant Vogtle 1 and 2.

Plant	ISI Interval	ASME Section XI Edition / Addenda	Interval Start	Interval End
Vogtle Nuclear Plant, Units 1 and 2	4	2007 Edition / 2008 Addenda	05/31/2017	05/30/2027

4. Applicable Code Requirements

Subsection IWL-2421(b) states that when the conditions of IWL-2421(a) are met, the inspection dates and examination requirements may be as follows.

(1) For the containment with the first Structural Integrity Test, all examinations required by IWL-2500 shall be performed at 1, 3, and 10 years and every 10 years thereafter. Only the examinations required by IWL-2524 and IWL-2525 need be performed at 5 and 15 years and every 10 years thereafter.

(2) For each subsequent containment constructed at the site, all examinations required by IWL-2500 shall be performed at 1, 5, and 15 years and every 10 years thereafter. Only the examinations required by IWL-2524 and IWL-2525 need be performed at 3 and 10 years and every 10 years thereafter.

Vogtle Electric Generating Plant (VEGP), Unit 1 and Unit 2 is currently required to examine the post-tensioning system every 10 years.

Subsection IWL-2500 requires examinations be performed in accordance with the requirements of Table IWL-2500-1.

Table IWL-2500-1, Item Number L2.10 requires that selected tendon force and elongation be measured.

Table IWL-2500-1, Item Number L2.20 requires that tendon single wire samples be 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. The selected tendons are subsequently retensioned as required per IWL-2523.3 because wire removal requires detensioning in order to safely obtain wire samples.

Table IWL-2500-1, Item Number L2.30 requires that a detailed visual examination be performed on selected tendon anchorage hardware and adjacent concrete extending 2 feet from the edge of the bearing plate. 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.

Table IWL-2500-1, Item number L2.40 and L2.50 require that samples of selected tendon corrosion protection medium (CPM) and free water be obtained and analyzed.

5. Reason for Request

ASME Section XI Subsection IWL requires periodic visual examination and physical testing of Containment Building concrete as well as physical testing of post-tensioning systems. The examination and testing to date has indicated the post-tensioning system is expected to maintain its safety-related function through the period of extended operation. This alternative proposes to perform visual examination only of the concrete containment and accessible steel hardware visible without tendon cover removal during the 35th year (Unit 1) / 30th year (Unit 2) surveillance. Physical testing would be performed only if visual examination results indicate a need for such testing as determined by the Responsible Engineer (IWL-2330). The 35th year (Unit 1) / 30th year (Unit 2) surveillance is required to be completed no later than April 14, 2020 based on last performance. The 40th year (Unit 1) / 35th year (Unit 2) surveillance would be due at August 1, 2025 and would be completed during the subsequent 4th inservice inspection interval. A common "re-baselining date", August 1 2010 (±1 year) is used to allow alignment of the schedule for all the Table IWL-2500-1 examinations (concrete and post-tensioning system) for Unit 1 and Unit 2 as stated in [Reference 2]. This one-time deferral of the physical testing of the post-tensioning system will continue to provide an acceptable level of quality and safety based on projected performance and implementation of physical testing should visual examination results indicate a need for such testing.

While this alternative is based on maintaining an acceptable level of quality and safety, there are additional benefits to deferring physical testing one surveillance cycle. Physical testing requires exposing the involved personnel to industrial safety hazards. Removing the tendon end caps and load testing or detensioning/tensioning the tendons also unnecessarily cycles the tendons and exposes the system to an unseal environment during testing. Below are specific hazards and undesirable conditions that would be eliminated for one surveillance cycle by this proposed alternative:

1. Most tendons are located at heights well above ground level that requires working at heights and the inherent risks associated with such work.
2. This work is often performed from hanging platforms open to outside weather conditions. The platform must be moved to a parked location in order to exit the platform safely.

3. Some areas are located in difficult-to-reach locations that have only one small access point.
4. Requires working with high pressure hydraulics.
5. Requires working in the vicinity of high energy plant systems.
6. Requires working with solvents and hot petroleum products and associated fumes.
7. Requires working with containers and pressurized lines filled with heated corrosion protection medium (grease).
8. Requires working in the vicinity of high levels of store elastic energy in the tendons. Sudden rotation during force measurement has resulted in high speed shim ejection.
9. Handling of heavy loads (test equipment) that also exposes plant equipment to hazards as well as the involved personnel to hazards.
10. While tendon testing is most often not performed in radiation areas, there are occasionally some tendons tested in areas that involve radiation fields.
11. Performing examination/testing on a reduced frequency reduces the repetitive loading required for force measurement or detensioning and retensioning.
12. Eliminating tendon end cap removal would prevent exposing the tendon hardware to environmental conditions.
13. Elimination of tendon end cap removal will reduce environmental waste (e.g., solvents, used grease, other consumables).

6. Proposed Alternative and Basis for Use

Proposed Alternative

In accordance with 10 CFR 50.55a(z)(1), VEGP, Unit 1 & Unit 2 are proposing alternative examination requirements on the basis that these alternative actions will provide an acceptable level of quality and safety.

VEGP, Unit 1 & Unit 2 proposes to perform a General Visual Examination and Detailed Visual Examination (when required) of accessible concrete and exposed steel hardware as required by Section XI Table IWL-2500-1, Item Numbers L1.11 and L1.12, as modified by 10 CFR 50.55a. The examination and physical testing requirements of Section XI Table IWL-2500-1 Item Numbers L2.10, L2.20, L2.30, L2.40, and L2.50 will only be performed if the General Visual Examination and Detailed Visual Examination identify conditions where observations indicate there could be degradation of tendon hardware as documented by the Responsible Engineer in an engineering evaluation. Example conditions that could require removal of the tendon end cap and further examination per Item Numbers L2.10, L2.20, L2.30, L2.40, and L2.50 are:

- Evidence of possible damage to the enclosed post-tensioning hardware as evidenced by conditions such as end cap deformation found during external visual examination. Conditions observed by removal of the end cap would determine the extent of additional examinations per L2.10, L2.20, L2.30, L2.40, or L2.50.
- Active corrosion on a bearing plate or end cap that requires further investigation as determined by the Responsible Engineer in an engineering evaluation.

Evidence of gross leakage of corrosion protection medium will be evaluated and a plan developed for corrective actions as defined in an engineering evaluation documented by the Responsible Engineer.

Physical testing of post-tensioning system examinations will be extended from 10 to 15 years and will be required in 2025 and 2040 for both units.

IWL Post-Tensioning System Examination and Physical Testing Requirements and Justification for Deviation

Enclosure 2 to this document provides a detailed discussion of the historical basis for examination and testing of containment post-tensioning systems. Enclosure 2 also includes the VEGP, Unit 1 & Unit 2 specific observations that provide a basis for deviation from the Section XI examination and testing requirements included in Table IWL-2500-1, Examination Category L-B.

Additional Supporting Actions

ASME Section XI Subsection IWL program at VEGP, Unit 1 & Unit 2 is credited for managing Containment Building degradation. The Examination Category L-A visual examinations (every 5 years) being performed are expected to be capable of identifying conditions that would allow water intrusion into the tendons and gross leakage of CPM (Corrosion Protection Medium) which would be precursors for providing an environment that could allow corrosion of the tendon wires or inaccessible tendon hardware covered by the tendon end cap. Such conditions would be evaluated by the Responsible Engineer to identify required additional actions to assure no corrosive environmental conditions exist. VEPG, Unit 1 & 2 mean prestresses are predicted to be acceptable well beyond the 40th year (Unit 1) / 35th year (Unit 2) surveillance based on acceptable performance over 30 years; therefore, extending the surveillance an additional 5 years will continue to provide an acceptable level of quality and safety.

Summary and Conclusions

The results of the post-tensioning system inservice examinations conducted at VEGP between 1987 to 2015 (Unit 1) and 1989 to 2015 (Unit 2) show that the system is continuing to perform its intended function and that it can be expected to do so until well past the January 2047 (Unit 1) and February 2049 (Unit 2) expiration of the extended operating period license. Visual examination planned for the 35th year (Unit 1) / 30th year (Unit 2) surveillance which will occur in 2020 will be adequate to determine when physical testing and examination per Examination Category L-B is required.

7. Duration of Proposed Alternative

This alternative will remain in effect for the 35th year (Unit 1) / 30th year (Unit 2) surveillance through the remainder the current 4th inservice inspection interval which is scheduled to end on May 30, 2027. The subsequent 40th year (Unit 1) / 35th year (Unit 2) surveillance is projected to occur at August 1, 2025, plus or minus a year, at which time a complete Section XI IWL examination will be performed.

8. Precedents

None

9. References

1) American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code, Section XI, 2007 Edition, 2008 Addenda.
2) Letter dated June 11, 2010, from the NRC to M.J.Ajluni, SNC, granting approval of the proposed alternative, VEGP-ISI-ALT-04, ADAMS Accession No. ML100900129

Vogtle Electric Generating Plant – Unit 1 and 2
<u>Proposed ISI Alternative VEGP ISI-ALT-19-01 for</u>
<u>Tendon Inservice Inspection Extension</u>

Enclosure 2

Containment Post-Tensioning System Inservice Inspection Technical Report

ALVIN W. VOGTLE ELECTRIC GENERATING PLANT UNITS 1 & 2 CONTAINMENT POST-TENSIONING SYSTEM INSERVICE INSPECTION TECHNICAL REPORT BASIS FOR PROPOSED EXTENSION OF EXAMINATION INTERVAL

Report Prepared by:
Howard T. Hill, PhD, P.E. (California Civil Certificate C 22265)
Revision 0, dated December 17, 2018

1. PURPOSE, CONTAINMENT / ISI PROGRAM DESCRIPTION AND ORGANIZATION

This report provides the technical evaluation / justification supporting a request for relief to allow deviation from 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 Vogtle containment ISI program conforms to these regulatory and code requirements with modifications as allowed by approved relief requests.

1.1 Containment Description

The Vogtle containments are 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 containments are designed for an accident pressure of 52 psig.

Each containment consists of a conventionally reinforced concrete flat base mat, a pre-stressed concrete three-buttress cylinder and a prestressed concrete hemispherical dome. The buttresses continue up to the 45° azimuth on the dome. The interior surface is lined with a ¼ inch steel plate for leak tightness. Principal containment dimensions (References 7.3, 7.24 and 7.25) are:

- Cylinder height – 158 ft. 9 in.
- Cylinder / dome inside radius (to the inside face of the steel liner) – 70 ft.
- Cylinder wall / dome concrete thickness (exclusive of the steel liner) – 3 ft. 9 in.
- Base mat thickness – 10 ft. 6 in.
- Equipment opening (the largest wall penetration) diameter – 20 ft.

The cylinder wall and dome are pre-stressed with tendons composed of 55 ASTM A416 (Reference 7.4) Grade 270 twisted strands. Strand nominal diameter is ½ inch and the steel area is 0.153 in^2. The corresponding specified minimum breaking strength of a tendon is 55 * 0.153 in^2 * 270 ksi = 2,272 kip. Strands are secured in tapered holes at the anchor heads with serrated, hardened steel wedges.

The pre-stressing system consists of circumferential (also horizontal or hoop) and inverted U tendon groups. Circumferential tendons anchor at buttresses that extend out from the face of the cylinder wall and dome. Inverted U tendons anchor at the bottom of the base mat; a tunnel (the tendon gallery) below the mat provides access to the tendon anchorages.

The circumferential group is comprised of 168 overlapping hoop tendons, each spanning a nominal 240 degrees. Of these, 141 are located below the dome spring line. The remaining 27 circumferential tendons are located between the spring line and the dome 45° azimuth.

Two sub-groups of inverted U tendons pre-stress the cylinder wall and dome in the meridional direction[1]. The sub-groups, each consisting of 37 tendons, intersect over the dome at 90 degrees in plan.

Containment tendons were initially tensioned to the mean end anchorage seating forces shown in the table below (References 7.5 and 7.6).

Unit	Inverted U Tendons	Cylinder Hoop Tendons	Dome Hoop Tendons
1	1,586 kip	1,605 kip	1,580 kip
2	1,571 kip	1,590 kip	1,592 kip

After tendons were tensioned, the ducts and end anchorage caps were filled with a micro-crystalline wax (Visconorust 2090-P4 supplied by the Viscosity Oil Company) for corrosion protection.

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.

[1] Only the central inverted U tendons are purely meridional. Those away from the center provide a circumferential force component.

Minimum required mean forces, determined by periodic measurements, are, as specified in Reference 7.7:

- Cylinder circumferential tendon minimum required mean force – 1,336 kip
- Dome circumferential tendon minimum required mean force – 1,370 kip
- Inverted U tendon minimum required mean force – 1,405 kip

1.2 Containment ISI Program Summary Description

Continuing structural[2] integrity of the VEGP 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 (References 7.8 and 7.9). The ISI program requires visual examination of the entire containment concrete surface and examination and testing of random samples selected from the tendon population. Surface 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 with the following approved modifications.

- Baseline Date Change

  A common baseline date, 01 August 2010, for system surveillance replaced (Reference 7.9) the separate containment Structural Integrity Test (SIT) baseline dates, 23 Aug 86 for Unit 1 and 14 Nov 88 for Unit 2, as specified in Subsection IWL.

- Visual Examinations and Laboratory Testing of CPM / Free Water

  Visual examinations of tendon end anchorage hardware (requires removal of end caps), laboratory testing of corrosion protection medium (CPM) samples and collection / testing of free water found at end anchorages are currently performed at the IWL mandated 5-year intervals but are scheduled in accordance with the common baseline date. These examinations and tests were performed (both units) in 2010 and 2015; future examinations and tests are currently scheduled for 2020 and every 5 years thereafter.

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

- Tendon Force Measurement and Strand Sample Testing

  Unit 1 and Unit 2 tendon force measurements and strand sample strength / ductility tests[3] are performed at the IWL mandated 10-year intervals. In accordance with the relief request, the Unit 1 and Unit 2 measurements / tests are not staggered (i.e., one unit in 2010 and every 10 years thereafter and the other in 2015 and every 10 years thereafter); Unit 1 and Unit 2 force measurements and Unit 1 strand tests were performed in 2010 and are currently scheduled for 2020 and every 10 years thereafter.

1.3 Report Organization

The remainder of this report consists of the following 7 parts and an appendix.

Part 2 – Summary of Proposed Deviations, Visual Examination Program Enhancements and Conclusions

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

Part 4 – VEGP Examination History and Results Analysis / Evaluation

Part 5 – Overall Summary, Conclusions and Recommendations

Part 6 - Future Examinations, Testing Enhancements and Related Commitments

Part 7 – References

Part 8 – Tables and Figures

Appendix – Normalization Factor / Normalized Force Calculation

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[3] Unit 2 tendons cannot be de-tensioned for strand removal (see Section 4.4). In lieu of testing Unit 2 hoop and inverted U tendon strand samples, another Unit 1 tendon is de-tensioned. A strand removed from this tendon provides the required test samples. This alternative procedure has been followed since Unit 2 tendon forces were first measured in 1991.

2. SUMMARY OF PROPOSED DEVIATIONS, VISUAL EXAMINATION PROGRAM ENHANCEMENTS AND CONCLUSIONS

The following departures from the currently approved ISI program are proposed and evaluated in this report.

- Extend the interval for complete post-tensioning system examinations from 10 to 15 years; perform complete Unit 1 and Unit 2 examinations in 2025 and 2040.
- Eliminate the requirement for intermediate visual examinations of system hardware (along with associated CPM sampling / testing).
- Reduce the requirement for de-tensioning / re-tensioning of tendons, strand removal and strand sample testing to removal / testing of a single hoop tendon strand in 2025; subsequent requirements will be based on the evaluation of the 2025 test results.
- Limit initial corrosion protection medium laboratory tests 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 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. Visual examination of the exposed areas of the containment concrete surface, exposed areas of the tendon bearing plates and tendon end caps will continue to be performed at 5-year intervals in accordance with past practice. Visual examination procedures will be enhanced to ensure that unexpected post-tensioning system problems are identified in a timely manner. Enhancements will include the following.

- Direct visual examination (IWL-2310) of tendon end caps, bearing plates and anchorage area concrete for evidence of damage / deformation, corrosion, cracking and corrosion protection medium leakage will be performed where access to anchorage areas is available (e.g., tendon gallery and buttress areas accessible from roofs, platforms or ladders). Where direct visual examination is not possible, remote examination (IWL-2310) techniques (high power optics and / or drone mounted cameras) will be used.
- If an end anchorage area examination uncovers a condition indicative of possible damage to the enclosed post-tensioning system hardware or an anchor head failure, the end cap will be removed for further examination by the Responsible Engineer (IWL-2330). Additional actions will be taken as specified by the Responsible Engineer (RE).

- If an end anchorage area examination uncovers active corrosion [Reference 7.2, Par. IWL-3221.3(b)] on a bearing plate or end cap, the condition will be evaluated by the RE. Corrective action will be taken as specified by the RE.
- If an end anchorage area examination uncovers concrete cracks that are considered by the RE to have potential structural significance, a detailed visual examination [IWL-2310(b)] of the condition will be performed and further evaluation performed as specified by the RE.
- Examinations will be performed to detect gross leakage of CPM. If observed CPM leakage is considered by the RE to constitute gross leakage, a corrective action plan (e.g., end cap gasket replacement and duct refilling / top-off) will be prepared by the RE and implemented.

This report and the Relief Request that it supports address only proposed departures from the inservice inspection requirements covered by ASME Section XI, Subsection IWL Table IWL-2500-1 Examination Category L-B. The Category L-A concrete surface examinations will continue to be performed in accordance with the current ISI plan (and with the enhancements noted above). Containment liner and penetration assembly inservice inspection requirements specified in Subsection IWE will continue to be implemented in accordance with the current ISI plan.

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 Unit 1 and Unit 2 containment structural integrity 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 7.10) 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.

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

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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.

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, 45 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 VEGP 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 VEGP. The general conclusions regarding post-tensioning system performance are listed below. Conclusions specific to VEGP 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.

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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, only Vogtle is currently operating.

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.

  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

As previously noted, the only operating units in the US that have containments prestressed with stranded tendons are VEGP 1 and 2. The Vogtle plant is, for that reason, the only easily accessible source for strand test data. All other prestressed containments at operating plants have ASTM A421 (Reference 7.11) wire tendons. While the following discussion addresses wire testing, for which there is ample available data, the evaluations and conclusions are equally applicable to strand since the materials, cold drawn carbon steel, used to fabricate both types of tendon are essentially the same

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 7.11) 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. VEGP EXAMINATION HISTORY AND RESULTS ANALYSIS / EVALUATION

The visual examination results and test data used in the development of Sections 4.1 through 4.5 are those documented in VEGP inservice inspection reports, References 7.12 through 7.19.

VEGP has completed, to date, 8 surveillances of the Unit 1 post-tensioning system and 7 surveillances of the Unit 2 system. These examinations were conducted in accordance with Regulatory Guide 1.35, Revision 2 or 10CFR50.55a / ASME Section XI Subsection IWL. The 1991 and subsequent surveillance programs incorporate approved modifications to the cited governing documents.

Calendar Year	IWL Year Unit 1	IWL Year Unit 2	Governing Document(s)
1987	1	N/A	Reg Guide 1.35
1989	3	1	Reg Guide 1.35
1991	5	3	Reg Guide 1.35
1995	10	5	Reg Guide 1.35
2000	15	10	10CFR50.55a / IWL
2005	20	15	10CFR50.55a / IWL
2010	25	20	10CFR50.55a / IWL
2015	30	25	10CFR50.55a / IWL

The following subsections, 4.1 through 4.5, of this report provide a comprehensive evaluation of VEGP post-tensioning system examination results documented in the applicable surveillance reports. Subsection 4.1 develops the time base used in evaluating the performance of the containment post-tensioning system. It also clarifies the differences between the several schemes used to identify a particular surveillance. The remaining subsections address the following aspects of examination results acquired during the surveillances performed over the 1987 – 2015 period.

Subsection 4.2 – Tendon force trends and forecasts

- Unit 1 and Unit 2 cylinder hoop tendon force trends and forecasts
- Unit 1 and Unit 2 dome hoop tendon force trends and forecasts
- Unit 1 and Unit 2 inverted U tendon force trends and forecasts

Subsection 4.3 –End anchorage condition

Subsection 4.4 – Extracted strand condition and mechanical properties

Subsection 4.5 – Corrosion protection medium chemical properties and free water analysis

The proposed extension of the tendon examination interval to 15 years is justified if the extension can be separately justified for each of the 4 post-tensioning system performance categories listed above.

4.1 Time Base and Surveillance Classification

The common time base, or benchmark date, for evaluating Unit 1 and Unit 2 post-tensioning system performance and the surveillance classification schemes are covered in 4.1.1 and 4.1.2 below.

4.1.1 Benchmark Date

Subsection IWL uses the containment structural integrity test (SIT) date[8] as the reference date for examinations (surveillances) and specifies that these be performed 1, 3 and 5 years following the SIT and every 5 years thereafter. It also specifies that the first 3 surveillances be performed within a 1 year window centered on the SIT anniversary date and that subsequent examinations be performed within a 2 year window, also centered on the SIT anniversary date.

The SIT date serves as a good benchmark for a single unit site and, for a two-unit or multi-unit site if there is a significant time lag between completion of the individual containment structures. The VEGP Unit 1 and 2 SIT dates, 23 August 1986 (Reference 7.20) and 14 November 1988 (Reference 7.21), respectively, are separated by almost 28 months. Construction pre-stressing operation completion dates, 26 April 1986 and 3 Dec 1986 (Reference 7.7), are separated by just over 7 months.

The condition of the post-tensioning system is determined to a great extent by the time since its completion. As much of this report addresses time-dependent changes in the condition of the post-tensioning system, it is reasonable to use a common benchmark date for the 2 units if system completion dates are not widely separated.

A date of 15 August 1986 is used in this report as a common benchmark date for evaluating the condition of the Unit 1 and Unit 2 post-tensioning systems. This date is 3.6 months after the completion of the Unit 1 system and 3.6 months prior to completion of the Unit 2 system. The most recent surveillance that included tendon force measurements and tendon strand mechanical property tests was performed during October, November and December of 2010 (Reference 7.18) or approximately 24 years after the benchmark date. The 3.6 month interval between system completion and the benchmark date is only a small fraction (about 1.3%) of the interval between system

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[8] Treated as the date when peak SIT pressure was attained.

completion and the 2010 surveillance. Therefore, it is concluded that the 15 August 1986 benchmark date serves as a reasonable common date for assessing the time-dependent performance of units.

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

The value of T assigned to each surveillance is computed, as shown below, as the time from T_0 (15 August 1986) to the approximate mid-point of the surveillance. The surveillance mid-point is a date (rounded to the middle or end of the month) midway between the surveillance starting and ending dates as documented in the applicable surveillance report (References 7.12 through 7.19). The 1995 and 2015 surveillance reports show the starting and ending dates as month and day. The remaining reports only indicate starting and ending month; in these cases, mid-month is assumed for the purpose of computing T.

Surveillance Calendar Year	Surveillance Start Date	Surveillance End Date	Appx. Mid-Point (Rounded)	T, Years
1987	Sep 87	Dec 87	31 Oct 87	1.2
1989	Sep 89	Nov 89	15 Oct 89	3.2
1991	Sep 91	Oct 91	30 Sep 91	5.1
1995	27 Jun 95	17 Aug 95	15 Jul 95	8.9
2000	May 00	Jul 00	15 Jun 00	13.8
2005	Jun 05	Sep 05	31 Jul 05	18.9
2010	Oct 10	Dec 10	15 Nov 10	24.2
2015	11 Nov 15	30 Dec 15	30 Nov 15	29.3

4.1.2 Surveillance Classification Schemes

Surveillances are variously identified by sequence number, IWL year, actual year of performance and time since the benchmark date. The table on the following page shows the correspondence between these surveillance identification schemes and also identifies, for each surveillance, the examinations / tests performed at each of the units.

VEGP Units 1 & 2 – Containment Post-Tensioning System Inservice Inspection (Tendon Surveillance) Classification							
Calendar Year	**T, Time Since T_0, Years[2]**	**Unit 1[1]**			**Unit 2[1]**		
		Consecutive Surveillance Number	**IWL Surveillance Year[3]**	**Tendon Force Measurement**	**Consecutive Surveillance Number**	**IWL Surveillance Year**	**Tendon Force Measurement**
1987	1.2	1	1	Yes	N/A	N/A	N/A
1989	3.2	2	3	Yes	1	1	No
1991	5.1	3	5	No[1]	2	3	Yes
1995	8.9	4	10	No[1]	3	5	Yes
2000	13.8	5	15	Yes	4	10	No
2005	18.9	6	20	No[1]	5	15	Yes
2010	24.2	7	25	Yes	6	20	Yes
2015	29.3	8	30	No	7	25	No

Note 1: All surveillances include end anchorage (including concrete surrounding bearing plates) visual examinations, examinations for free water and collection / analysis of corrosion protection medium samples. Surveillances that include Unit 1 tendon force measurements also include removal and testing of a strand extracted from one hoop and one inverted U tendon. Surveillances that include Unit 2 tendon force measurements also include removal and testing of a strand from a single Unit 1 tendon (see later discussion for details). Force in this tendon is measured and documented.

Note 2: Time T_0 is 15 August 1986, a date approximately midway between the 26 April 86 and 03 Dec 86 completion of Unit 1 & Unit 2, respectively, construction prestressing operations. Time T is equal to 0 at T_0 and is computed for the approximate midpoint of the applicable surveillance. See discussion in above text.

Note 3: ASME Section XI, Subsection IWL specifies surveillances at 1, 3, and 5 years following the containment SIT and every 5 years thereafter. See discussion in the above text.

4.2 Tendon Force Trends and Forecasts

[Note: To ensure a distinction between Unit 1 and Unit 2 tendons in this report, the unit number is added before the tendon designator. Also, for clarity, hoop, or horizontal, tendons are designated by the letter 'H' and inverted U tendons by the letter 'U'. For example, Unit 2 hoop tendon 99 and Unit 1 inverted U tendon 18-94 are identified as 2H-99 and 1U18-94, respectively.]

Forces in designated sample tendons and additional Unit 1 tendons, designated in lieu of Unit 2 tendons for strand extraction, were measured during each examination. Measured force trends and forecasts provide ample evidence that mean pre-stressing in the containment cylinder and dome will remain above the lower limits specified in Gen-100 (Reference 7.7) until well after the expiration of the Unit 1 and Unit 2 extended operating licenses (2047 and 2049, respectively). Cylinder hoop, dome hoop and inverted U tendon force trends and forecasts are presented and discussed in 4.2.1, 4.2.2 and 4.2.3 below.

Tendon force trends and forecasts are determined for both measured and normalized forces[9] to ensure completeness of the presentation. Normalizing is a calculational process applied to account for variations in initial lock-off force and for the elastic shortening losses that result from sequential tensioning. Normalized forces are generally used only to make group means computed for small samples more representative of population means. In theory, normalizing should greatly reduce the scatter of tendon force data. But, as is subsequently shown, reduction, if any, is generally modest.

Forces documented for each examination are listed in Tables 2 through 7 and plotted in Figures 1 through 14. Separate tables and figures were prepared for each unit and each group of tenons. Three separate plots, as discussed below, are provided for the cylinder hoop and inverted U tendon groups. Due to the limited number of dome hoop tendons examined, these are covered by a single plot for each unit.

The first of the three plots shows measured and normalized forces documented for each of the surveillances and the log-linear trend lines (which represents expected group means) fitted to these by the method of least squares, as developed in Reference 7.22, and extrapolated to T (years since T_0) = 100. As discussed above, normalization should greatly reduce scatter. But, considerable scatter is also evident in the normalized force plots. This is a common phenomenon, probably due to variations in actual initial force (at the completion of tensioning operations) resulting from the greatly simplified normalizing process as well as thermal and other effects not accounted for in the computation of normalizing factors.

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[9] Normalized forces are computed as described, and are tabulated, in the Appendix.

The second shows measured forces, the measured force trend line and the 95% lower confidence limit (LCL) on mean force. The LCL, computed using the expressions developed in Reference 7.22, serves as a statistical lower bound on mean force; true mean force has a statistically computed probability (in the present case, 95%) of lying above the computed LCL value. Both the trend line and LCL are extrapolated to T = 100 years.

The third plot shows only common tendon[10] measured forces with a log-linear trend line. In both cases (hoop and inverted U) common tendon plots exhibit relatively little scatter. Such scatter as there is can be attributed to limitations on measurement accuracy and the effect of end anchorage temperature on lift-off force.

Dome hoop tendon plots show only measured and normalized forces with associated trend lines. As the number of dome hoop forces measured is quite small, a calculated LCL would not be meaningful and is not shown. Also, there are no common dome hoop tendons.

4.2.1 Unit 1

Cylinder hoop, dome hoop and inverted U tendon trends and forecasts are separately addressed below.

4.2.1.1 Cylinder Hoop Tendon Trends and Forecast

Measured and normalized cylinder hoop tendon forces are listed in Table 2 and plotted on Figure 1. Both the measured and normalized forces are scattered but are well above the 1,336 kip lower limit and, at least from T = 3.2, do not appear to be trending down at a significant rate. The fitted trend lines, which include the T = 1.2 data, are close together and cross the T = 100 ordinate at F_{HC} = ~1,490 kip. The measured forces, normalized forces and the associated trends all show that mean cylinder hoop prestressing force will remain above the 1,336 kip lower limit by a large margin throughout the operating lifetime of the unit. Measured and normalized trend slopes are (-)62.2 and (-)45.8, respectively, kip per unit logarithmic interval.

Measured forces, the measured force trend and the computed 95% LCL on mean force are shown on Figure 2. The 95% LCL curve crosses the T = 100 ordinate at 1,450 kip or, 114 kip above the lower limit.

[10] One cylinder hoop tendon and one inverted U tendon in each containment were designated as common tendons prior to the first surveillance, and are examined during each surveillance as specified in Regulatory Guide 1.35 and Subsection IWL. The remaining tendons in a surveillance sample are selected at random from a population that excludes those previously examined. Common tendons are not de-tensioned for strand removal.

Figure 3 is a plot of Unit 1 cylinder hoop common tendon 1H-83 measured forces and log-linear trend. There is relatively little data scatter, as would be expected. The slope of the common tendon trend is (-)61.3 kip per unit logarithmic interval which is quite close to that computed for the mean using all measured force data and shown in Figures 1 & 2.

4.2.1.2 Dome Hoop Tendon Trends and Forecast

Measured and normalized dome hoop tendon forces are listed in Table 3 and plotted on Figure 4. The plot shows relatively little scatter. Forces are well above the 1,370 kip lower limit and, at least from T = 3.2, do not appear to be trending down at a significant rate. The fitted trend lines, which include the T = 1.2, data are close together and cross the T = 100 ordinate at F_{HD} values of ~1,480 and ~1,460 kip, respectively. The measured forces, normalized forces and the associated trends all show that mean dome hoop prestressing force will remain above the 1,370 kip lower limit by a large margin throughout the operating lifetime of the unit. Measured and normalized trend slopes are (-)49.7 and (-)63.9, respectively, kip per unit logarithmic interval. These slopes are in the same range as those computed for the cylinder hoop tendon trend lines.

As the number, 5, of tendon force data points is insufficient to yield a meaningful LCL curve, the LCL is not plotted. Also, as noted above, there is no common dome hoop tendon.

4.2.1.3 Inverted U Tendon Trends and Forecast

Measured and normalized inverted U tendon forces are listed in Table 4 and plotted on Figure 5. Both the measured and normalized forces are scattered (the latter are less so) but are well above the 1,405 kip lower limit and, at least from T = 3.2, do not appear to be trending down at a significant rate. The fitted trend lines, which include the T = 1.2 data, are close together and cross the T = 100 ordinate at F_U = ~1,495 kip. The measured forces, normalized forces and the associated trends all show that mean inverted U prestressing force will remain above the 1,405 kip lower limit by a large margin throughout the operating lifetime of the unit. Measured and normalized trend slopes are (-)25.0 and (-)33.6, respectively, kip per unit logarithmic interval.

Measured forces, the measured force trend and the computed 95% LCL on mean force are shown on Figure 6. The 95% LCL curve crosses the T = 100 ordinate at ~1,447 kip or, 42 kip above the lower limit.

Figure 7 is a plot of Unit 1 inverted U common tendon 1U18-94 measured forces and log-linear trend. There is relatively little data scatter, as would be expected. The slope of the common tendon trend is (-)19.4 kip per unit logarithmic interval. This is quite close to the (-)25.0 kip per unit logarithmic interval computed for the mean using all measured force data and shown in Figures 5 & 6.

4.2.2 Unit 2

Cylinder hoop, dome hoop and inverted U tendon trends and forecasts are separately addressed below.

4.2.2.1 Cylinder Hoop Tendon Trends and Forecast

Measured and normalized cylinder hoop tendon forces are listed in Table 5 and plotted on Figure 8. Both the measured and normalized forces are scattered but are well above the 1,336 kip lower limit. The fitted trend lines are close together and cross the T = 100 ordinate at F_{HC} = ~1,460 kip. The measured forces, normalized forces and the associated trends all show that mean cylinder hoop prestressing force will remain above the 1,336 kip lower limit by a large margin throughout the operating lifetime of the unit. Measured and normalized trend slopes are (-)17.0 and (-)21.2, respectively, kip per unit logarithmic interval.

The above computed slopes are significantly more shallow than those shown for Unit 1 tendon forces in Figure 1. This is expected since there is no Unit 2 force data for T = 1.2 and T = 3.2 years (Unit 2 tendon forces were not measured during the 1987 and 1989 surveillances); i.e., for the early years following prestressing when the rate of force loss is greater than it is during later years, as discussed in 3.4.1.

Measured forces, the measured force trend and the computed 95% LCL on mean force are shown on Figure 9. The 95% LCL curve crosses the T = 100 ordinate at ~1,414 kip or, 78 kip above the lower limit. This LCL curve diverges more from the trend line than does the corresponding Unit 1 LCL curve. This is a consequence of having less data, but data with a similar degree of scatter, for Unit 2.

Figure 10 is a plot of Unit 2 cylinder hoop common tendon 2H-99 measured forces and log-linear trend. There is relatively little data scatter, as would be expected. The slope of the common tendon trend is positive, (+)8.9 kip per unit logarithmic interval. As the trend is almost flat, a relatively minor adjustment to the scatter of the force data can easily result in a small negative slope. For example, if the trend is re-computed for the rightmost 3 force data points (T = 8.9, 18.9 & 24.2 years), which cover 80% of the linear interval between 5.1 and 24.2 years, the slope changes to (-)18.1 kips per unit logarithmic interval. This is quite close to the (-)17.0 slope of the trend line fitted to all data and shown in Figures 8 and 9.

Close correspondence between the slope of the trend line fitted to all measured forces and that fitted to the low scatter common tendon forces supports the conclusion that the former is a valid measure of the mean prestressing force trend.

4.2.2.2 Dome Hoop Tendon Trends and Forecast

Measured and normalized dome hoop tendon forces are listed in Table 6 and plotted on Figure 11. The plot shows relatively little scatter but as there are only four data points, the trend lines can be easily dominated by minor variations in the ordinate of a single point. All forces are above the 1,370 kip lower limit. The fitted trend lines are widely divergent with slopes of (-)99.8 and (-)35.1 kips per unit logarithmic interval computed for the measured and normalized forces, respectively. These cross the T = 100 year ordinate at F_{HD} values of ~1,375 and ~1,456 kip, respectively. The measured forces, normalized forces and the associated trends all show dome hoop prestressing force remaining above the 1,370 kip lower limit throughout the operating lifetime of the unit.

As the number, 4, of force data points is insufficient to yield a meaningful LCL curve, the LCL is not plotted. Also, as noted above, there is no common dome hoop tendon.

4.2.2.3 Inverted U Tendon Trends and Forecast

Measured and normalized inverted U forces are listed in Table 7 and plotted on Figure 12. Both the measured and normalized forces are scattered (the latter are less so) but are above the 1,405 kip lower limit. The fitted trend lines, which are somewhat divergent, both show force increasing with time. This is expected given the appearance of the tendon force data. Slopes of the measured and normalized force trend lines are (+)71.7 and (+)48.0, respectively, kips per unit logarithmic interval. As there is no reasonable scenario under which tendon force can increase over time, it is concluded that the true trend is essentially flat and that the computed trend lines represent the effect of data scatter (a consequence of variations in sample tendon initial seating force, temperature during the surveillance, measurement accuracy and, possibly, other variable factors) rather than actual mean prestressing force[11].

Measured forces, the measured force trend and the computed 95% LCL on mean force are shown on Figure 13. The 95% LCL curve is effectively flat from T = 24.2 years to T = 100 years which supports the conclusion stated in the previous paragraph. It crosses the T = 100 ordinate at ~1,477 kip or, 72 kip above the lower limit.

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[11] While the computed positive trends are not meaningful, these are not, in any event, a concern since both cross the T = 100 year ordinate at a prestress level below that applied during construction.

Figure 14 is a plot of inverted U common tendon 2U20-92 measured forces and the log-linear trend. There is relatively little data scatter about the trend line, as would be expected for a common tendon. However, the computed slope of the trend is a positive (+)58.2 kips per unit logarithmic interval, a result that is, as previously noted, inconsistent with any reasonable scenario of structural behavior.

While the common tendon data scatter appears to be minimal, an error in measuring or recording the first data point (1,408 kip at T = 5.1 years) could have a major effect on the slope of the trend without having much apparent impact on the degree of scatter. The plots on Figures 12 and 13 provide some evidence that this force measurement could be an outlier (it is well below all of the other measured forces). If it is treated as such and eliminated from the trend computation, the slope of the line fitted to the remaining three data points is (-)1.5 kip per unit logarithmic interval. This is an essentially flat trend and consistent with the flat trend of the LCL values plotted on Figure 13. The trend of force in this tendon will be re-computed and evaluated again when data acquired during the during the next surveillance becomes available.

4.2.3 Unit 1 and Unit 2 Comparison

There appears to be a significant difference in the rates at which Unit 1 and Unit 2 tendon forces are changing over time. The computed slopes of the cylinder hoop and inverted U[12] tendon measured / normalized force trend lines, which are tabulated below, confirm this observation.

Unit	Computed Trend Line Slope, kips per Unit Logarithmic Interval	
	Cylinder Hoop Tendons Measured / Normalized	Inverted U Tendons Measured / Normalized
1	(-)62.9 / (-)46.3	(-)25.4 / (-)34.1
2	(-)17.0 / (-)21.2	(+)71.7 / (+)48.0

As previously noted, Unit 2 tendon forces were first measured during the 1991 surveillance, about 5 years following completion of construction prestressing operations. Unit 1 tendon forces were first measured in measured in 1987, only 1 year after prestressing operations were completed. The slopes of the Unit 1 trend lines reflect the more rapid decrease of tendon force during the first few years under load. As a consequence, the Unit 1 trends are expected to show a greater average rate of loss. The trends will be re-computed and evaluated when the results of next surveillance are available.

[12] Comparisons of dome hoop trends is not considered meaningful since these trends are based on a very small number of force values (5 and 4 for Unit 1 and Unit 2, respectively).

As discussed above, the Unit 2 inverted U tendon forces appear to be increasing over time. Since this cannot be explained by any reasonable scenario, it is concluded that the computed trends are a consequence of data scatter caused by the variations in tendon initial seating force as well as variable factors not otherwise accounted for. Again, the trends will be re-computed evaluated when the results of the next surveillance are available.

4.2.4 Tendon Mean Force Trend Summary and Conclusions

The trend of the mean force was evaluated separately for the Unit 1 and Unit 2 containments and for each of the tendon groups (cylinder hoop, dome hoop and inverted U). In all cases projected mean prestressing force remains above the applicable lower limit through T = 100 (year 2086) or almost 40 years after the expiration of the Unit 1 and Unit 2 extended operating licenses (2047 and 2049, respectively). And, in all cases, the evaluation shows that mean prestressing force will remain well above the applicable lower limit through 01 August 2026 (T = 40.0), the latest date for completion of the next surveillance under the proposed 15-year interval.

The following table, which uses data from the plots on Figures 1 -14, summarizes, for each unit, the projected mean tendon force and margin above the lower limit for each of the tendon groups. Margin at T = 40 years and at T = 100 years is calculated for the measured force trend, the normalized force trend and, for the cylinder hoop and inverted U tendon groups, at the 95% LCL. The LCL is not computed for the dome hoop group as discussed above

Unit	Group / Mean Force Lower Limit	Trend	Projected Mean / Margin Above Lower Limit, kip	
			T = 40	T = 100
1	Cylinder Hoop / 1,336 kip	Measured	1,512 / 176	1,487 / 151
		Normalized	1,510 / 174	1,491 / 155
		Measured LCL	1,484 / 148	1,450 / 114
	Dome Hoop / 1,370 kip	Measured	1,498 / 128	1,478 / 108
		Normalized	1,486 / 116	1,461 / 91
	Inverted U / 1,405 kip	Measured	1,505 / 100	1,495 / 90
		Normalized	1,507 / 102	1,493 / 88
		Measured LCL	1,470 / 65	1,447 / 42

Unit	Group / Mean Force Lower Limit	Trend	Projected Mean / Margin Above Lower Limit, kip	
			T = 40	T = 100
2	Cylinder Hoop / 1,336 kip	Measured	1,467 / 131	1,460 / 124
		Normalized	1,467 / 131	1,458 / 122
		Measured LCL	1,438 / 102	1,415 / 79
	Dome Hoop / 1,370 kip	Measured	1,415 / 45	1,375 / 5
		Normalized	1,470 / 100	1,456 / 86
	Inverted U / 1,405 kip	Measured	1,522 / 117	1,551 / 146
		Normalized	1,522 / 117	1,541 / 136
		Measured LCL	1,477 / 72	1,477 / 72

The foregoing evaluations of tendon force trends as well as the margins tabulated above show that group mean prestressing forces will remain well above the minimum required levels through 2026 and will not fall below those levels at any time before 2086 (T = 100).

This supports the conclusion that the post-tensioning system surveillance should be extended to 15 years, with the next surveillance to be completed by the end of July 2026. As is currently done (and as mandated in 10CFR50.55a), the trends of group mean prestressing forces will be re-computed and evaluated at that time to confirm that the mean values will remain above the applicable minimums until the latest date (July 2041) for completion of the subsequent surveillance.

4.3 End Anchorage Condition

During each of the surveillances, end anchorage areas were visually examined for evidence of corrosion, presence of free water, broken strands, 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.

4.3.1 Corrosion

No active corrosion was observed on bearing plates (these are galvanized), anchor heads, wedges, shims, strand tails, or extracted strands. Observed corrosion was limited to category 2 or, alternatively, category B, generally defined as light rust removable with a few passes of fine grit emery cloth. Anchor heads, shims and strand were found to be well coated with CPM and, with the exception noted in 4.3.2 below, dry. Consequently, it is concluded that corrosion found on these items occurred during fabrication, transport or storage or otherwise prior to the time that the tendon duct and end anchorage areas were filled with CPM.

4.3.2 Free Water

Except as discussed below, no free water was found in tendon end caps, on tendon end anchorage hardware or on extracted strands during any of the 8 surveillances.

The sole instance of free water is documented in the 1987 surveillance report. Approximately 0.1 l (3 oz.) of water was found at the 1H-14 buttress 2 end anchorage. The end cap plug was missing (it was replaced during the surveillance), apparently since original construction, which provided an opening for rain runoff to enter the end cap. No corrosion was found after the anchorage hardware had been cleaned of its CPM coating.

The 1987 surveillance report does not indicate the water was analyzed to determine pH. The reported absorbed water content of the 1H-14 buttress 2 anchorage CPM sample is 0.59%. While this is the largest of the values listed for any of the 1987 surveillance samples, it is only marginally greater than the 2nd largest value of 0.47% documented for the 1H-49 buttress 1 anchorage (no free water found) sample.

The water found at the buttress 2 end of 1H-14 is considered to be the result of a singular event and not indicative of a more widespread condition.

4.3.3 Broken / Protruding Strand

Only 3 broken / protruding strands, as noted below, were found during the 8 surveillances.

- 1987 Surveillance – One 1U58-128 strand was found (presumably following de-tensioning of the tendon; the report does not state this) to be ~13 inches longer than the remaining 54. This would have been consistent with the strand slipping through unseated wedges during initial tensioning and being subsequently cut to the same length as the fully tensioned strands. The strand was verified to be properly seated during re-tensioning and cut to length when re-tensioning was completed.
- 2000 Surveillance – Two broken strands were detected during re-tensioning of tendon 1U70-116. The tendon was de-tensioned and the broken strands removed for testing. The breaks were close together, ~177 ft. from the anchorage 116 end and ~344 ft. from the anchorage 70 end. The report does not provide a detailed description of the breaks but does state that these must have been the result of damage done to the strands prior to or during installation in the duct.

Samples cut from either side of both breaks were tested for tensile strength and elongation at failure. All four samples met the minimum requirements for strength and elongation as documented in Section 4.4 below.

4.3.4 Load Bearing Components Damage / Distortion

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

4.3.5 Concrete Cracking Adjacent to Bearing Plates

Concrete extending out 24 inches from the edges of hoop tendon bearing plates was visually examined for cracking. There is no exposed concrete adjacent to inverted U tendon anchorages; the entire tendon gallery ceiling is steel plate which served as the bottom form during concrete placement. Cracks exceeding 0.01 inches in width are recorded and require evaluation for structural significance. Several such cracks, as noted below, were found over the course of the surveillance program.

- 1995 Surveillance – A 'V' shaped crack ~30 inches long with a maximum width of 0.10 inches was found near the side of the 1H-153 (a dome hoop tendon) buttress 2 bearing plate. The crack does not radiate out from the bearing plate. Also, it is not in an area of the concrete subject to a significant level of stress level resulting from expansion forces (generated by the conical wedge below the bearing plate) and is otherwise too short to have any structural significance.
- 2000 Surveillance – One crack ~13 inches long with a maximum width of 0.03 inches was found extending almost vertically up from the top right (outside face) corner of the 1H-13 buttress 3 bearing plate. The crack does not extend to the outside face of the buttress. As there are no other cracks shown on the examination data sheet to be radiating from the bearing plate corners, it is highly unlikely that the observed crack is due to expansion forces. Based on the short length of the crack, its orientation (almost vertical) and the lack of additional cracks in the area, it is concluded that the observed condition has no structural significance.
- 2010 Surveillance – Two cracks, one 9 inches long with a maximum width of 0.020 inches and the other 10.5 inches long with a maximum width of 0.035 inches were found adjacent to the outside vertical edge of the 2H-99 buttress 3 bearing plate. Both extend to the outside face of the buttress but do not continue on the outside face. These are joined by a narrower crack. Neither crack originates at a corner of the bearing plate. Based on the limited extent of the cracks and pattern, it is concluded that theses have no structural significance. These cracks are addressed in NCR #

FN1062-003 (included in the 2010 surveillance report, Reference 7.18) and were accepted by engineering evaluation as documented therein.

- 2015 Surveillance – One crack, 10 inches long with a maximum width of 0.030 inches was found extending almost vertically down from the lower right-hand corner of the 2H-99 buttress 3 bearing plate to a construction joint. The crack does not cross the joint. A second crack with a width <0.010 inches joins the upper right-hand corner of the plate with the lower corner of that above. The limited extent and orientation of the crack suggest that it has no structural significance. This crack is addressed in NCR # FN1115-005 (included in the 2015 surveillance report, Reference 7.19) and was accepted by engineering evaluation as documented therein.

As noted, none of the cracks described above is considered to have structural significance. Also, there is nothing about the nature of the cracks above to suggest that these are service or age-related. Therefore, it is concluded that the cracks probably resulted from something that occurred during construction (e.g., minor movement of the formwork during the early stages of curing). It is also possible that the widths increased due to later shrinkage.

4.3.6 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 2015) and show no trends of deteriorating condition.

There have been no findings of active corrosion on bearing plates, anchor heads, wedges, shims or strand. Inactive corrosion is limited to category 2 (minor light rust).
No free water has been found in end caps, on anchor heads, on wedges, on shims or on strand with the unique exception of that found during the 1987 surveillance at the buttress 2 anchorage of 1H-14 as discussed in 4.3.2 above. The reason for the water intrusion, a missing plug, into the end cap was immediately apparent. No corrosion was found on the system hardware enclosed by the cap.

Only 2 discontinuous strands have been found, both in the same tendon. As the breaks were at essentially the same location along the tendon length, these were concluded to have been the result of strand damage that occurred prior to or during original installation. The 2 broken strands represent only a minuscule fraction of the ~13,300 strands (242 tendons comprised of 55 strands) that provide the prestressing force in each of the containments. One protruding strand was found. The strand was determined to be continuous with the protrusion probably resulting from a failure of the wedges to seat during original tensioning.

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

Several concrete cracks with maximum widths exceeding the threshold of 0.010 inch were found over the course of the surveillance program. None of these is considered to have structural significance. Also, and none is considered to be service or age-related but, rather, a probable minor construction defect, possibly enlarged by later shrinkage of the surrounding concrete.

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.

This supports the conclusion that the post-tensioning system surveillance should be extended to 15 years, with the next surveillance to be completed by the end of July 2026. Conditions will be thoroughly evaluated at that time to confirm that these continue to provide evidence of ongoing stability.

4.4 Strand Examination and Test Results Evaluation

During each of the containment examination periods from 1987 through 2010 (T = 1.2 years through T = 24.2 years) strands were extracted from designated Unit 1 tendons for visual examination and mechanical property testing.

As previously discussed in this report, containment post-tensioning system examinations were performed in accordance with the following alternating schedule.

Year / T	Unit 1 Examinations / Tests	Unit 2 Examinations / Tests
1987 / 1.2	Visual / CPM / Tendon Force	N/A
1989 / 3.2	Visual / CPM / Tendon Force	Visual / CPM
1991 / 5.1	Visual / CPM	Visual / CPM / Tendon Force
1995 / 8.9	Visual / CPM	Visual / CPM / Tendon Force
2000 / 13.8	Visual / CPM / Tendon Force	Visual / CPM
2005 / 18.9	Visual / CPM	Visual / CPM / Tendon Force
2010 / 24.2	Visual / CPM / Tendon Force	Visual / CPM / Tendon Force
2015 / 29.3	Visual / CPM	Visual / CPM

Unit 1 tendon force measurements were specified for the 1987, 1989, 2000 and 2010 surveillances. During each of these, a strand was extracted from one hoop tendon and one inverted U tendon. In addition, 2 broken strands were extracted from tendon 1U70-116 during the 2000 surveillance.

Unit 2 tendon force measurements were specified for the 1991, 1995, 2005 and 2010 surveillances. The Unit 2 design does not allow for tendon de-tensioning and strand extraction[13]. Therefore, the Unit 2 surveillance procedure requires, as an alternative, removal of a strand from a single Unit 1 tendon alternately selected from the hoop and inverted U groups. This extracted strand serves in lieu of a Unit 2 strand. The strands extracted from the Unit 1 hoop and inverted U tendons during the 2010 surveillance served this purpose; there was no need to de-tension an additional Unit 1 tendon.

Each extracted strand was visually examined and tested to determine mechanical properties. Results of these examinations and tests are discussed in 4.4.1 and 4.4.2 below.

4.4.1 Strand Visual Examination and Condition Evaluation

The entire length of each extracted strand was visually examined for signs of physical damage, corrosion and any other indications of degradation.

A corrosion level of G, or Good, which is one Level below E, or Excellent, was reported for the two strands extracted during the 1987 surveillance. As the strand examination data sheets included in the surveillance report do not document any areas of observed corrosion along the lengths of the two strands, it is reasonable to conclude that no rust was found and that the G level may have been assigned as a result of the normal coloration of the wires making up the strand.

All strands extracted during subsequent surveillances were reported as having no visible corrosion (also noted as Level E, Level 1 or bright metal).

No physical damage (but, see discussion of the two broken 1U70-116 strands found during the 2000 surveillance) or other indication of degradation was reported for any of the 13 strands extracted during the seven surveillances conducted between 1987 and 2010. As noted above, tendon force was not monitored during the 2015 surveillance; therefore, no tendons were de-tensioned for strand extraction at that time.

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[13] Designated Unit 1 tendons are provided with shims between the anchor heads and bearing plates. These shims can be removed to de-tension the tendon. Unit 2 anchor heads are all in direct contact with the bearing plates and the strand tails extending beyond the anchor heads are too short to accommodate de-tensioning.

4.4.2 Wire Tensile Strength

Test specimens were cut from both ends and the middle of each designated test strand. Broken strand test specimens were cut from the segments on both sides of the break. All specimens were tested to determine tensile strength and elongation at failure, a quantitative measure of ductility.

Results of tensile strength tests are listed in Table 8 and illustrated graphically on Figures 15 and 16. The table and figures include, in addition to the results of the required tests, the tensile strengths reported for specimens cut from the two 1U70-116 broken strands.

Figure 15 includes a trend line that indicates a possible slow decrease in tensile strength with time. This trend is inconsistent with the expectation for ASTM A4146 strand (mechanical properties at reasonably low temperatures should be essentially invariant) and probably results more from differences in testing laboratory procedures, test equipment and technician experience than any actual long-term decrease in strength. And, as discussed in Part 3 of this report, tendon wire[14] test results often show large fluctuations, both positive and negative, from surveillance to surveillance. These fluctuations are concluded to be the result of testing practice rather than erratic variations in the mechanical properties of the wire.

Figure 16 is a truncated plot showing wire test results documented for the 1995 through 2010 surveillances. The trend of the data is essentially flat (~2.6 ksi loss per unit logarithmic interval) which is consistent with the expectation for the ASTM A416 strand.

Strength values shown on Figure 15 for the 1991 and 2005 (T = 5.1 years and 18.9 years respectively) surveillances have the characteristics that are expected for tests performed in strict accordance with ASTM A1061 (Reference 7.23) as specified in ASTM A416. These are:

- Values shown for the 3 specimens cut from a given strand are tightly grouped.
- The mean value for each strand is greater than, but close to the specified minimum of 270 ksi.
- There is no apparent change in the mean over the interval, almost 14 years, between the two sets of tests.

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[14] As noted in Table 1, VEGP is the only operating US plant with stranded containment tendons. All other US prestressed containments use wire tendons. These are made up of 90 to 186 straight (wire tendons have a small degree of twist to equalize stress in curved ductwork), parallel ¼ inch wires secured at the anchor heads by cold formed button heads. The wire, which conforms to ASTM A421, has a required minimum tensile strength of 240 ksi.

For the above reasons, it is concluded that the ongoing tensile strength of the ASTM A416 strand, as demonstrated by the 1991 and 2005 examination year tests, will remain above the specified 270 ksi minimum throughout the operating lifetimes of VEGP Units 1 & 2. Therefore, it seems reasonable to eliminate strand testing, with the attendant need to subject the affected tendons to a full cycle of loading to 80% of ultimate strength, from future surveillances.

The trend line shown on Figure 15, while not considered to represent actual strand strength, crosses the 270 ksi ordinate at T = ~75 years (mid-2061), about 12 years after the expiration of the Unit 2 extended operating license.

However, given the trend plotted on Figure 15, it is recommended that strand testing be done during the next surveillance but be limited to samples cut from a single hoop tendon strand. This testing must be done by a laboratory experienced in performing such tests using equipment that meets all applicable ASTM requirements. If the results of these tests confirm the expectation that strand strength is not decreasing with time, no future testing should be required.

4.4.3 Wire Elongation at Failure

Table 9 lists the elongation at failure documented for the three test specimens cut from each extracted wire and the mean elongation computed for the surveillance year. The reports documenting the testing performed on 1987, 1989 and 1991 surveillance samples show the elongations as >3.5% (the specified minimum) rather than the actual values at failure, which may not have been determined[15].

All specimens tested met the acceptance criterion. Measured elongations at failure, where these are reported, vary from 3.9% to 5.48%, a reasonable range. The mean values computed for each surveillance vary from 4.15% to 5.07% and do not show a trend.

Based on the test data and computed mean values show in Table 9, it is concluded that strand ductility does not change over time and that it will continue to be satisfactory, with elongation at failure >3.5%, over the operating lifetime of the plant. It is also concluded that further testing to verify ductility is not needed and, pending evaluation of the 2025 surveillance test results, should be eliminated from the surveillance program.

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[15] ASTM A1061, cited in ASTM A416 as the testing procedure to be used for strand, does not require determining elongation at the failure load if an elongation of at least 3.5% has been measured prior to specimen break.

4.4.4 Strand Visual Examination / Test Summary and Conclusions

Surveillance data shows that strand is free of active corrosion and other visible indications of degradation. This data also shows that strand ductility is not changing with time under load and is remaining well above the required minimum as verified by the reported values of test sample elongation at failure.

The results of tensile strength tests indicate a possible decrease in strength with time. But, given the nature of the strand material (cold drawn carbon steel wire), such a decrease seems unlikely. For this reason, it is tentatively concluded that the apparent decrease is a consequence of data scatter resulting from variations in testing practice and not a manifestation of changes in material mechanical properties. ASTM A421 wire test results often show relatively large (e.g., mean wire strength variations between 240 and 285 ksi) random up and down movements of strength over time. While this usually results in a saw tooth plot, random realignment of the results could show a clear trend, either increasing or decreasing over time.

While there should be no need to continue extracting and testing strand during future surveillances, the recommendation in this report is that a single strand be extracted from a hoop tendon during the next surveillance and tested. If the tests on the specimens cut from this strand confirm the expectation that strand tensile strength is not changing, no further strand testing should be done.

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

4.5 Corrosion Protection Medium Testing

Corrosion protection medium (CPM) was collected at the ends of sample tendons during each of the surveillances completed to date. Each CPM sample was tested for the presence of three corrosive ions (chlorides, nitrates and sulfides), absorbed water content and neutralization number.

The testing procedures for absorbed water content and neutralization number use bulk samples. While the former are standardized and easily performed, the latter are complex, relying on a procedure that is defined only in Subsection IWL Table IWL-2525-1. As the neutralization number tests are conducted only on Visconorust CPM, testing laboratories may not maintain the institutional skills needed to ensure that these are always done in a consistent manner. As a consequence, the results of neutralization number tests tend to have a considerable degree of scatter and to show significant variations from surveillance to surveillance, a point to consider in results evaluation

Tests for corrosive ions do not determine the concentration in bulk samples but, rather, the concentration in a quantity of distilled water kept in contact with a prepared CPM surface area for a specified time and at a specified temperature. The procedures for determining ion concentration in the water sample have changed over time to reflect advances in analytical chemistry techniques as well as other changes to the standardized ASTM and APHA procedures used in testing the water extractions. Also, the corrosive ion test procedures (as well as sample preparation techniques) may have varied among the different laboratories used for this work. This must be accounted for in the evaluation of test results.

Corrosion protection medium test results are summarized below and addressed in detail in subsections 4.5.1 through 4.5.3 below. Conclusions and recommendations for future testing are included in 4.5.4.

- All samples met the Table IWL-2525-1 upper limit (10 ppm) on chloride, nitrate and sulfide ion concentration. Maximum ppm concentrations reported for the three ions are, respectively, 0.4, 2.40 and 0.70.
- All samples met the Table IWL-2525-1 upper limit (10%) on absorbed water content. Maximum reported water content is 1.00%
- All samples met the Table IWL-2525-1 lower limit (17.5) on base number (the measure of reserve alkalinity). The lowest reported base number is 20.3.

4.5.1 Corrosive Ion Concentrations

Table 10 lists the following summary data applicable to the ion concentrations documented in the surveillance reports.

- Surveillance year / No. of samples tested
- Maximum, mean (if > 0.5 ppm) and minimum chloride concentration
- Maximum, mean (if > 0.5 ppm) and minimum nitrate concentration
- Maximum, mean (if > 0.5 ppm) and minimum sulfide concentration

The maximum chloride ion concentration reported is 0.40 ppm (many later values are shown only as <0.5 ppm). Mean concentrations calculated for each of the surveillances are all below 0.5 ppm. These values, both of which are only small fractions of the upper limit of 10 ppm, show no trend over time. Maximum and minimum concentrations are reported as <0.5 ppm for the 1995 and later surveillances. This is a presumed lower limit of resolution for the analytical technique used in 1995 and later.

The maximum nitrate ion concentration reported is 2.40 ppm as determined for samples collected during the 2000 surveillance. The mean calculated for the 2000 surveillance samples is 1.68 ppm. All other maximum and mean values are significantly less. A concentration of 2.40 ppm is below 25% of the upper limit of 10 ppm. And, maximum and mean concentrations shown no trend over time. Maximum and minimum concentrations are reported as <0.5 ppm for the 2005, 2010 and 2015 surveillances and the 1995 surveillance minimum is also reported as <0.5 ppm. This is a presumed lower limit of resolution for the analytical technique used in 1995 and later.

The maximum sulfide ion concentration reported is 0.70 ppm as determined for samples collected during the 2000 surveillance. The mean calculated for the 2000 surveillance samples is 0.55 ppm. All other maximum and mean values are less. Both the 2000 maximum and mean are small fractions of the upper limit of 10 ppm. And, maximum and mean concentrations shown no trend over time. Maximum and minimum concentrations are reported as <0.5 ppm for the 1995, 2005, 2010 and 2015 surveillances. This is a presumed lower limit of resolution for the analytical technique used in 1995 and later.

Considering the above discussion of ion concentration patterns and the lack of significant or active corrosion on end anchorage hardware and extracted strand, it is concluded that the presence of corrosive ions in CPM is not a concern.

4.5.2 Absorbed Water Content

Table 11 lists, for each of the surveillances, maximum, mean and minimum sample water contents. Maximum reported values vary from 0.27% to 1.00%, all well below the 10% upper limit with no trend over time. All mean values are <0.5%.

4.5.3 Reserve Alkalinity / Neutralization Number

CPM samples were tested to ensure the ongoing protective feature of the formulation. These tests determine the neutralizing ability of the CPM when it is subjected to a strong acid in accordance with the procedure detailed in ASME Section XI, Subsection IWL. Test results are reported as a neutralization, or base, number computed as described in Table IWL-2525-1.

While the testing procedure detailed in IWL appears straight forward, the quality of results may depend to a considerable degree on the exact manner in which a test is performed. Therefore, reported neutralization number values may vary somewhat from a presumed 'true value' depending on laboratory practices, skill / experience of the lab technicians, quality of equipment / reagents used and other factors. Considering the variations in results from surveillance to surveillance, as discussed below, it is reasonable to postulate that there may be reasonably large differences between reported numbers and 'true values'.

Results of neutralization number tests conducted during consecutive surveillances are listed in Tables 12 & 13, illustrated graphically by Figures 17 & 18 and summarized below. The figures show log-linear trend lines for reference only (there is no general evidence that the neutralization number of the Visconorust product decreases in any particular manner over time).

- The Figures 17 and 18 plots both show that the neutralization number may be trending down over time. However, the degree of scatter and the large random up and down movements in mean value suggest that the apparent trends may be the result of variations in laboratory practice rather than actual change in the CPM characteristic.
- Unit 1 and unit 2 results appear to differ with the Unit 2 mean trending down at a greater rate. Again, this may be the result of laboratory practice as the Unit 1 and Unit 2 samples may have been delivered at different times and analyzed by different technicians. There is no logical reason for the difference unless the bulk material used to fill the tendons came from different lots, each with its own characteristic formulation.
- Even if the trends are accepted as being reflective of time-dependent loss in effective neutralization capability of the CPM, the Unit 1 and Unit 2 mean values are still well above the 17.5 minimum (Reference 7.7) at T = 100,

While the data covered in the above summary show that there is a possible loss of neutralization number over time, both unit trend lines remain well above the 17.5 minimum through 2086 (T = 100 years); the Unit 1 and Unit 2 extended operating licenses expire in 2047 and 2049, respectively. Based on this, it is concluded that the CPM will continue to provide a high level of corrosion protection over the operating lifetime of both units.

4.5.4 Summary and Conclusion - CPM Test Results

Post-tensioning system end anchorage hardware has been examined for corrosion during 8 surveillances and extracted strand examined during 7 spanning a period of 28 years from 1987 to 2015. Corrosion protection medium samples collected during these surveillances have been tested for the presence of corrosive ions, absorbed water and reserve alkalinity. The results of these examinations and tests are summarized below.

- There has been no evidence of active corrosion; observed corrosion consists of light rusting that probably occurred during handling, shipping, storage or installation of tendon hardware or otherwise prior to filling of the tendon ductwork with CPM.

- Corrosive ion (chlorides, nitrates, sulfides) concentration is well below the upper limit of 10 ppm and shows no trend of increasing over time. With the exception of the nitrate concentrations reported for the 2000 surveillance samples, all concentrations are below 1 ppm. The 2000 nitrate results (maximum of 2.40 ppm) are concluded to be outliers and the probable result of a laboratory procedure misapplication.
- Absorbed water content is well below the 10% (of dry weight) limit and shows no trend of increasing over time; no sample water content has exceeded 1%.
- Neutralization numbers (base numbers) vary over a wide range but all are above the 17.5 lower limit. While test data show a possible decrease in the mean number over time, the trends (represented by log-linear regression lines for consistency with the tendon force graphs) remain above the 17.5 lower limit to well beyond T = 100 years.

An evaluation of the CPM test results, as summarized above, leads to the conclusion that the interval between collecting samples and performing such tests can be extended to 15 years with no adverse consequences.

In addition, unless evidence of active corrosion is found during visual examinations of end anchorage hardware and / or extracted strand, free water 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.

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 below.

5.1 Surveillance Results Overall Summary

The results of the 8 post-tensioning system surveillances conducted at VEGP between 1987 and 2015 show that the system is continuing to perform its intended function and that it can be expected to do so until well past the expiration of the Unit 1 and Unit 2 extended operating licenses (2047 and 2049, respectively). Performance of the system, 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 and, for the cylinder hoop and inverted U groups, by 95% lower confidence limit computations, to remain above the specified minimum until well after expiration of the extended operating licenses. The projections of the cylinder hoop tendon trends and the Unit 1 inverted U tendon trends are supported by the low scatter trends of common tendon force data. The Unit 2 inverted U tendon trends, which are based on a smaller data set, indicate that mean force is increasing with time. As explained in Part 4, there are a number of possible reasons for the apparent positive trends, none of which can be readily quantified. These trends will re-computed and evaluated after more data has been acquired during the next surveillance.

5.1.2 Condition of End Anchorage Hardware and Extracted Strands

End anchorage hardware and tendon strands extracted for tensile testing show no signs of damage or 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.

The two broken strands documented in the 2000 surveillance report were determined to have been the result of a singular event (damage prior to or during original installation) and not indicative of system degradation.

Only one instance of free water was reported. About 0.1 l (3 ounces) of free water was found in the (Unit 1) 1H-14 buttress 2 anchorage end cap during the 1987 surveillance. The water, which was determined to have entered the cap through an unplugged opening, caused no corrosion of system hardware, leading to the conclusion that the corrosion protection medium is preforming as intended. A plug was threaded into the opening to restore the intended design configuration.

5.1.3 Tendon Wire Strength and Ductility

Tensile tests on samples cut from extracted strands show that ultimate strength and ductility (quantified by the measured elongation at failure) remaining above specified minimum values. Test results show that ductility has not been affected by the time under load.

Test data trending indicates that tensile strength may be decreasing over time but the evidence for this is not conclusive; past precedent with ASTM A421 wire testing suggests that the apparent trend of decreasing tensile strength is, in all likelihood, the result of testing errors. In any case, the apparent tensile strength trend shows that strength will meet the acceptance criterion until T = 75 years (mid-2061), 12 years after the expiration of the Unit 2 extended operating license.

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 ion concentration and water content. Mean neutralization number may be slowly decreasing over time but computed trends show that it will remain well above the specified minimum through T = 100 years. In particular:

- All reported absorbed water content values are below the 10% (of dry weight) upper limit. The greatest water content reported is 1.00%.
- All corrosive ion concentrations are well below the upper limit of 10 ppm. Maximum reported concentrations of chlorides, nitrates and sulfides are 0.40 (many later values are shown only as <0.5 ppm), 2.40 and 0.70, respectively.
- Neutralization numbers are all above the 17.5 lower acceptance limit. Both Unit 1 and Unit 2 numbers appear to trend down with time but the trended values remain well above 17.5 through T = 100 years. As discussed in Parts 3 and 4, the patterns of the numbers reported by the laboratories tend to fluctuate over a relatively wide range from surveillance to surveillance. For this reason, it was concluded that the computed trends may reflect variations in testing procedures, technician skill / experience and other laboratory dependent factors as much as actual differences in neutralization number.

5.2 Conclusions

Based on the evaluations detailed in Part 4 of this technical report and summarized above, it is concluded that the VEGP post-tensioning system will continue to perform its design function until well after the expiration of the Unit 1 and Unit 2 extended operating licenses (2047 and 2049, respectively) and, in particular, that:

- Tendon group mean forces will remain above the specified minima.
- End anchorage hardware and tendon wire will remain free of active corrosion.
- Tendon strand ductility will not change over time and will remain acceptable throughout the operating lifetime of the plant.
- While probably not the case, mean strand tensile strength could be slowly decreasing over time. However, it will remain above the specified 270 ksi minimum until at least T = 75 years (mid-2061).
- Corrosion protection medium will retain its protective properties with no unacceptable degradation over time.
- Free water was found only once. It was the result of a construction oversight and did not cause corrosion. Free water should not be a future concern.

5.3 Recommendations

On the basis of the above conclusions, it is recommended that the interval between post-tensioning system surveillances, which include examinations identified Reference 7.2, Table IWL-2500-1, Examination Category L-B, Items L2.10 through L2.50, be increased from the present 10 years to 15 years, maintaining the same re-baselining date of 01 August 2010. [Scheduling of the visual examination of the containment concrete surface is not addressed in this report and will continue in accordance with plant ISI program.]

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 strand extraction.

It is also recommended to limit strand mechanical property testing during the next surveillance to a single strand extracted from one hoop tendon and to eliminate future strand testing if justified by the results of the next test. Incorporating this recommendation will further reduce the potentially damaging repetitive loading experienced by tendons during de-tensioning / re-tensioning.

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.

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 EXAMINATION ENHANCEMENTS

As noted in Part 2 of this technical report, visual examinations of the containment exterior will continue at 5-year intervals in accordance with IWL-2410. These will include examinations of tendon end caps, bearing plates and anchorage area concrete for evidence of damage / deformation, corrosion, cracking and CPM leakage. Direct visual examination (IWL-2310) will be performed where there is close in access to tendon anchorage areas (the tendon gallery and buttress areas accessible from grade level, floors, roofs, platforms or ladders). If direct visual examination is not possible, remote visual examination (IWL-2310) techniques (high power optics and / or drone mounted cameras) will be used.

If an end anchorage area examination uncovers a condition indicative of possible damage to the enclosed post-tensioning system hardware or an anchor head failure, the end cap will be removed for further examination and evaluation by the Responsible Engineer (RE). Additional actions will be taken as specified by the RE following the evaluation.

If an end anchorage area examination uncovers active corrosion on a bearing plate or end cap, the condition will be evaluated by the RE and corrective measures implemented if and as specified by the RE.

If an end anchorage area examination uncovers concrete cracks that are considered by the RE to have potential structural significance, the RE will perform a detailed examination (IWL-2310) and evaluation of the condition and specify corrective or follow-up measures as deemed appropriate.

Visual examinations will also focus on gross leakage of CPM. If gross leakage is detected, a corrective action (e.g., end cap gasket replacement and duct refilling / top-off) plan will be prepared by the RE. The corrective action plan will be implemented in accordance with RE requirements.

If free water in amounts sufficient for analysis is found during examinations it will be collected and tested to determine pH. In addition, the RE will evaluate the condition and specify additional examinations and tests as deemed necessary to determine if the free water has caused corrosion.

Also, as discussed in Section 4.2 (and, as required by 10CFRT50.55a / Subsection IWL), trends of tendon forces will be re-computed and evaluated following each surveillance. These evaluations will be performed to ensure that ongoing prestressing force in each of the Unit 1 and Unit 2 tendon groups will remain well above the specified minimum level throughout the interval between the current surveillance and the latest date for completion of the subsequent surveillance.

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 Vogtle Electric Generating Plant, *Final Safety Analysis Reports Update*, Revision 22 – 9/18 Update.

7.4 ASTM A416, *Standard Specification for Low-Relaxation, Seven-Wire Steel Strand for Prestressed Concrete*, Published by the American Society for Testing and Materials.

7.5 Vogtle Electric Generating Plant Calculation X2CJ02.06.04, *Stress Calculation*, Revision 1, 24 November 1997.

7.6 Vogtle Electric Generating Plant Calculation X2CJ02.06.05, *Stress Calculation*, Version 2.0, 14 December 2017.

7.7 Vogtle Electric Generating Plant Engineering Programs Document GEN-100, *Containment Tendon Surveillance Requirements*, Revision 5.1, 05 January 2018.

7.8 Vogtle Electric Generating Plant Relief Request RR VEGP-ISI-RR-01 (Unit 2), *Containment Testing Alternatives*, Approved by USNRC letter dated 11 June 2010.

7.9 Vogtle Electric Generating Plant Relief Request RR VEGP-ISI-ALT-04 (Units 1 and 2), *Containment Testing Alternatives*, Approved by USNRC letter dated 11 June 2010.

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

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

7.12 *First Year Physical Surveillance of the Vogtle Electric Generation Plant / Unit 1 Physical Surveillance*, Revision 1, Precision Surveillance Corporation, 22 December 1988.

7.13 *Tendon Surveillance Test Report / Unit 1 – Third Year Inservice / Unit 2 – First Year Inservice / Units 1 and 2 Containment Structure / Post-Tensioning System / Vogtle Electric Generating Plant / Georgia Power Company*, Revision 0, VSL Corporation, December 1989.

7.14 *Tendon Surveillance Test Report / Unit 1 – Fifth Year Inservice / Unit 2 – Third Year Inservice / Units 1 and 2 Containment Structures / Post-Tensioning System / Vogtle Electric Generating Plant / Georgia Power Company*, Revision 0, VSL Corporation, November 1991.

7.15 *Fourth Period Visual Surveillance Unit 1 and Third Period Physical Surveillance Unit 2 Containment Buildings at Vogtle Nuclear Plant*, Revision 0, Precision Surveillance Corporation, reissued with amended pages 27 November 1995.

7.16 *Fifth Period Physical Tendon Surveillance of Unit 1 and Fourth Period Visual Tendon Surveillance of Unit 2 at the Vogtle Nuclear Plant*, Revision 0, Precision Surveillance Corporation, 28 September 2000.

7.17 *Sixth Period Visual Surveillance of Unit 1 and Fifth Period Physical Surveillance of Unit 2 Containment Building at the Vogtle Electric Generating Plant / Post Tensioning Surveillance Report*, Revision 2, Precision Surveillance Corporation, 17 January 2005.

7.18 *Final Report for the Vogtle Unit 1 - 7th Period (25th Year) and Unit 2 - 6th Period (20th Year) Containment Building Tendon Surveillance (Document No. VT-N1062-500)*, Revision 0, Precision Surveillance Corporation, 21 November 2011.

7.19 *Final Report for the Unit 1 - 30th Year and Unit 2 – 25th Year Tendon Surveillance at Vogtle Electric Generating Station (Document No. REP-1115-510)*, Revision 0, Precision Surveillance Corporation, 23 March 2016.

7.20 *Georgia Power Company / A. W. Vogtle Nuclear Power Plant / Unit 1 / Report on Containment Structural Integrity Test*, Bechtel Western Power Corporation, August 1986.

7.21 *Georgia Power Company / Vogtle Electric Generating Plant / Unit 2 / Primary Containment Structural Integrity Test / Final Report*, Bechtel Power Corporation, December 1988.

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

7.23 ASTM A1061, *Standard Test Method for Testing Multi-Wire Steel Prestressing Strand*, Published by the American Society for Testing and Materials.

7.24 VEGP Drawing 1X2D01K001, Containment Prestressing Requirement / Key Plan (Unit 1), Revision 5.

7.25 VEGP Drawing 2X2D01K001, Containment Prestressing Requirement / Key Plan (Unit 2), Revision 4.

7.26 USNRC Regulatory Guide 1.35.1, Determining Prestressing Forces for Inspection of Prestressed Concrete Containments, Issued July 1990.

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
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
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 Cylinder Hoop Tendon Forces					
Surveillance Year	T, Time Since T_0, Years	Tendon	F_M, Measured Force, kip	NF, Normalization Factor	F_N, Normalized Force, kip
1987	1.2	1H-14	1,628	0.99077	1,613
		1H-45	1,617	0.97677	1,579
		1H-49	1,585	0.99045	1,570
		1H-69	1,650	0.98139	1,619
		1H-83	1,610	0.97985	1,578
		1H-88	1,629	0.99520	1,621
		1H-126	1,658	0.94965	1,575
		1H-139	1,588	0.99171	1,575
1989	3.2	1H-6	1,562	0.97463	1,522
		1H-7	1,567	0.94994	1,489
		1H-18	1,579	1.02672	1,621
		1H-23	1,529	0.99520	1,522
		1H-58	1,558	0.98982	1,542
		1H-73	1,569	0.98919	1,552
		1H-83	1,563	0.97985	1,532
		1H-110	1,519	1.00941	1,533
1995	8.9	1H-120[1]	1,606	0.98668	1,585
2000	13.8	1H-13	1,534	1.01236	1,553
		1H-30	1,584	0.99648	1,578
		1H-83	1,520	0.97985	1,489
2010	24.2	1H-29	1,553	1.00161	1,555
		1H-83	1,535	0.97985	1,504
		1H-92	1,500	0.99936	1,499

Note1: Unit 1 tendon de-tensioned for strand removal; no other Unit 1 tendons examined in 1995.

Table 3 - Summary of Unit 1 Dome Hoop Tendon Forces					
Surveillance Year	**T, Time Since T_0, Years**	**Tendon**	**F_M, Measured Force, kip**	**NF, Normalization Factor**	**F_N, Normalized Force, kip**
1987	1.2	1H-149	1,605	0.96059	1,542
		1H-151	1,566	1.03689	1,624
1989	3.2	1H-145	1,520	1.02936	1,565
2000	13.8	1H-148	1,518	0.98609	1,497
2010	24.2	1H-167	1,522	0.99426	1,513

Table 4 Summary of Unit 1 Inverted U Tendon Forces					
Surveillance Year	**T, Time Since T_0, Years**	**Tendon**	**F_M, Measured Force, kip**	**NF, Normalization Factor**	**F_N, Normalized Force, kip**
1987	1.2	1U4-108	1,587	1.00351	1,593
		1U18-94	1,508	1.03251	1,557
		1U42-144	1,575	1.01289	1,595
		1U58-128	1,553	1.01387	1,575
1989	3.2	1U13-99	1,505	1.01518	1,528
		1U18-94	1,456	1.03251	1,503
		1U31-81	1,518	0.99778	1,515
		1U35-77	1,552	0.96917	1,504
1991	5.1	1U10-102[1]	1,556	0.98066	1,526
2000	13.8	1U18-94	1,463	1.03251	1,511
		1U70-116	1,586	0.97822	1,551
		1U74-112	1,530	1.00096	1,531
2005	18.9	1U21-91[1]	1,506	1.00899	1,520
2010	24.2	1U18-94	1,477	1.03251	1,525
		1U49-137	1,510	1.01256	1,529
		1U55-131	1,547	0.97670	1,511

Note1: Unit 1 tendon de-tensioned for strand removal; no other Unit 1 tendons examined in 1991 & 2005.

Table 5 - Summary of Unit 2 Cylinder Hoop Tendon Forces					
Surveillance Year	T, Time Since T_0, Years	Tendon	F_M, Measured Force, kip	NF, Normalization Factor	F_N, Normalized Force, kip
1991	5.1	2H-31	1,442	1.01247	1,460
		2H-36	1,483	1.00097	1,484
		2H-71	1,511	0.99260	1,500
		2H-99	1,439	1.00227	1,442
		2H-103	1,493	1.00488	1,500
1995	8.9	2H-26	1,470	1.03176	1,517
		2H-46	1,474	1.00162	1,476
		2H-64	1,537	0.98249	1,510
		2H-74	1,488	1.01747	1,514
		2H-99	1,467	1.00227	1,470
		2H-114	1,508	0.97350	1,468
2005	18.9	2H-66	1,478	0.97658	1,443
		2H-99	1,458	1.00227	1,461
		2H-111	1,450	1.01781	1,476
2010	24.2	2H-32	1,472	0.98910	1,456
		2H-99	1,447	1.00227	1,450
		2H-125	1,493	1.01446	1,515

Table 6 - Summary of Unit 2 Dome Hoop Tendon Forces					
Surveillance Year	T, Time Since T_0, Years	Tendon	F_M, Measured Force, kip	NF, Normalization Factor	F_N, Normalized Force, kip
1991	5.1	2H-155	1,488	0.99055	1,474
		2H-163	1,523	1.00512	1,531
2005	18.9	2H-159	1,426	1.03116	1,470
2010	24.2	2H-152	1,454	1.02277	1,487

Table 7 - Summary of Unit 2 Inverted U Tendon Forces					
Surveillance Year	**T, Time Since T_0, Years**	**Tendon**	**F_M, Measured Force, kip**	**NF, Normalization Factor**	**F_N, Normalized Force, kip**
1991	5.1	2U11-101	1,514	0.98732	1,495
		2U13-99	1,464	1.01665	1,488
		2U20-92	1,408	1.02535	1,444
1995	8.9	2U18-94	1,474	1.02603	1,512
		2U20-92	1,456	1.02535	1,493
		2U26-86	1,502	0.99425	1,493
		2U69-117	1,455	1.01400	1,475
2005	18.9	2U20-92	1,444	1.02535	1,481
		2U21-91	1,491	1.03662	1,546
		2U56-130	1,549	0.97526	1,511
2010	24.2	2U8-104	1,553	0.96498	1,499
		2U20-92	1,460	1.02535	1,497
		2U25-87	1,523	0.99776	1,520

Table 8 - Strand Test Results, Tensile Strength, ksi							
Tendon	**Time Since T_0, Years**						
	1.2	**3.2**	**5.1**	**8.9**	**13.8**	**18.9**	**24.2**
1H-49	284.6						
	286.3						
	285.3						
1U58-128	287.3						
	289.2						
	290.2						
1H-110		285.3					
		281.7					
		282.4					
1U31-81		284.3					
		285.3					
		285.6					
1U10-102			281.7				
			282.0				
			282.4				
1H-120				272.4			
				279.5			
				277.3			
1H-30					271.2		
					273.2		
					273.9		
1U70-116 Strand 1					275.2		
					285.0		
					278.4		
1U70-116 Strand 2					282.4		
					275.8		
1U70-116 Strand 3					272.5		
					272.5		
1U21-91						281.6	
						282.1	
						282.1	
1H-29							271.8
							272.9
							277.3
1U49-137							272.9
							277.3
							271.8
Means	**287.2**	**284.1**	**282.0**	**276.4**	**276.0**	**281.9**	**274.0**

Table 9 - Strand Test Results, Elongation at Failure, %							
Tendon	Time Since T_0, Years						
	1.2	3.2	5.1	8.9	13.8	18.9	24.2
1H-49	>3.5						
	>3.5						
	>3.5						
1U58-128	>3.5						
	>3.5						
	>3.5						
1H-110		>3.5					
		>3.5					
		>3.5					
1U31-81		>3.5					
		>3.5					
		>3.5					
1U10-102			>3.5				
			>3.5				
			>3.5				
1H-120				3.9			
				4.7			
				4.7			
1H-30					5.28		
					4.86		
					4.65		
1U70-116 Strand 1					5.48		
					4.86		
					4.86		
1U70-116 Strand 2					5.28		
					5.07		
1U70-116 Strand 3					5.07		
					5.28		
1U21-91						4.02	
						4.02	
						4.40	
1H-29							4.00
							4.38
							4.76
1U49-137							4.39
							4.20
							4.60
Means	**>3.5**	**>3.5**	**>3.5**	**4.43**	**5.07**	**4.15**	**4.39**

Table 10 – CPM Sample Corrosive Ion Concentrations

Surveillance Year / No. of Samples	Ion Concentration, ppm[1,2]								
	Chloride			Nitrate			Sulfide		
	Max	Mean[3]	Min	Max	Mean[3]	Min	Max	Mean	Min
1987 / 28	0.368	N/A	<0.044	0.175	N/A	<0.05	0.020	N/A	0.001
1989 / 53	<0.1	N/A	<0.1	0.7	N/A	<0.1	<0.1	N/A	<0.1
1991 / 47	0.40	N/A	0.10	0.18	N/A	<0.10	0.10	N/A	0.01
1995 / 36	<0.50	N/A	<0.50	0.97	0.68	<0.50	<0.50	N/A	<0.50
2000 / 28	<0.50	N/A	<0.50	2.40	1.66	2.40	0.70	0.55	<0.50
2005 / 30	<0.50	N/A	<0.50	<0.50	N/A	<0.50	<0.50	N/A	<0.50
2010 / 28	<0.50	N/A	<0.50	<0.50	N/A	<0.50	<0.50	N/A	<0.50
2015 / 28	<0.50	N/A	<0.50	<0.50	N/A	<0.50	<0.50	N/A	<0.50

Note 1: Maximum and minimum concentrations are from the sample test results given in the applicable surveillance reports. Unit 1 and Unit 2 sample test results are similar and are combined for the purpose of this table.

Note 1: The number of significant figures used for the values entered in this table is the same as that shown in the applicable surveillance report.

Note 2: Mean concentration is shown as 'N/A' if the computed value is less than 0.50 ppm (i.e., less than 5% of the 10 ppm acceptance limit). It is also shown as N/A if the maximum concentration listed above is not more than 0.50 ppm. Otherwise, mean concentration is computed using all sample test results listed in the applicable surveillance report. If a test result is shown as '<' a lower limit of laboratory resolution value, it is conservatively treated as equal to that limit.

Table 11 – CPM Sample Absorbed Water Content

Surveillance Year / No. of Samples	Absorbed Water Content, %[1,2]		
	Max	Mean[1]	Min
1987 / 28	0.59	N/A	0.11
1989 / 53	0.5	N/A	<0.1
1991 / 47	1.00	N/A	<0.10
1995 / 36	0.40	N/A	<0.10
2000 / 28	0.56	N/A	<0.10
2005 / 30	0.30	N/A	<0.10
2010 / 28	0.24	N/A	<0.10
2015 / 28	0.27	N/A	<0.10

Note 1: Maximum and minimum percentages are from the sample test results given in the applicable surveillance reports. Unit 1 and Unit 2 sample test results are similar and are combined for the purpose of this table.

Note 1: The number of significant figures used for the values entered in this table is the same as that shown in the applicable surveillance report.

Note 2: Mean percentage is shown as 'N/A' if the computed value is less than 0.50% (i.e., less than 0.05 of the 10% acceptance limit). It is also shown as N/A if the maximum percentage listed above is not more than 0.50%. Otherwise, mean percentage is computed using all sample test results listed in the applicable surveillance report. If a test result is shown as '<' a lower limit of laboratory resolution value, it is conservatively treated as equal to that limit.

Table 12 - Unit 1 CPM Sample Neutralization Number							
Surveillance Year / T							
1987 / 1.2	1989 / 3.2	1991 / 5.1	1995 / 8.9	2000 / 13.8	2005 / 18.9	2010 / 24.2	2015 / 29.3
52.83	54.2	60.0	25.1	62.7	55.4	59.4	33.6
54.09	50.1	58.9	64.8	62.0	38.7	54.9	28.7
54.85	58.1	54.1	57.2	44.2	48.2	60.2	51.3
58.75	56.3	56.1	57.7	50.5	40.6	54.1	54.9
57.66	53.0	61.2	55.5	51.3	45.6	51.9	50.0
55.27	59.2	57.8	70.0	48.7	40.2	60.4	23.0
54.25	56.3	52.7	55.5	55.6	38.9	59.2	22.5
55.15	56.6	56.7	50.7	53.9	42.6	60.6	42.1
58.66	60.0	51.6	56.1	41.6	43.0	61.9	33.4
55.21	54.6	53.9	55.0	43.2	40.1	61.9	36.2
48.97	55.1	58.9	46.3	39.9	44.6	66.0	53.4
55.52	54.0	56.1	44.7	45.1	48.8	72.4	37.4
54.91	56.2	56.7	53.4	48.5	45.4	70.9	59.3
69.1	60.1	57.8	50.6	45.3	39.4	71.1	53.3
72.11	47.2	70.1	53.9		45.5		
70.79	47.7	73.5	51.1		45.2		
70.67	60.1	68.2					
57.86	56.0	72.9					
54.71	71.5	72.1					
59.88	64.9	72.7					
56.78	64.5	66.2					
55.38	52.8	69.3					
53.81	54.2	62.8					
59.06	57.7	73.2					
59.07	60.9	52.5					
59.09	55.8	57.8					
55.80	60.9						
55.68							

Table 13 - Unit 2 CPM Sample Neutralization Number						
Surveillance Year / T						
1989 / 3.2	1991 / 5.1	1995 / 8.9	2000 / 13.8	2005 / 18.9	2010 / 24.2	2015 / 29.3
59.7	55.5	54.6	64.4	46.3	69.6	54.5
59.0	55.3	54.5	52.2	46.1	59.4	42.2
57.1	54.1	54.5	51.5	46.1	56.2	40.7
57.0	54.1	52.2	48.6	45.6	55.7	37.2
56.0	54.1	52.1	48.5	40.5	55.6	30.2
55.8	53.0	51.1	47.8	39.4	54.1	29.0
55.6	52.2	50.2	46.5	37.1	52.3	28.0
55.3	52.2	49.9	46.5	36.2	51.2	27.5
55.1	51.3	49.7	45.4	34.4	50.9	27.4
54.9	50.5	49.2	38.8	34.2	49.3	25.8
54.7	50.2	46.6	38.4	34.1	48.6	25.1
53.9	50.2	45.6	37.7	32.7	48.5	23.6
53.8	49.9	45.2	36.9	32.6	47.7	20.3
52.9	49.9	44.9	34.8	30.7	44.9	20.3
52.8	49.1	44.2				
52.6	48.5	43.0				
51.8	48.3	40.8				
51.8	46.0	40.1				
50.7	45.7	39.1				
50.3	45.2	32.6				
48.4	43.5					
48.2						
48.1						
47.5						
47.4						
45.9						

Figure 1 - Unit 1 Cylinder Hoop Tendon Measured & Normalized Force Trends

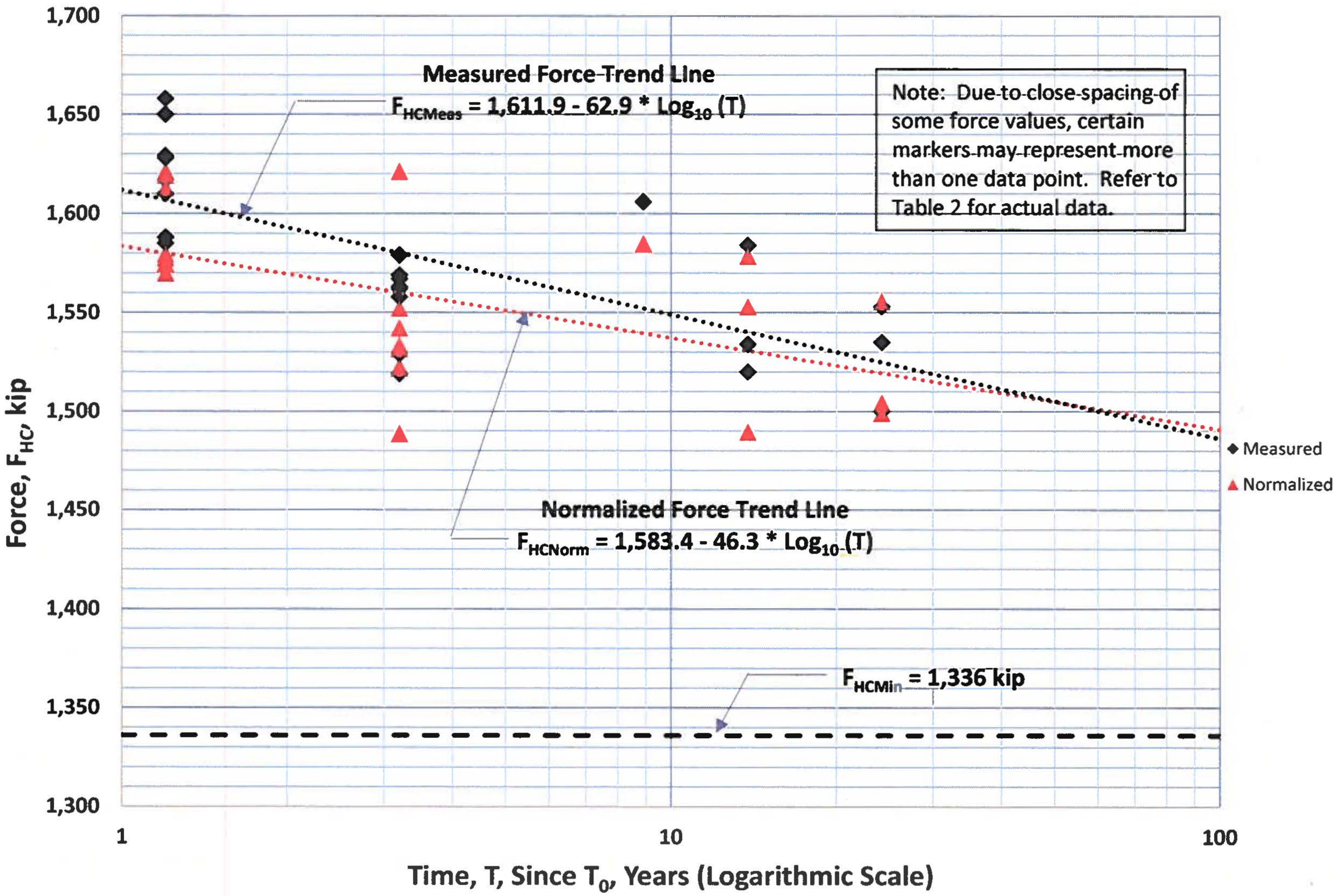


Figure 2 - Unit 1 Cylinder Hoop Tendon Measured Force Trend & LCL

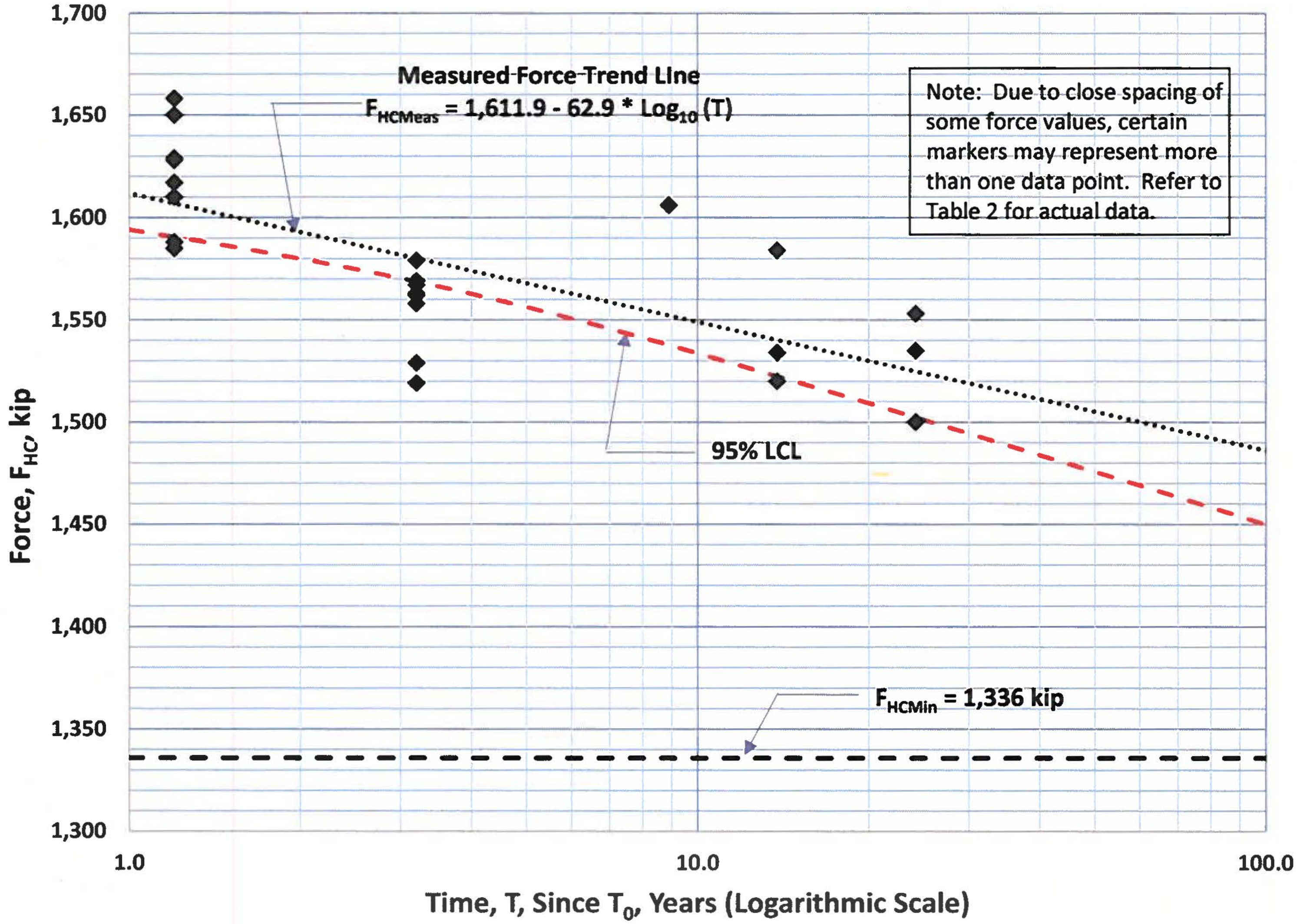
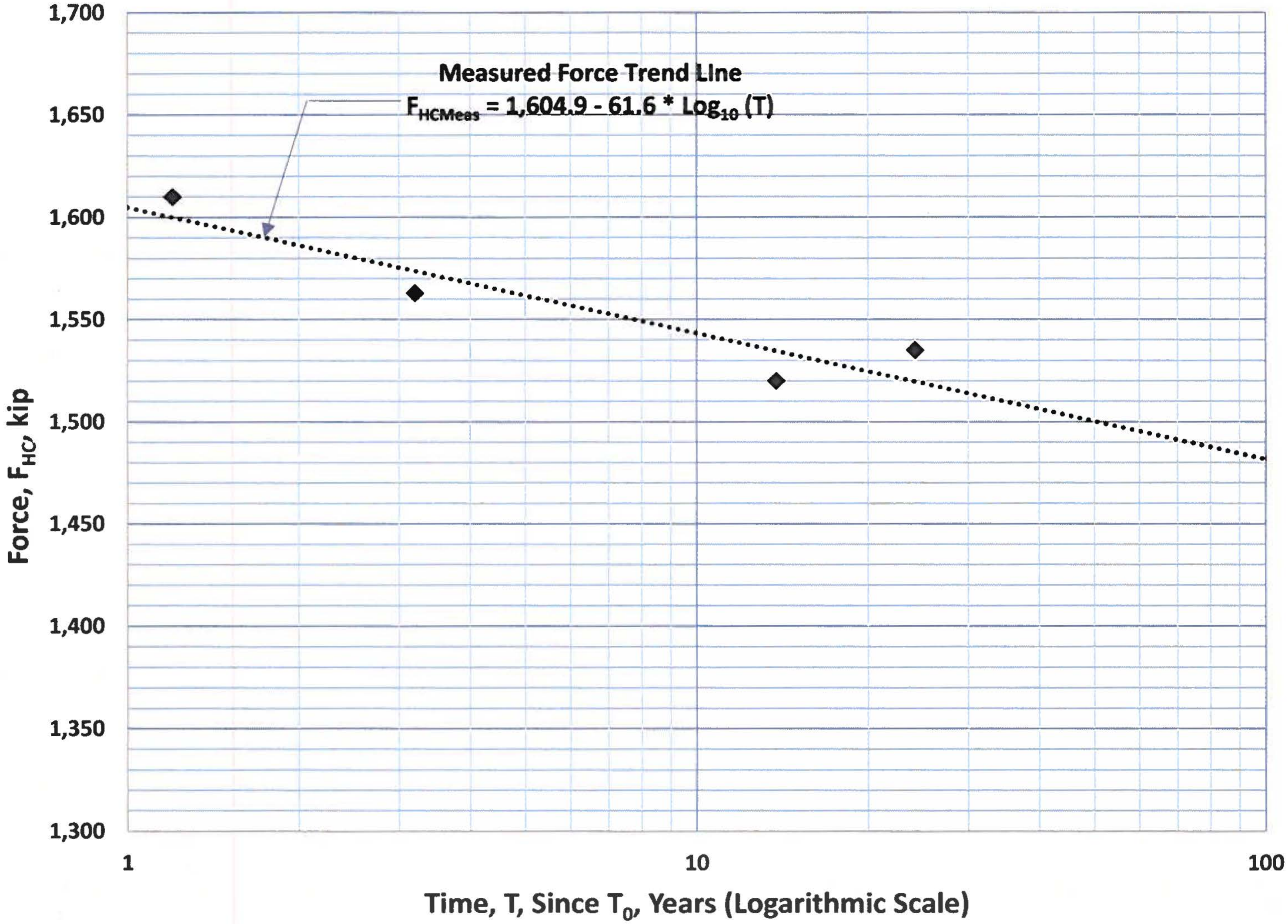


Figure 3 - Unit 1 Cylinder Hoop Common Tendon (1H-83) Force Trend



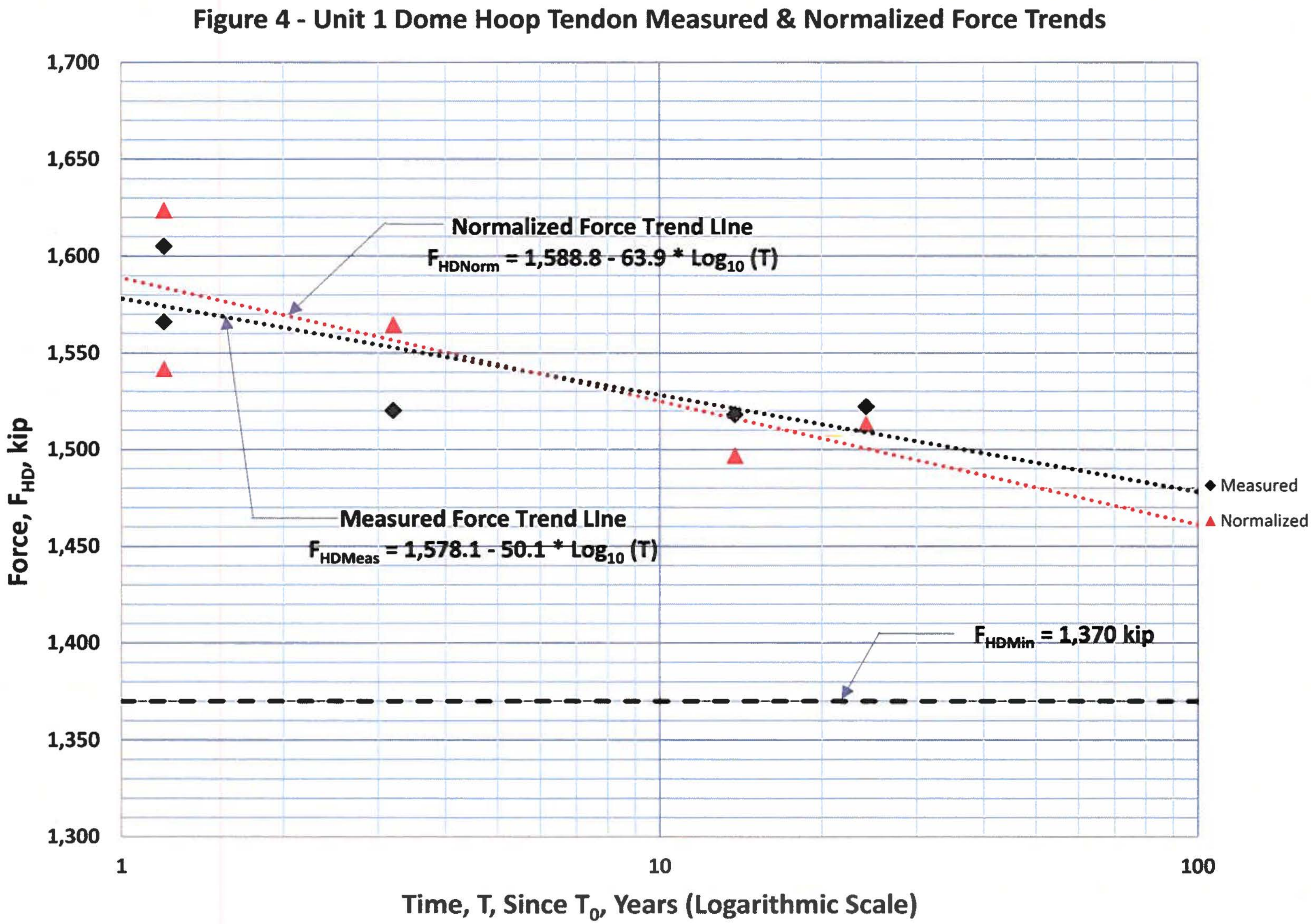
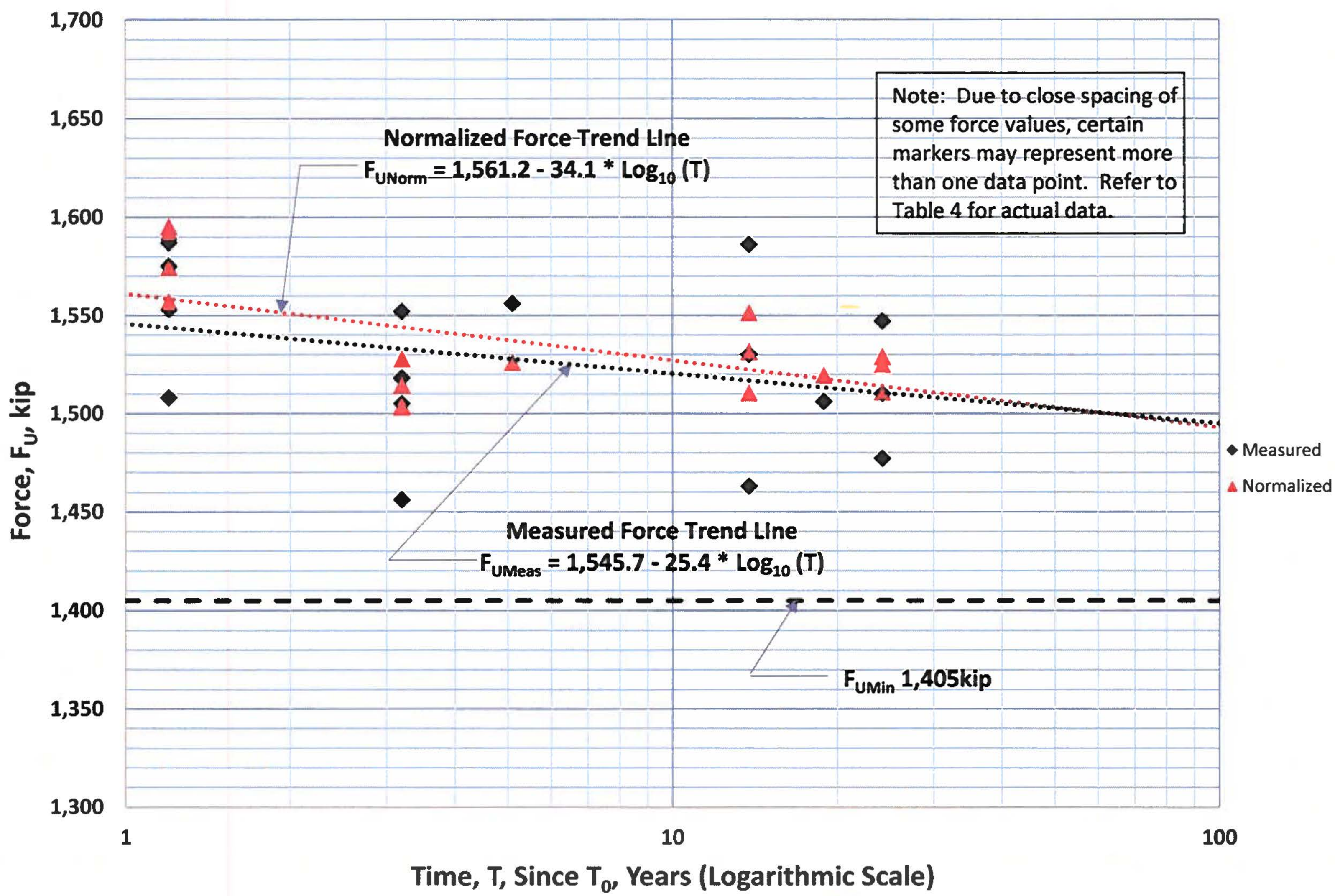


Figure 4 - Unit 1 Dome Hoop Tendon Measured & Normalized Force Trends
Normalized Force Trend Line
F_HDNorm = 1,588.8 - 63.9 * Log10 (T)
Measured Force Trend Line
F_HDMeas = 1,578.1 - 50.1 * Log10 (T)
F_HDMin = 1,370 kip
1,700
1,650
1,600
1,550
1,500
1,450
1,400
1,350
1,300
1
10
100
Force, F_HD, kip
Time, T, Since T0, Years (Logarithmic Scale)
Measured
Normalized

Figure 5 - Unit 1 Inverted U Tendon Measured & Normalized Force Trends



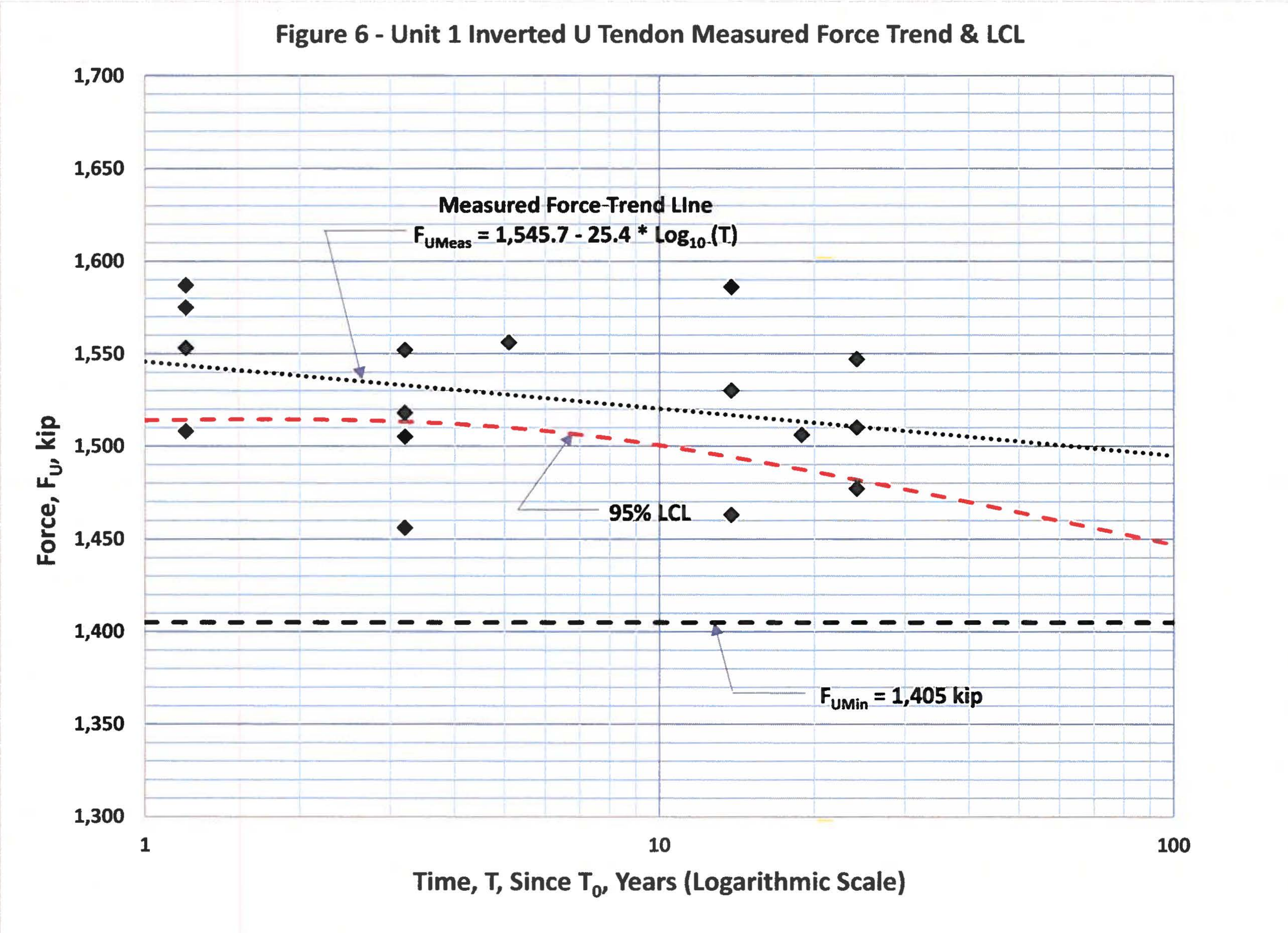
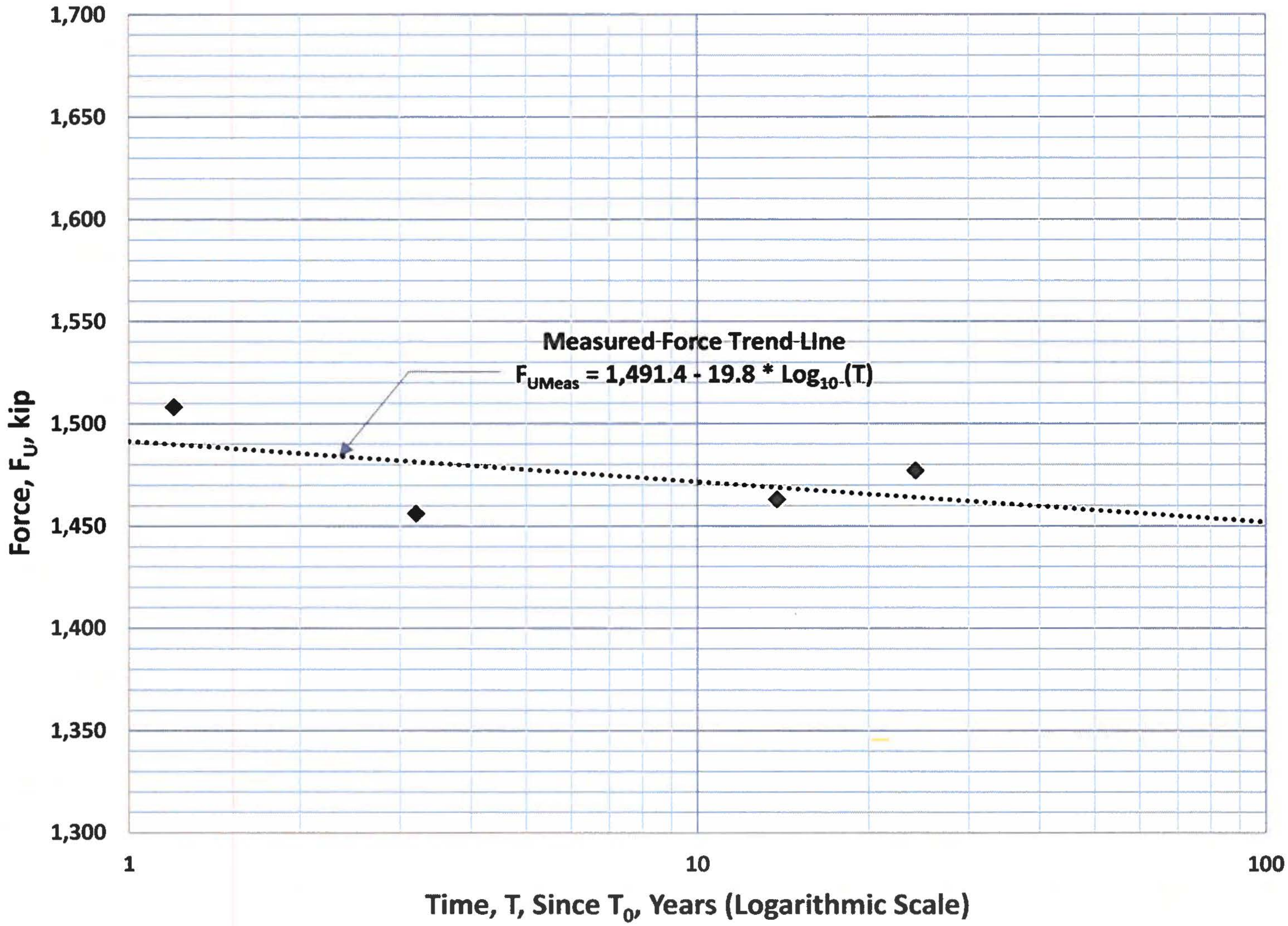


Figure 6 - Unit 1 Inverted U Tendon Measured Force Trend & LCL
Measured Force-Trend Line
F_{UMeas} = 1,545.7 - 25.4 * Log_{10} (T)
95% LCL
F_{UMin} = 1,405 kip
Force, F_U, kip
1,700
1,650
1,600
1,550
1,500
1,450
1,400
1,350
1,300
1
10
100
Time, T, Since T_0, Years (Logarithmic Scale)

Figure 7 - Unit 1 Inverted U Common Tendon (1U18-94) Force Trend



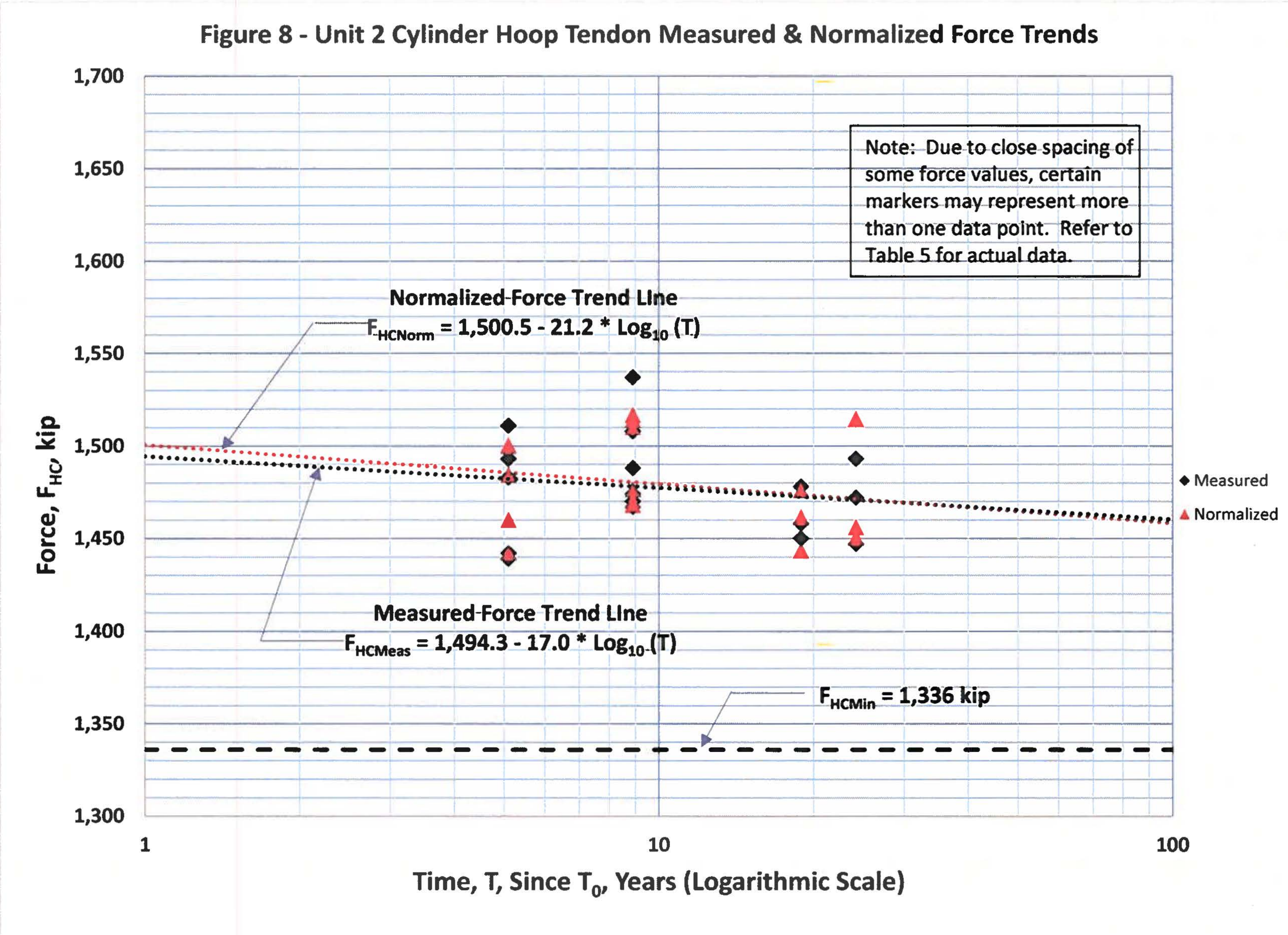


Figure 8 - Unit 2 Cylinder Hoop Tendon Measured & Normalized Force Trends
Note: Due to close spacing of some force values, certain markers may represent more than one data point. Refer to Table 5 for actual data.
Normalized-Force Trend Line
F_HCNorm = 1,500.5 - 21.2 * Log10 (T)
Measured-Force Trend Line
F_HCMeas = 1,494.3 - 17.0 * Log10 (T)
F_HCMin = 1,336 kip
Measured
Normalized
Force, F_HC, kip
1,700
1,650
1,600
1,550
1,500
1,450
1,400
1,350
1,300
1
10
100
Time, T, Since T0, Years (Logarithmic Scale)

Figure 9 - Unit 2 Cylinder Hoop Tendon Measured Force Trend & LCL

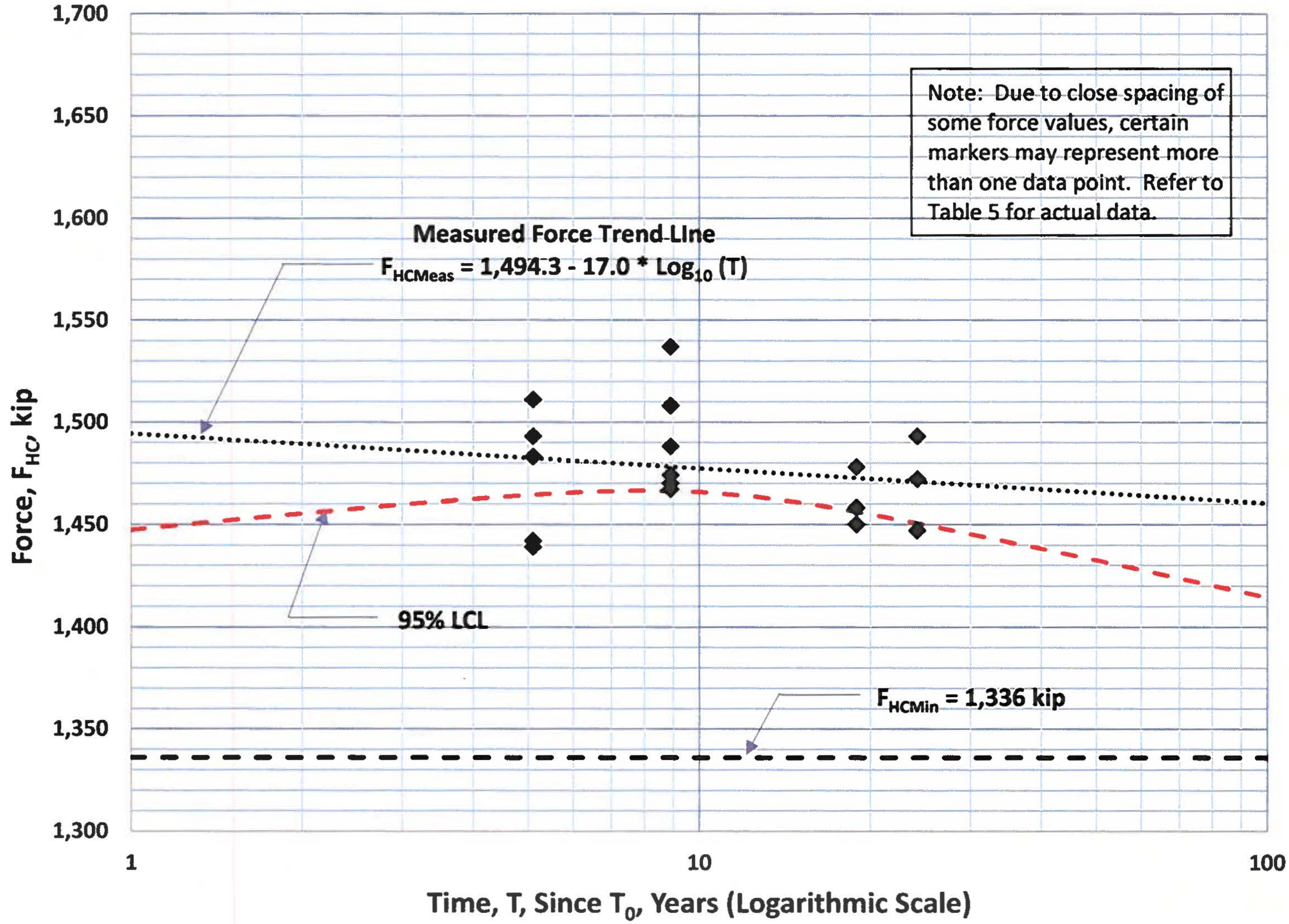
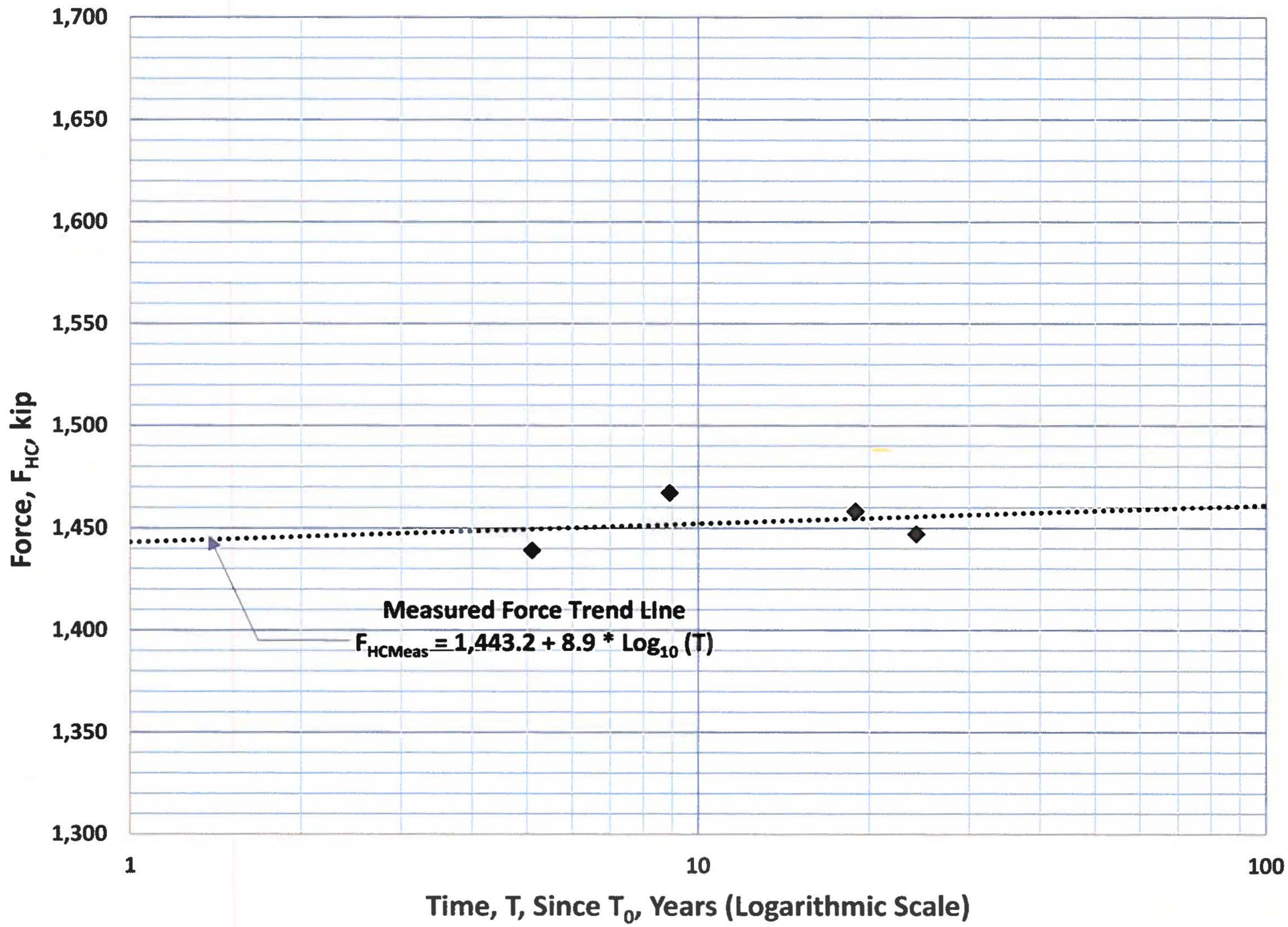


Figure 10 - Unit 2 Cylinder Hoop CommonTendon (2H99) Measured Force Trend



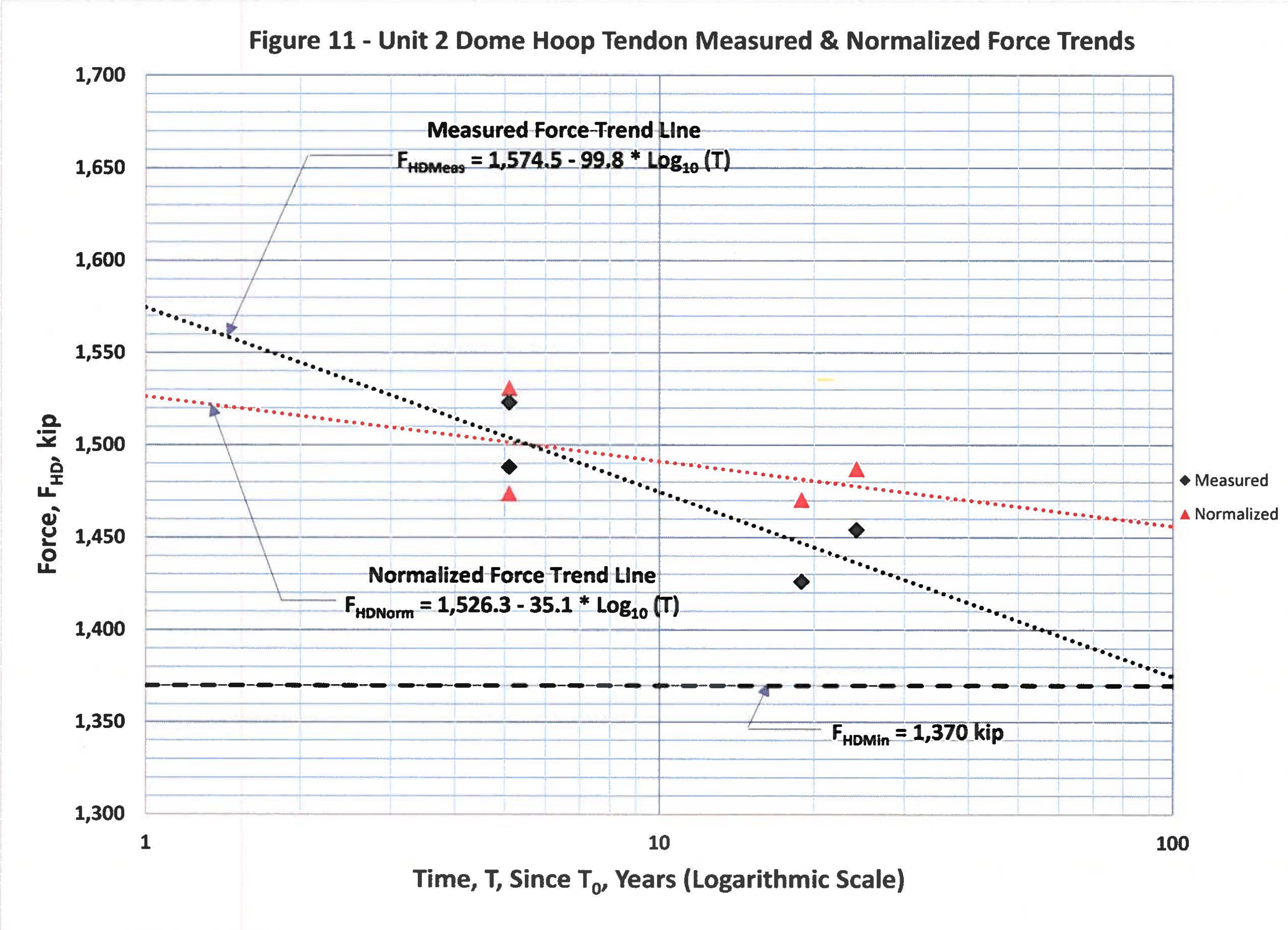
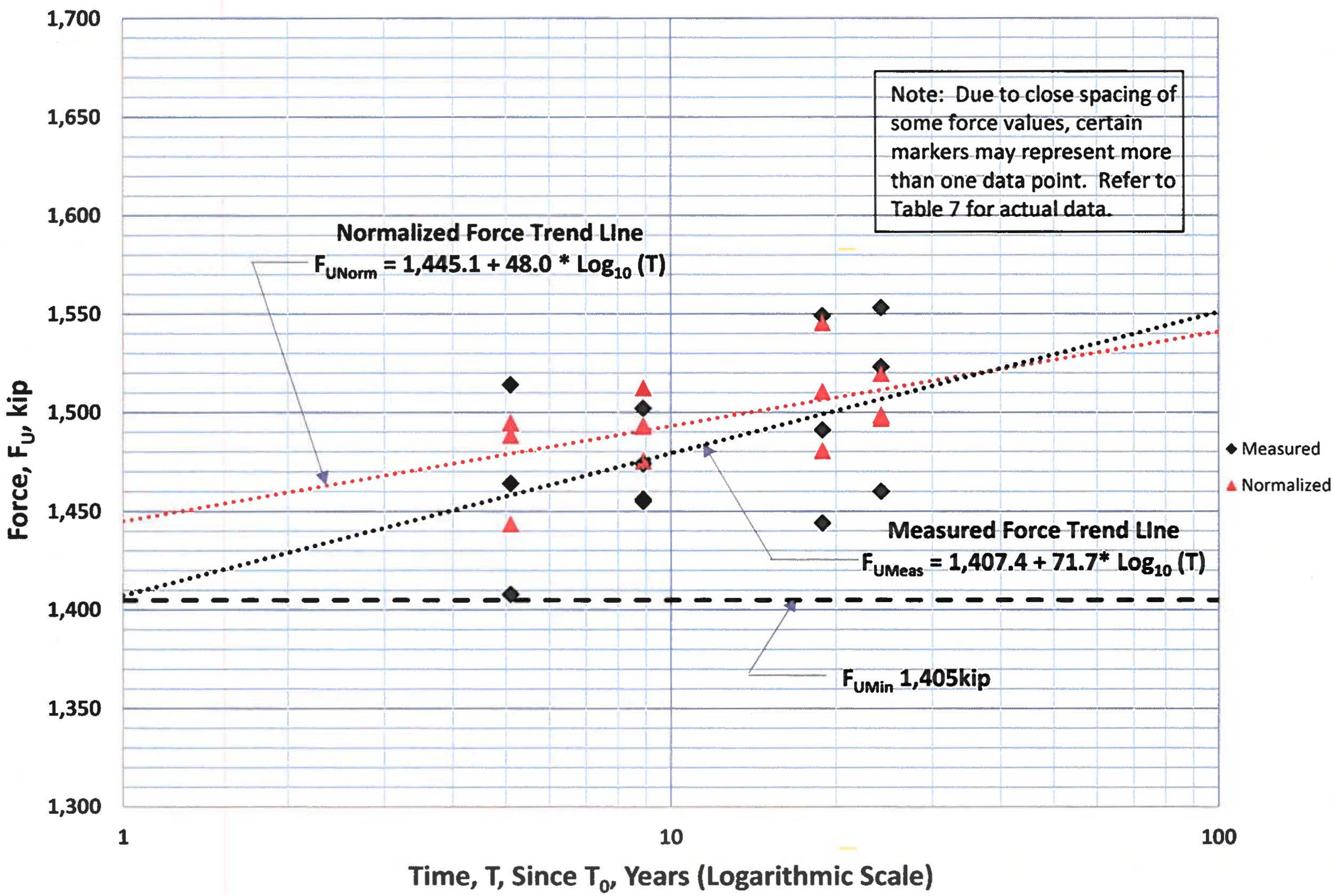


Figure 11 - Unit 2 Dome Hoop Tendon Measured & Normalized Force Trends
Measured Force Trend Line
F_{HDMeas} = 1,574.5 - 99.8 * Log_{10} (T)
Normalized Force Trend Line
F_{HDNorm} = 1,526.3 - 35.1 * Log_{10} (T)
F_{HDMin} = 1,370 kip
Measured
Normalized
Force, F_{HD}, kip
Time, T, Since T_0, Years (Logarithmic Scale)
1,700
1,650
1,600
1,550
1,500
1,450
1,400
1,350
1,300
1
10
100

Figure 12 - Unit 2 Inverted U Tendon Measured & Normalized Force Trends



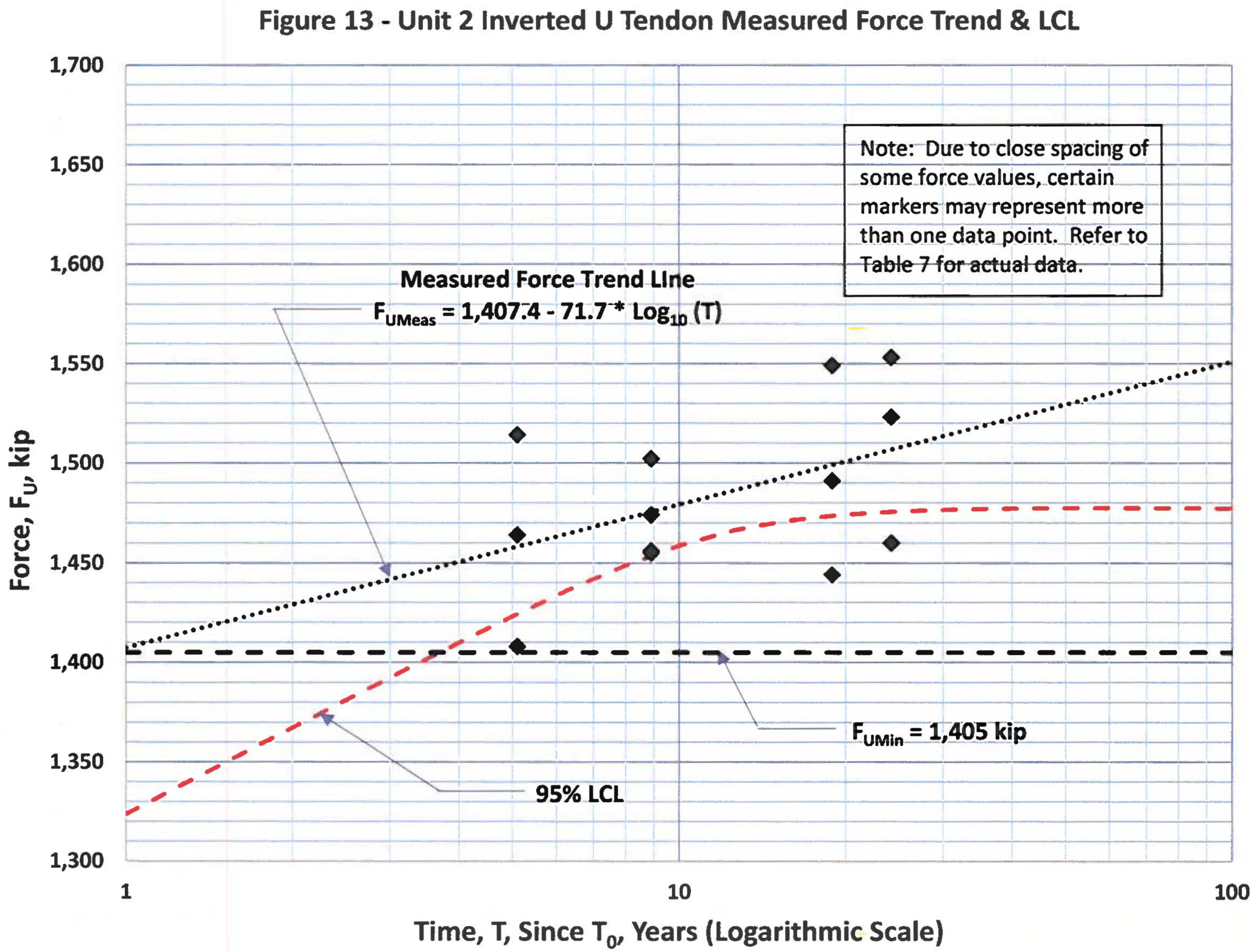
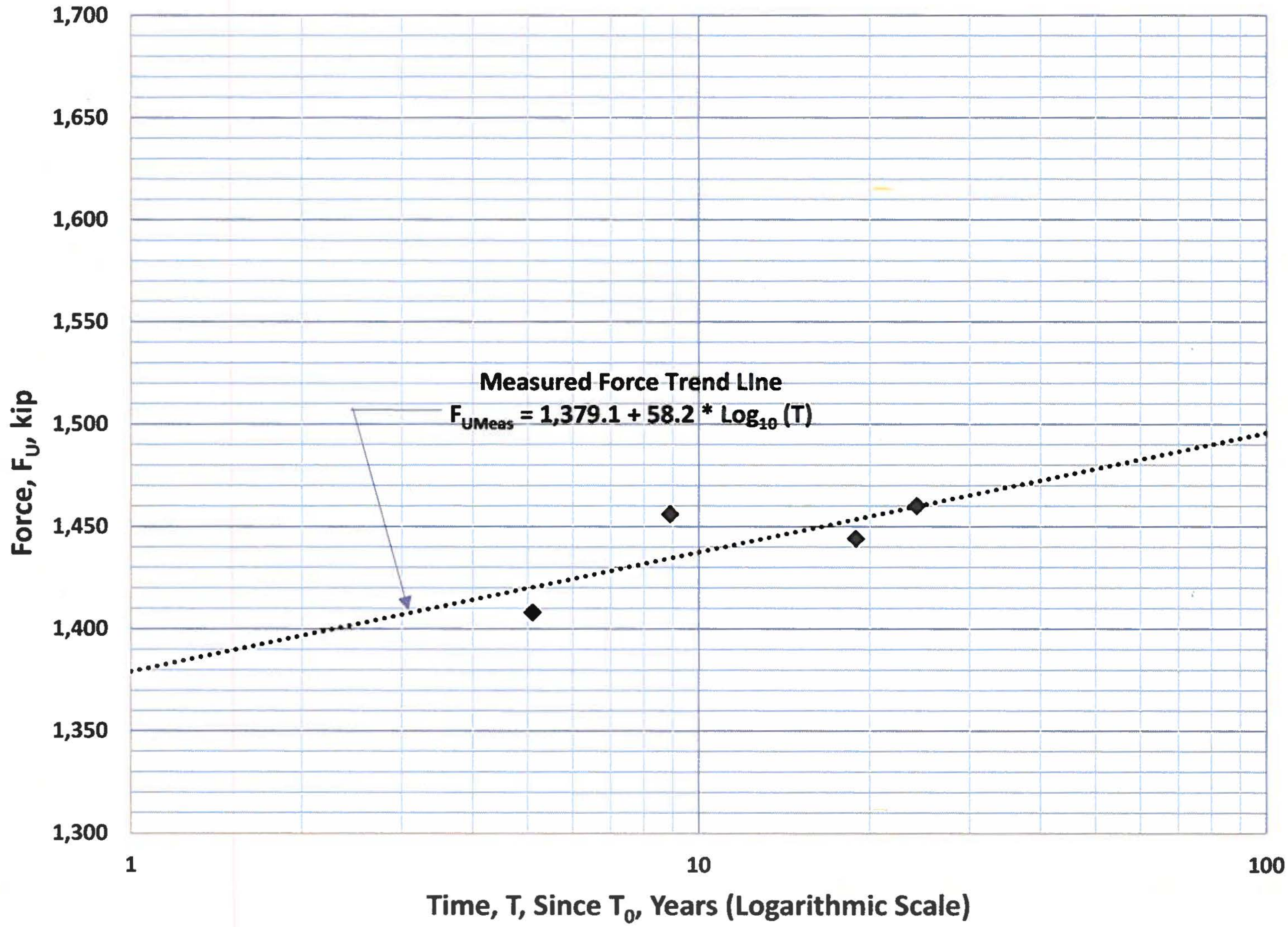


Figure 13 - Unit 2 Inverted U Tendon Measured Force Trend & LCL
1,700
1,650
1,600
1,550
1,500
1,450
1,400
1,350
1,300
Force, F_U, kip
1
10
100
Time, T, Since T_0, Years (Logarithmic Scale)
Note: Due to close spacing of some force values, certain markers may represent more than one data point. Refer to Table 7 for actual data.
Measured Force Trend Line
F_{UMeas} = 1,407.4 - 71.7 * Log_{10} (T)
F_{UMin} = 1,405 kip
95% LCL

Figure 14 - Unit 2 Inverted U Common Tendon (2U20-92) Force Trend



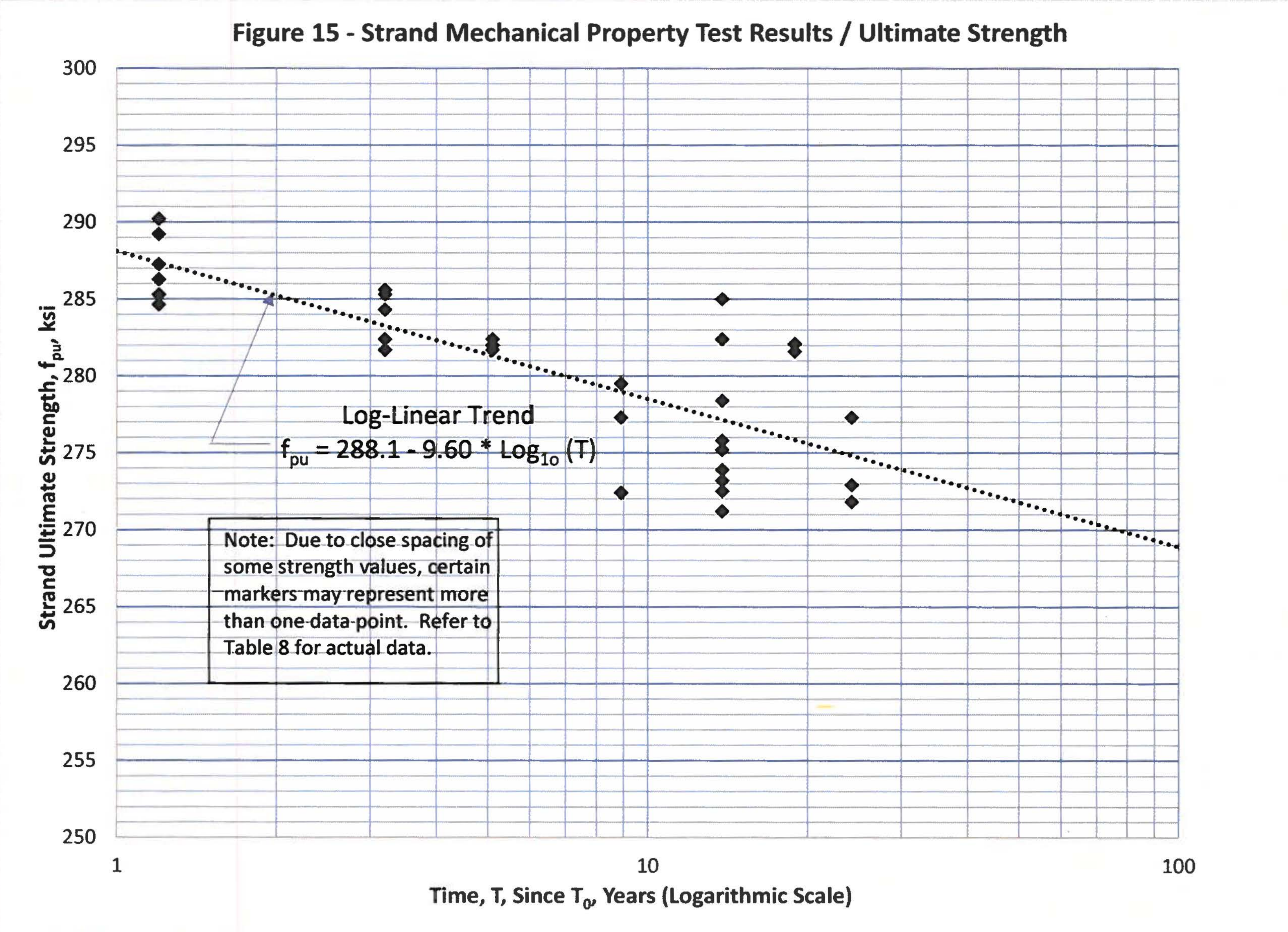
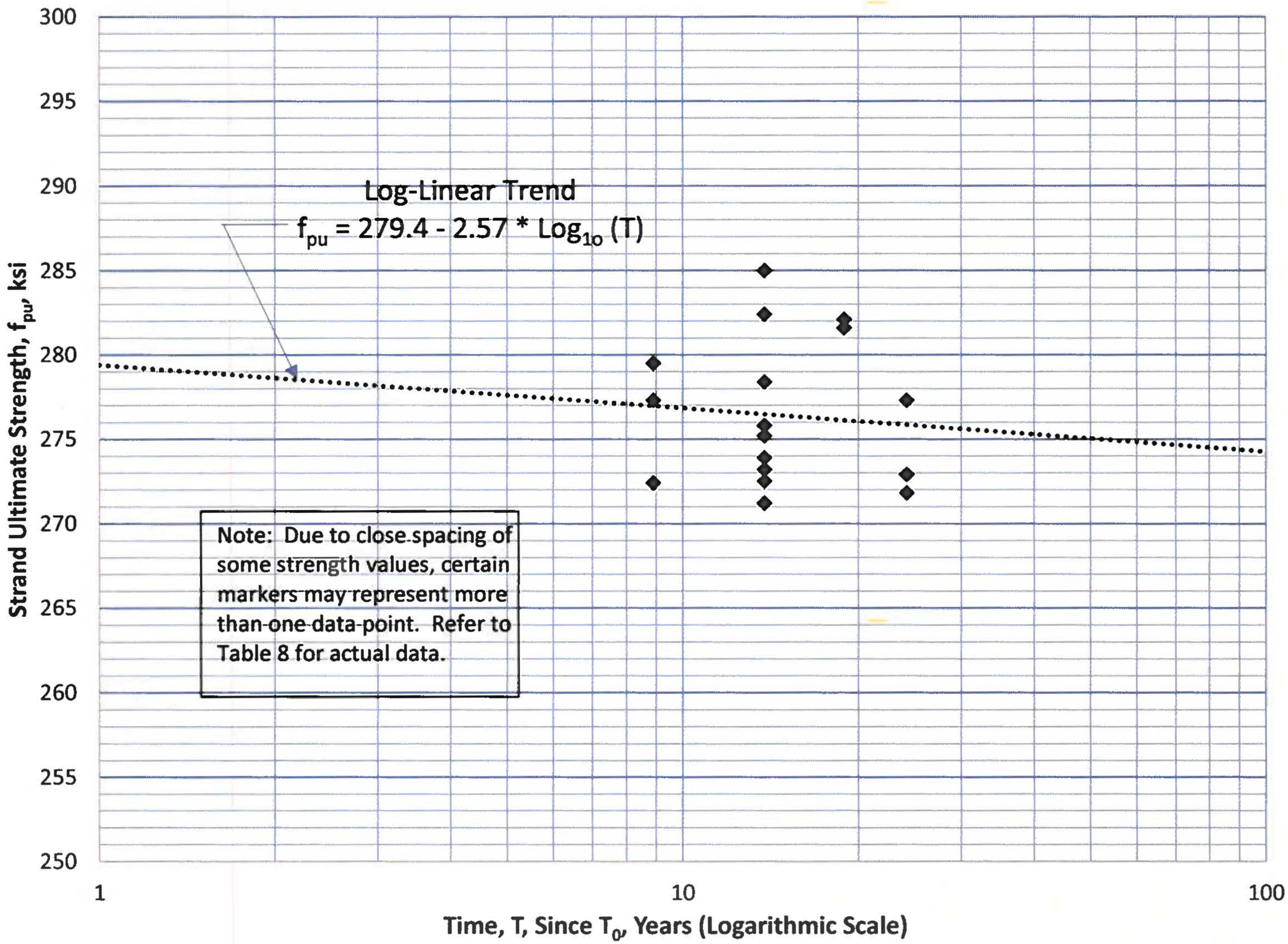


Figure 15 - Strand Mechanical Property Test Results / Ultimate Strength
Strand Ultimate Strength, fpu, ksi
300
295
290
285
280
275
270
265
260
255
250
1
10
100
Time, T, Since T0, Years (Logarithmic Scale)
Log-Linear Trend
fpu = 288.1 - 9.60 * Log10 (T)
Note: Due to close spacing of some strength values, certain markers may represent more than one data point. Refer to Table 8 for actual data.

Figure 16 - Strand Mechanical Property Test Results (1995 - 2010) / Ultimate Strength



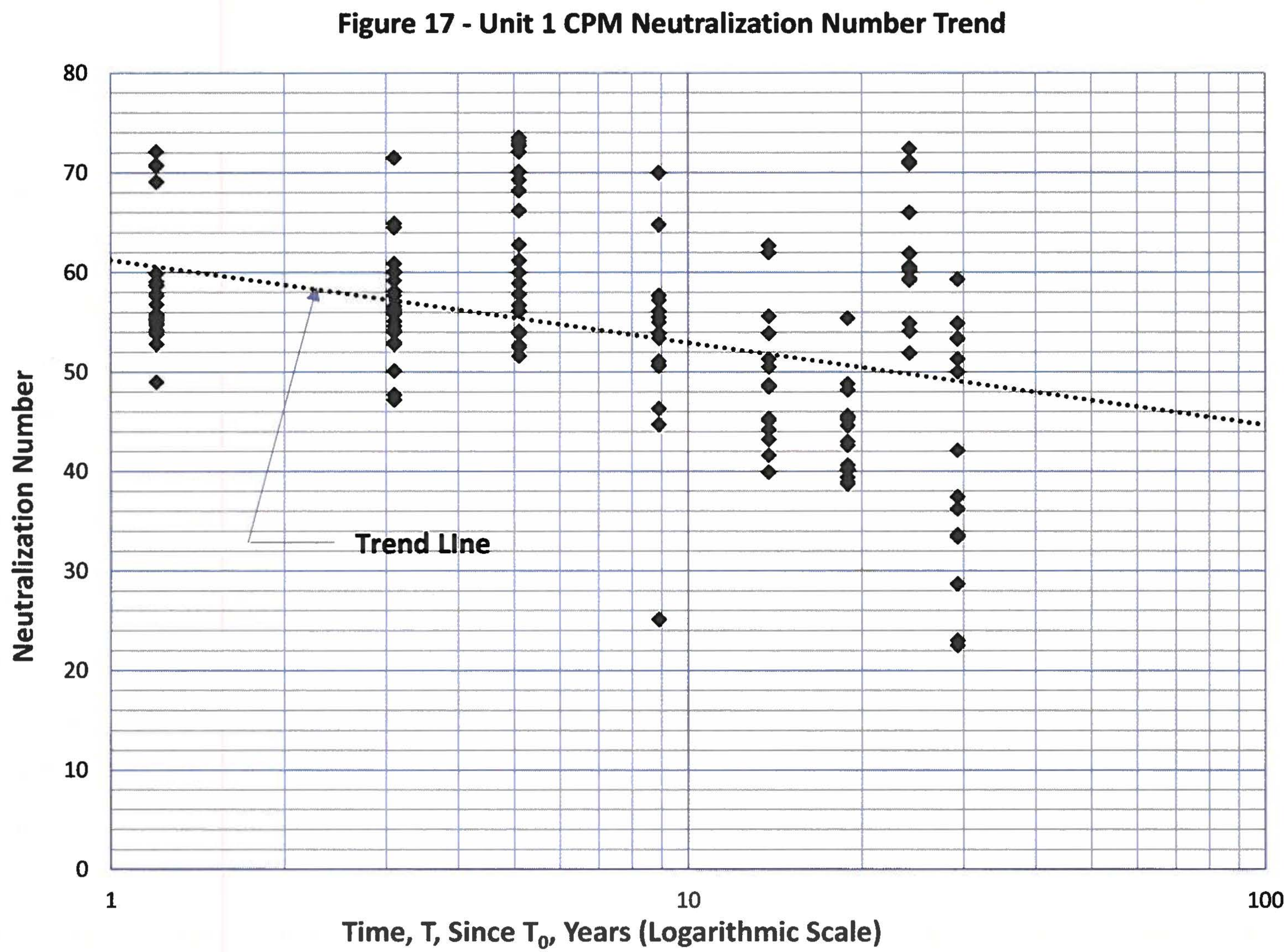
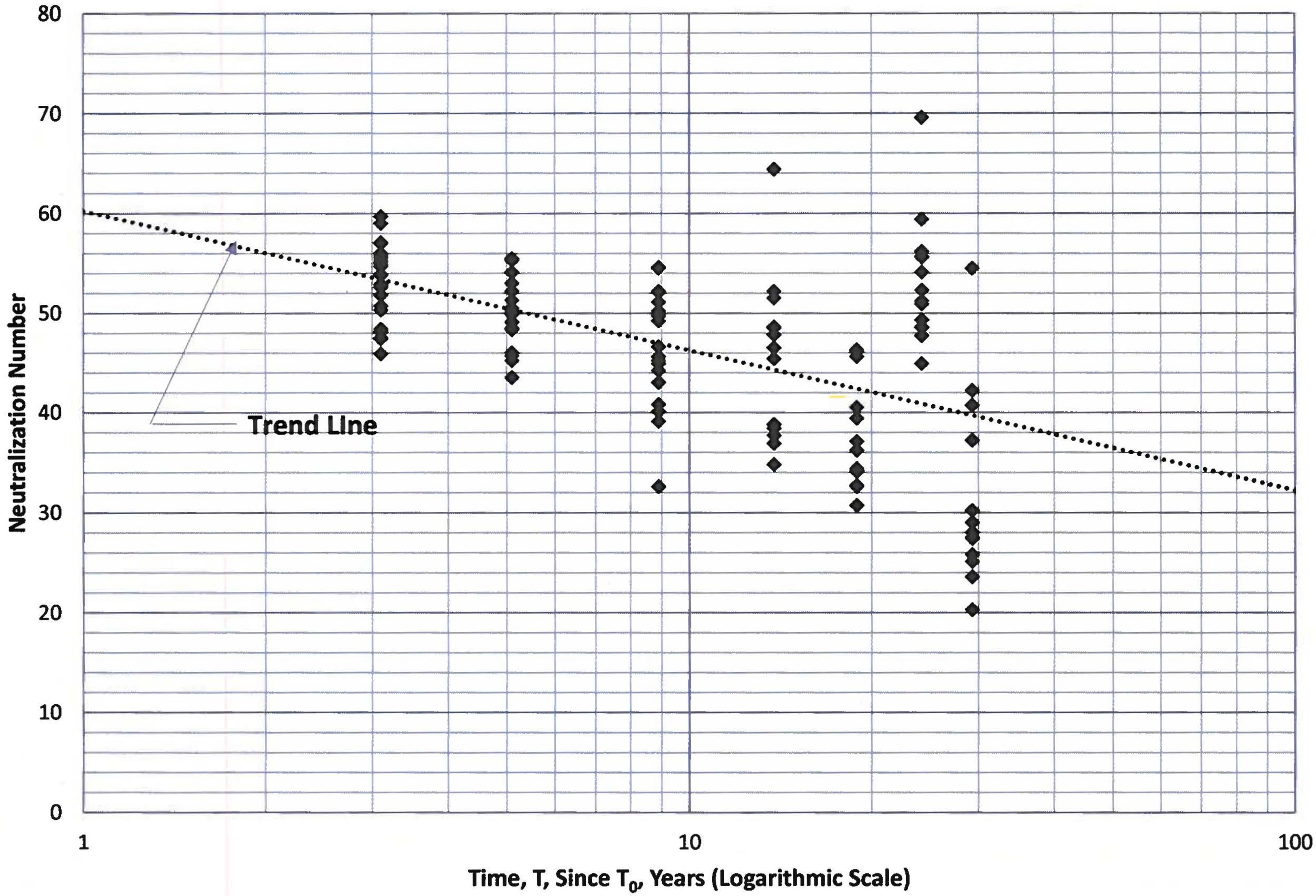


Figure 17 - Unit 1 CPM Neutralization Number Trend
80
70
60
50
40
30
20
10
0
Neutralization Number
Trend Line
1
10
100
Time, T, Since T_0, Years (Logarithmic Scale)

Figure 18 - Unit 2 CPM Neutralization Number Trend



Appendix – Normalization Factor / Normalized Force Calculation

[Note: The normalization factors computed below are based on calculation results tabulated in two early design documents, References 7.5 and 7.6. These factors are intended only for use in developing the normalized force plots and trends presented in this report. These may differ somewhat from factors derived in later pre-stressing force calculations that focus on predicting time dependent forces in individual tendons and that possibly utilize a more detailed analytical approach than was used in the earlier design calculations.]

As surveillance samples are relatively small, mean pre-stressing force computed using the small sample force measurements is often significantly above or below the true mean determined by all tendons in the group. This deviation results from the combined effects of two separate phenomena. One, the initial seating forces documented for the group sample tendons may be well above or below the mean seating force computed for all tendons in the group. And, two, the shortening / relaxation loss (loss of force in a tendon resulting from the concrete strain induced by subsequent tensioning activity and ongoing creep shrinkage and relaxation) may also be well above or below the mean loss. True mean pre-stressing force is estimated by normalizing measured sample tendon forces to account for effects of these phenomena.

Measured forces are multiplied by a computed normalization factor that, in its most basic form, is the ratio of group mean force (mean seating force less mean shortening / relaxation loss) to force (seating force less loss) in a specific tendon at the completion of pre-stressing operations. Loss is generally computed only for the effect of elastic strains induced by tensioning activities. The effects of creep, shrinkage and relaxation occurring over the tensioning period are usually considered secondary effects and are ignored. Elastic shortening loss is normally computed by a simplified procedure that accounts only for the order of tensioning. This procedure, which is addressed in USNRC Regulatory Guide 1.35.1 (Reference 7.26), does not account for incremental response of the concrete shell to the force induced by tensioning tendons at varying distances from the tendon of interest.

For the purpose of this report, normalization factor, NF, for a tendon is computed as:

$NF = F_{M0} / F_{i0}$

where

F_{M0} is the initial group mean force after elastic shortening losses

F_{i0} is the initial force in the tendon after elastic shortening losses

Initial seating forces and initial forces after elastic shortening losses (i.e., at the completion of prestressing) are tabulated for the tendons each Unit 1 group and each Unit 2 group in References 7.5 and 7.6, respectively. Two force values are shown for each tendon, one for each anchorage. These tabulations also list the group mean initial seating force and the group mean force, F_{M0}, after elastic shortening losses.

Normalization factors and normalized forces computed for each of the surveillance tendons are listed in Tables A-1 through A-6 below. Each table consists of the following 9 columns.

Tendon – The ID number of the surveillance tendon.

T – Time in years since T_0 (15 August 1986) assigned to the surveillance.

F_{init1} – Force after elastic shortening losses shown for the first listed tendon end in the P INIT. column of the applicable Reference 7.5 or 7.6 table (note that the tendon end forces are listed on separate lines).

F_{init2} – Force after elastic shortening losses shown for the second listed tendon end in the P INIT. column of the applicable Reference 7.5 or 7.6 table (note that the tendon end forces are listed on separate lines).

F_{i0} = (F_{init1} + F_{init2}) / 2– Mean end anchorage force after elastic shortening losses.

F_{M0} - Initial group mean force after elastic shortening losses from the last row under the P INIT. column of the applicable Reference 7.5 or 7.6 table.

F_{Meas} – Measured lift-off force documented in the applicable surveillance report (References 7.12 through 7.18).

NF – Normalization factor as defined above.

F_{Norm} = F_{Meas} * NF – Normalized force

Table A-1 - Unit 1 Cylinder Hoop Normalization Factor and Normalized Force (kips)								
Tendon	T	F_{Init1}	F_{Init2}	F_{I0}	F_{M0}	F_{Meas}	NF	F_{Norm}
1H-14	1.2	1,574	1,567	1,570.5	1,556	1,628	0.99077	1,613
1H-45	1.2	1,571	1,615	1,593.0	1,556	1,617	0.97677	1,579
1H-49	1.2	1,560	1,582	1,571.0	1,556	1,585	0.99045	1,570
1H-69	1.2	1,583	1,588	1,585.5	1,556	1,650	0.98139	1,619
1H-83	1.2	1,605	1,571	1,588.0	1,556	1,610	0.97985	1,578
1H-88	1.2	1,593	1,534	1,563.5	1,556	1,629	0.99520	1,621
1H-126	1.2	1,647	1,630	1,638.5	1,556	1,658	0.94965	1,575
1H-139	1.2	1,569	1,569	1,569.0	1,556	1,588	0.99171	1,575
1H-6	3.2	1,600	1,593	1,596.5	1,556	1,562	0.97463	1,522
1H-7	3.2	1,612	1,664	1,638.0	1,556	1,567	0.94994	1,489
1H-18	3.2	1,530	1,501	1,515.5	1,556	1,579	1.02672	1,621
1H-23	3.2	1,559	1,568	1,563.5	1,556	1,529	0.99520	1,522
1H-58	3.2	1,529	1,615	1,572.0	1,556	1,558	0.98982	1,542
1H-73	3.2	1,557	1,589	1,573.0	1,556	1,569	0.98919	1,552
1H-83	3.2	1,605	1,571	1,588.0	1,556	1,563	0.97985	1,532
1H-110	3.2	1,506	1,577	1,541.5	1,556	1,519	1.00941	1,533
1H-120	8.9	1,536	1,618	1,577.0	1,556	1,606	0.98668	1,585
1H-13	13.8	1,570	1,504	1,537.0	1,556	1,534	1.01236	1,553
1H-30	13.8	1,544	1,579	1,561.5	1,556	1,584	0.99648	1,578
1H-83	13.8	1,605	1,571	1,588.0	1,556	1,520	0.97985	1,489
1H-29	24.2	1,518	1,589	1,553.5	1,556	1,553	1.00161	1,555
1H-83	24.2	1,605	1,571	1,588.0	1,556	1,535	0.97985	1,504
1H-92	24.2	1,542	1,572	1,557.0	1,556	1,500	0.99936	1,499

Table A-2 - Unit 1 Dome Hoop Normalization Factor and Normalized Force (kips)								
Tendon	T	F_{Init1}	F_{Init2}	F_{I0}	F_{M0}	F_{Meas}	NF	F_{Norm}
1H-149	1.2	1,625	1,623	1,624.0	1,560	1,605	0.96059	1,542
1H-151	1.2	1,532	1,477	1,504.5	1,560	1,566	1.03689	1,624
1H-145	3.1	1,543	1,488	1,515.5	1,560	1,520	1.02936	1,565
1H-148	13.8	1,556	1,608	1,582.0	1,560	1,518	0.98609	1,497
1H-167	24.2	1,559	1,579	1,569.0	1,560	1,522	0.99426	1,513

Table A-3 - Unit 1 Inverted U Normalization Factor and Normalized Force (kips)								
Tendon	T	F_{Init1}	F_{Init2}	F_{I0}	F_{M0}	F_{Meas}	NF	F_{Norm}
1U4-108	1.2	1,561	1,572	1,566.5	1,572	1,587	1.00351	1,593
1U18-94	1.2	1,510	1,535	1,522.5	1,572	1,508	1.03251	1,557
1U42-144	1.2	1,545	1,559	1,552.0	1,572	1,575	1.01289	1,595
1U58-128	1.2	1,509	1,592	1,550.5	1,572	1,553	1.01387	1,575
1U13-99	3.2	1,548	1,549	1,548.5	1,572	1,505	1.01518	1,528
1U18-94	3.2	1,510	1,535	1,522.5	1,572	1,456	1.03251	1,503
1U31-81	3.2	1,554	1,597	1,575.5	1,572	1,518	0.99778	1,515
1U35-77	3.2	1,632	1,612	1,622.0	1,572	1,552	0.96917	1,504
1U10-102	5.1	1,584	1,622	1,603.0	1,572	1,556	0.98066	1,526
1U18-94	13.8	1,510	1,535	1,522.5	1,572	1,463	1.03251	1,511
1U70-116	13.8	1,637	1,577	1,607.0	1,572	1,586	0.97822	1,551
1U74-112	13.8	1,556	1,585	1,570.5	1,572	1,530	1.00096	1,531
1U21-91	18.9	1,551	1,565	1,558.0	1,572	1,506	1.00899	1,520
1U18-94	24.2	1,510	1,535	1,522.5	1,572	1,477	1.03251	1,525
1U49-137	24.2	1,540	1,565	1,552.5	1,572	1,510	1.01256	1,529

Table A-4 - Unit 2 Cylinder Hoop Normalization Factor and Normalized Force (kips)								
Tendon	T	F_{Init1}	F_{Init2}	F_{IO}	F_{MO}	F_{Meas}	NF	F_{Norm}
2H-31	5.1	1,550	1,498	1,524.0	1,543	1,442	1.01247	1,460
2H-36	5.1	1,506	1,577	1,541.5	1,543	1,483	1.00097	1,484
2H-71	5.1	1,528	1,581	1,554.5	1,543	1,511	0.99260	1,500
2H-99	5.1	1,529	1,550	1,539.5	1,543	1,439	1.00227	1,442
2H-103	5.1	1,489	1,582	1,535.5	1,543	1,493	1.00488	1,500
2H-26	8.9	1,534	1,457	1,495.5	1,543	1,470	1.03176	1,517
2H-46	8.9	1,552	1,529	1,540.5	1,543	1,474	1.00162	1,476
2H-64	8.9	1,579	1,562	1,570.5	1,543	1,537	0.98249	1,510
2H-74	8.9	1,511	1,522	1,516.5	1,543	1,488	1.01747	1,514
2H-99	8.9	1,529	1,550	1,539.5	1,543	1,467	1.00227	1,470
2H-114	8.9	1,597	1,573	1,585.0	1,543	1,508	0.97350	1,468
2H-66	18.9	1,530	1,630	1,580.0	1,543	1,478	0.97658	1,443
2H-99	18.9	1,529	1,550	1,539.5	1,543	1,458	1.00227	1,461
2H-111	18.9	1,492	1,540	1,516.0	1,543	1,450	1.01781	1,476
2H-32	24.2	1,552	1,568	1,560.0	1,543	1,472	0.98910	1,456
2H-99	24.2	1,529	1,550	1,539.5	1,543	1,447	1.00227	1,450
2H-125	24.2	1,520	1,522	1,521.0	1,543	1,493	1.01446	1,515

Table A-5 - Unit 2 Dome Hoop Normalization Factor and Normalized Force (kips)								
Tendon	T	F_{Init1}	F_{Init2}	F_{IO}	F_{MO}	F_{Meas}	NF	F_{Norm}
2H-155	5.1	1,592	1,582	1,587.0	1,572	1,488	0.99055	1,474
2H-163	5.1	1,569	1,559	1,564.0	1,572	1,523	1.00512	1,531
2H-159	18.9	1,527	1,522	1,524.5	1,572	1,426	1.03116	1,470
2H-152	24.2	1,534	1,540	1,537.0	1,572	1,454	1.02277	1,487

Table A-6 - Unit 2 Inverted U Normalization Factor and Normalized Force (kips)								
Tendon	**T**	**F_{Init1}**	**F_{Init2}**	**F_{I0}**	**F_{M0}**	**F_{Meas}**	**NF**	**F_{Norm}**
2U11-101	5.1	1,589	1,565	1,577.0	1,557	1,514	0.98732	1,495
2U13-99	5.1	1,553	1,510	1,531.5	1,557	1,464	1.01665	1,488
2U20-92	5.1	1,533	1,504	1,518.5	1,557	1,408	1.02535	1,444
2U18-94	8.9	1,526	1,509	1,517.5	1,557	1,474	1.02603	1,512
2U20-92	8.9	1,533	1,504	1,518.5	1,557	1,456	1.02535	1,493
2U26-86	8.9	1,524	1,608	1,566.0	1,557	1,502	0.99425	1,493
2U69-117	8.9	1,527	1,544	1,535.5	1,557	1,455	1.01400	1,475
2U20-92	18.9	1,533	1,504	1,518.5	1,557	1,444	1.02535	1,481
2U21-91	18.9	1,499	1,505	1,502.0	1,557	1,491	1.03662	1,546
2U56-130	18.9	1,590	1,603	1,596.5	1,557	1,549	0.97526	1,511
2U8-104	24.2	1,609	1,618	1,613.5	1,557	1,553	0.96498	1,499
2U20-92	24.2	1,533	1,504	1,518.5	1,557	1,460	1.02535	1,497
2U25-87	24.2	1,613	1,508	1,560.5	1,557	1,523	0.99776	1,520