6.5 Inadequate Tendon Re-tensioning in Surveillance Activities

Description:

The NRC requires periodic inspections of the containment concrete and post-tensioning system following ASME Code Section XI, Subsection IWL (FM 6.5 Exhibit 1). The subsection requires lift-off measurements of a subset of the dome, vertical, and hoop tendons. The criteria established for tendons “passing” or “failing” are described in NRC RegGuide 1.35 (FM 6.5 Exhibit 2) for surveillances 1 through 5, and in NRC RegGuide 1.35.1 (FM 6.5 Exhibit 3) for surveillances 6 through 8.

The predicted tendon force loss curves which establish acceptance criteria “base” values, are calculated for each tendon using known force loss mechanisms (FM 6.5 Exhibit 4, FM 6.5 Exhibit 5-w/o attachments, and FM 6.5 Exhibit 6) and design basis data taken from the plant’s Design Basis Documents (FM 6.5 Exhibit 12).

The CR3 containment has a history of measured tendon forces being below the RegGuide 1.35.1 requirements applied to the established “base” values (FM 6.5 Exhibit 7 and FM 6.5 Exhibit 8). This has resulted in periodic re-tensioning of numerous hoop tendons to -0% +6% of the “base” value (FM 6.5 Exhibit 2). These re-tensioning activities could potentially lead to excessive or uneven stressing of the containment concrete.

Data to be collected and Analyzed:

1. Review ASME Code Section XI, Subsection IWL (FM 6.5 Exhibit 1);
2. Review NRC RegGuide 1.35 (FM 6.5 Exhibit 2) and RegGuide 1.35.1 (FM 6.5 Exhibit 3);
3. Review tendon force loss mechanisms (FM 6.5 Exhibit 4) and tendon force loss calculations (FM 6.5 Exhibit 5);
4. Review input parameters to force loss curves (FM 6.5 Exhibit 12);

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5. Review tendon surveillance lift-off data (FM 6.5 Exhibit 7 and FM 6.5 Exhibit 8);
6. Review regression analysis done by PSC and Progress Energy to explain tendons "failing" (FM 6.5 Exhibit 9);
7. Draw tendon force curves for hoop tendons tested multiple times in bay 34 (FM 6.5 Exhibit 10);
8. Look for NCR for over-tensioning data;
9. Calculate stresses in the concrete from tendon re-tensioning (FM 6.5 Exhibit 11);

Verified Supporting Evidence:

a. Examination of the tendon surveillance records indicate "runs" of hoop tendons that did not meet the requirement of >95% predicted value (FM 6.5 Exhibit 7 and FM 6.5 Exhibit 8);
b. Tendon force loss curves show a force loss with time that is faster than predicted values (FM 6.5 Exhibit 10);

Verified Refuting Evidence:

a. No NCRs were found indicating re-tensioning above predicted value +6% force;
b. The four components going into the tendon force loss prediction are the elastic shortening, concrete shrinkage, concrete creep, and wire relaxation (FM 6.5 Exhibit 4). The regression analysis performed by PSC and Progress Energy on measured tendon forces show a better correlation than the predicted curves (FM 6.5 Exhibit 9). It also indicates that RegGuide 1.35.1 used with the CR3 DBD numbers may have underestimated the expected force loss, particularly for the horizontal tendons, resulting in overly conservative acceptance criteria, additional testing expansion, and re-tensioning activities to a higher than necessary base predicted value (-0%,+6%). Re-tensioning was conservative in ensuring that sufficient compressive pre-stress was maintained above the minimum required level, and well below the 1,635 kips original tensioning value;
c. Re-tensioning above the predicted value but below the original tensioning of 1,635 kips would not lead to additional stresses in the containment wall (FM 6.5 Exhibit 11);

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Discussion: The issue of tendon force losses being larger than the "predicted" values has been present at CR3 for the last three surveillances. It has been explained by CR3 and PSC by the use of a wrong "yardstick" as calculated in the tendon force loss prediction curves. A regression analysis was used instead to approximate tendon force losses that match better with measured lift-off forces. Our analysis of the data agrees with the CR3 and PSC assessment that the "yardstick" by which a tendon is said to "fail" is not correct. Therefore the tendon force losses are systematically under-estimated and the tendons "fail" to meet the predicted lift-off forces. The lift-off values are however much higher than the minimum values required for safe operation of the containment.
Conclusion: Tendon re-tensioning during surveillance activities did not contribute to the delamination.

SUBSECTION IWL REQUIREMENTS FOR CLASS CC CONCRETE COMPONENTS OF LIGHT-WATER COOLED PLANTS

Tables

ARTICLE IWL-1000
SCOPE AND RESPONSIBILITY

IWL-1100 SCOPE

(a) This Subsection provides the rules and requirements for preservice examination, inservice inspection and repair of the reinforced concrete and the post-tensioning systems of Class CC components, herein referred to as concrete containments as defined by CC-1000.

(b) The rules and requirements of this Subsection do not apply to the following:

(1) steel portions not backed by concrete;

(2) shell metallic liners;

(3) penetration liners extending the containment liner through the surrounding shell concrete.

IWL-1200 ITEMS SUBJECT TO EXAMINATION

IWL-1210 EXAMINATION REQUIREMENTS

The examination requirements of this Subsection shall apply to concrete containments.

IWL-1220 ITEMS EXEMPT FROM EXAMINATION

The following items are exempt from the examination requirements of IWL-2000:

(a) tendon end anchorages that are inaccessible, subject to the requirements of IWL-2521.1;

(b) portions of the concrete surface that are covered by the liner, foundation material, or backfill, or are otherwise obstructed by adjacent structures, components, parts, or appurtenances.

ARTICLE IWL-2000
EXAMINATION AND INSPECTION

IWL-2100 INSPECTION

Examinations shall be verified by an Inspector.

IWL-2200 PRESERVICE EXAMINATION

Preservice examination shall be performed in accordance with the requirements of IWL-2500.

IWL-2210 EXAMINATION SCHEDULE

Preservice examination shall be completed prior to initial plant startup.

IWL-2220 EXAMINATION REQUIREMENTS

IWL-2220.1 Concrete

(a) Preservice examination shall be performed in accordance with IWL-2510.

(b) The preservice examination shall be performed following completion of the containment Structural Integrity Test.

IWL-2220.2 Unbonded Post-Tensioning Systems. The following information shall be documented in the preservice examination records. This information may be extracted from construction records.

(a) Date on which each tendon was tensioned.

(b) Initial seating force in each tendon.

(c) For each tendon anchorage, the location of all missing or broken wires or stands and unseated wires.

(d) For each tendon anchorage, the location of all missing or detached buttonheads or missing wedges.

(e) The product designation for the corrosion protection medium used to fill the tendon duct.

IWL-2230 PRESERVICE EXAMINATION OF REPAIRS AND MODIFICATIONS

(a) When a concrete containment or a portion thereof is repaired or modified during the service lifetime of a plant, the preservice examination requirements shall be met for the repair or modification.

(b) When the repair or modification is performed while the plant is not in service, the preservice examination shall be performed prior to resumption of service.

(c) When the repair or modification is performed while the plant is in service, the preservice examination may be deferred to the next scheduled outage.

IWL-2300 VISUAL EXAMINATION, PERSONNEL QUALIFICATION, AND RESPONSIBLE ENGINEER A92

IWL-2310 VISUAL EXAMINATION AND PERSONNEL QUALIFICATION

(a) VT-1C visual examinations are conducted to determine concrete deterioration and distress for suspect areas detected by VT-3C, and conditions (e.g., cracks, wear, or corrosion) of tendon anchorage and wires or strands. Minimum illumination, maximum direct examination distance, and maximum procedure demonstration lower case character height shall be as specified in IWA-2210 for VT-1 visual examination.

(b) VT-3C visual examinations are conducted to determine the general structural condition of concrete surfaces of containments by identifying areas of concrete deterioration and distress, such as defined in ACI 201.1 R-68. The minimum illumination, maximum direct examination distance, and maximum procedure demonstration lower case character height shall be as specified in IWA-2210 for VT-3 visual examination.

(c) The Owner's written practice shall define qualification requirements for concrete examination personnel in accordance with IWA-2300. Limited certification in accordance with IWA-2350 may be used for examiners limited to concrete.

IWL-2320 RESPONSIBLE ENGINEER

The Responsible Engineer shall be a Registered Professional Engineer experienced in evaluating the inservice condition of structural concrete. The Responsible Engineer shall have knowledge of the design and Construction Codes and other criteria used in design and construction of concrete containments in nuclear power plants.

The Responsible Engineer shall be responsible for the following:

(a) development of plans and procedures for examination of concrete surfaces;

(b) approval, instruction, and training of concrete examination personnel;

(c) evaluation of examination results;

(d) preparation of repair procedures;

(e) submittal of report to the Owner documenting results of examinations and repairs.

IWL-2400 INSERVICE INSPECTION SCHEDULE

IWL-2410 CONCRETE

(a) Concrete shall be examined in accordance with IWL-2510 at 1, 3, and 5 years following the completion of the containment Structural Integrity Test CC-6000 and every 5 years thereafter.

(b) The 1, 3, and 5 year examinations shall commence not more than 6 months prior to the specified dates and shall be completed not more than 6 months after such dates. If plant operating conditions are such that examination of portions of the concrete cannot be completed within this stated time interval, examination of those portions may be deferred until the next regularly scheduled plant outage.

(c) The 10 year and subsequent examinations shall commence not more than 1 year prior to the specified dates and shall be completed not more than 1 year after such dates.

IWL-2420 UNBONDED POST-TENSIONING SYSTEMS

(a) Unbonded post-tensioning systems shall be examined in accordance with IWL-2520 at 1, 3, and 5 years following the completion of the containment Structural Integrity Test and every 5 years thereafter.

(b) The 1, 3, and 5 year examinations shall com-

mence not more than 6 months prior to the specified dates and shall be completed not more than 6 months after such dates. If plant operating conditions are such that examination of portions of the post-tensioning system cannot be completed within this stated time interval, examination of those portions may be deferred until the next regularly scheduled plant outage.

(c) The 10 year and subsequent examinations shall commence not more than 1 year prior to the specified dates and shall be completed not more than 1 year after such dates.

IWL-2421 Sites With Two Plants

(a) For sites with two plants, the examination requirements for the concrete containments may be modified if both containments utilize the same prestressing system and are essentially identical in design, if post-tensioning operations for the two containments were completed not more than 2 years apart, and if both containments are similarly exposed to or protected from the outside environment.

(b) 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, 10, 20, and 30 years. Only the examinations required by IWL-2524 and IWL-2525 need be performed at 5, 15, 25, and 35 years.

(2) For the containment with the second Structural Integrity Test, all examinations required by IWL-2500 shall be performed at 1, 5, 15, 25, and 35 years. Only the examinations required by IWL-2524 and IWL-2525 need be performed at 3, 10, 20, and 30 years.

IWL-2500 EXAMINATION REQUIREMENTS

Examination shall be performed in accordance with the requirements of Table IWL-2500-1.

A92 IWL-2510 EXAMINATION OF CONCRETE

(1) Concrete surface areas, including coated areas, except those exempted by IWL-1200(b), shall be VT-3C visual examined for evidence of conditions indicative of damage or degradation, such as defined in ACI 201.1 R-68, in accordance with IWL-2310(b). Selected areas, such as those that indicate suspect conditions, shall receive a VT-1C examination in accordance with IWL-2310(a).

(b) The examination shall be performed by, or under the direction of, the Responsible Engineer.

(c) Visual examinations may be performed from floors, roofs, platforms, walkways, ladders, ground surface, or other permanent vantage points, unless temporary close-in access is required by the inspection plan.

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IWL-2520 EXAMINATION OF UNBONDED POST-TENSIONING SYSTEMS

IWL-2521 Tendon Selection

(a) Tendons to be examined during an inspection shall be selected on a random basis except as noted in IWL-2521(b) and (c). The population from which the random sample is drawn shall consist of all tendons which have not been examined during earlier inspections. The number of tendons to be examined during an inspection shall be as specified in Table IWL-2521-1.

(b) One tendon of each type (as defined in Table IWL-2521-1) shall be selected from the first year inspection sample and designated as a common tendon. Each common tendon shall be examined during each inspection. A common tendon shall not be detensioned unless required by IWL-3300. If a common tendon is detensioned, another common tendon of the same type shall be selected from the first year inspection sample.

(c) If a containment with a stranded post-tensioning system is constructed with a predesignated number of detensionable tendons, one tendon of each type shall be selected from among those which are detensionable. The remaining tendons shall be selected from among those which cannot be detensioned.

IWL-2521.1 Exemptions. The following requirements shall apply to tendon anchorages that are not accessible for examination because of safety or radiological hazards or because of structural obstructions.

(a) After the process of randomly selecting tendons to be examined, any inaccessible tendons shall be designated as exempt and removed from the sample.

(b) Substitute tendons shall be selected for all tendons designated as exempt. Each substitute tendon shall be selected so that it is located as close as possible to

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TABLE IWL-2500-1
EXAMINATION CATEGORIES

EXAMINATION CATEGORY L-A, CONCRETE							
Item No.	Parts Examined	Test or Examination Requirement	Test or Examination Method	Acceptance Standard	Extent of Examination	Frequency of Examination	Deferral of Examination
L1.10	Concrete Surface						
L1.11	All Areas	IWL-2510	Visual, VT-3C	IWL-3210	IWL-2510	IWL-2410	NA
L1.12	Suspect Areas	IWL-2510	Visual, VT-1C	IWL-3210	IWL-2510	IWL-2410	NA

EXAMINATION CATEGORY L-B, UNBONDED POST-TENSIONING SYSTEM							
Item No.	Parts Examined	Test or Examination Requirement	Test or Examination Method	Acceptance Standard	Extent of Examination	Frequency of Examination	Deferral of Examination
L2.10	Tendon	IWL-2522	IWL-2522	IWL-3221.1	IWL-2521	IWL-2420	NA
L2.20	Wire or Strand	IWL-2523	IWL-2523.2	IWL-3221.2	IWL-2523.1	IWL-2420	NA
L2.30	Anchorage Hardware and Surrounding Concrete	IWL-2524	Visual, VT-1 and VT-1C	IWL-3221.3	IWL-2524.1	IWL-2420	NA
L2.40	Corrosion Protection Medium	IWL-2525	IWL-2525.2(a)	IWL-3221.4	IWL-2525.1(a)	IWL-2420	NA
L2.50	Free Water	IWL-2525	IWL-2525.2(b)		IWL-2525.1(b)	IWL-2420	NA

TABLE IWL-2521-1
NUMBER OF TENDONS FOR EXAMINATION

Inspection Period	Percentage[1,2] of all Tendons of Each Type[3]	Required Minimum[1] Number of Each Type	Maximum Required Number of Each Type
1st year	4	4	10
3rd year	4	4	10
5th year	4	4	10
10th year	2	3	5
15th year	2	3	5
20th year	2	3	5
25th year	2	3	5
30th year	2	3	5
35th year	2	3	5

NOTES:

(1) Fractional tendon numbers shall be rounded to the next higher integer. Actual number examined shall not be less than the minimum required number and need not be more than the maximum required number.

(2) The reduced sample size listed for the 10th year and subsequent inspections is applicable only if the acceptance criteria of IWL-3221.1 are met during each of the earlier inspections.

(3) A tendon type is defined by its geometry and position in the containment; e.g., hoop, vertical, dome, helical, and inverted U.

the exempted tendon, and shall be examined in accordance with IWL-2520.

(c) Each exempted tendon shall be examined in accordance with IWL-2524 and IWL-2525 to the extent that the end anchorages of the exempt tendon are accessible either during operation or at an outage.

IWL-2522 Tendon Force Measurements

(a) The prestressing force in all inspection sample tendons shall be measured by lift-off or an equivalent test.

(b) Equipment used to measure tendon force shall be calibrated in accordance with a calibration procedure prior to the first tendon force measurement and following the final tendon force measurement of the inspection period. Accuracy of the calibration shall be within 1.5% of the specified minimum ultimate strength of the tendon. If the post-test calibration differs from the pretest calibration by more than the specified accuracy tolerance, the results of the examination shall be evaluated.

IWL-2523 Tendon Wire and Strand Sample Examination and Testing

IWL-2523.1 Tendon Detensioning and Sample Removal. One sample tendon of each type shall be completely detensioned. A single wire or strand shall be removed from each detensioned tendon.

IWL-2523.2 Sample Examination and Testing

(a) Each removed wire or strand shall be examined over its entire length for corrosion and mechanical damage. The examination shall determine the location of most severe corrosion, if any. Strand wires shall be examined for wedge slippage marks.

(b) Tension tests shall be performed on each removed wire or strand: one at each end, one at mid-length, and one in the location of the most corroded area, if any. The following information shall be obtained from each test:

(1) yield strength

(2) ultimate tensile strength

(3) elongation

IWL-2523.3 Retensioning. Tendons that have been detensioned shall be retensioned to at least the force predicted for the tendon at the time of the test. However, the retensioning force shall not exceed 70% of the specified minimum ultimate tensile strength of the tendon based on the number of effective wires or strands in the tendon at the time of retensioning.

IWL-2524 Examination of Tendon Anchorage Areas

IWL-2524.1 Visual Examination. A VT-1 visual examination in accordance with IWA-2411 shall be performed on the tendon anchorage hardware, including bearing plates, anchorheads, wedges, buttonheads, shims, and the concrete extending outward a distance of 2 ft from the edge of the bearing plate. The following shall be documented:

(a) concrete cracks having widths greater than 0.01 in.;

(b) corrosion, broken or protruding wires, missing buttonheads, broken strands, and cracks in tendon anchorage hardware;

(c) broken wires or strands, protruding wires and detached buttonheads following retensioning of tendons which have been detensioned.

IWL-2524.2 Free Water Documentation. The quantity of free water contained in the anchorage end cap as well as any which drains from the tendon during the examination process shall be documented.

IWL-2525 Examination of Corrosion Protection Medium and Free Water

IWL-2525.1 Samples

(a) Samples of the corrosion protection medium shall

TABLE IWL-2525-1
CORROSION PROTECTION MEDIUM ANALYSIS

Characteristic	Test Method	Acceptance Limit
Water content	ASTM D 95	In course of preparation
Water soluble chlorides	ASTM D 512 [Note (1)]	10 ppm maximum
Water soluble nitrates	ASTM D 992 [Note (1)]	10 ppm maximum
Water soluble sulfides	APHA 427 [Note (1)] (Methylene blue)	10 ppm maximum
Reserve alkalinity (Base number)	ASTM D 974 Modified [Note (2)]	[Note (3)]

NOTES:

(1) *Water Soluble Ion Tests.* The inside (bottom and sides) of a one (1) liter beaker, approx. OD 105 mm, height 145 mm, is thoroughly coated with 100 ±10 grams of the sample. The coated beaker is filled with approximately 900 ml of distilled water and heated in an oven at a controlled temperature of 100°F (37.8°C) ±2°F for 4 hours. The water extraction is tested by the noted test procedures for the appropriate water soluble ions. Results are reported as PPM in the extracted water.

(2) *ASTM D 974 Modified.* Place 10 g of sample in a 500 ml Erlenmeyer flask. Add 10 cc isopropyl alcohol and 5 cc toluene. Heat until sample goes into solution. Add 90 cc distilled water and 20 cc 1NH_2SO_4. Place solution on a steam bath for ½ hour. Stir well. Add a few drops of indicator (1% phenolphthalein) and titrate with 1NNaOH until the lower layer just turns pink. If acid or base solutions are not exactly 1N, the exact normalities should be used when calculating the base number. The Total Base Number (TBN), expressed as milligrams of KOH per gram of sample, is calculated as follows:

$$TBN = \frac{[(20)(N_A) - (B)(N_B)]\,56.1}{W}$$

where

B = milliliters NaOH
N_A = normality of H_2SO_4 solution
N_B = normality of NaOH solution
W = weight of sample in grams

(3) The base number shall be at least 50% of the as-installed value, unless the as-installed value is 5 or less, in which case the base number shall be no less than zero. If the tendon duct is filled with a mixture of materials having various as-installed base numbers, the lowest number shall govern acceptance.

be taken from each end of each tendon examined. Free water shall not be included in the samples.

(b) Samples of free water shall be taken where water is present in quantities sufficient for laboratory analysis.

IWL-2525.2 Sample Analysis

(a) Corrosion protection medium samples shall be thoroughly mixed and analyzed for reserve alkalinity, water content, and concentrations of water soluble chlorides, nitrates, and sulfides. Analyses shall be performed in accordance with the procedures specified in Table IWL-2525-1.

(b) Free water samples shall be analyzed to determine pH.

IWL-2526 Removal and Replacement of Corrosion Protection Medium

The amount of corrosion protection medium removed at each anchorage shall be measured and the total amount removed from each tendon (two anchorages) shall be recorded. The total amount replaced in each tendon shall be recorded and differences between amount removed and amount replaced shall be documented.

ARTICLE IWL-3000 ACCEPTANCE STANDARDS

IWL-3100 PRESERVICE EXAMINATION

IWL-3110 CONCRETE SURFACE CONDITION

IWL-3111 Acceptance by Examination

The condition of the surface is acceptable if the Responsible Engineer determines that there is no evidence of damage or degradation sufficient to warrant further evaluation or repair.

IWL-3112 Acceptance by Evaluation

Items with examination results that do not meet the acceptance standards of IWL-3111 shall be evaluated as required by IWL-3300.

IWL-3113 Acceptance by Repair

Repairs required to reestablish acceptability of an item shall be completed as required by IWL-3300. Acceptable completion of the repair shall constitute acceptability of the item.

IWL-3120 UNBONDED POST-TENSIONING SYSTEM

The condition of the unbonded post-tensioning system is acceptable if it met the requirements of the construction specification at the time of installation.

IWL-3200 INSERVICE EXAMINATION

IWL-3210 CONCRETE SURFACE CONDITION

IWL-3211 Acceptance by Examination

The condition of the concrete surface is acceptable if the Responsible Engineer determines that there is no evidence of damage or degradation sufficient to warrant further evaluation or repair.

IWL-3212 Acceptance by Evaluation

Items with examination results that do not meet the acceptance standards of IWL-3211 shall be evaluated as required by IWL-3300.

IWL-3213 Acceptance by Repair

Repairs to reestablish the acceptability of an item shall be completed as required by IWL-3300. Acceptable completion of the repair shall constitute acceptability of the item.

IWL-3220 UNBONDED POST-TENSIONING SYSTEMS

IWL-3221 Acceptance by Examination

IWL-3221.1 Tendon Force. Tendon forces are acceptable if:

(a) the average of all measured tendon forces, including those measured in IWL-3221.1(b)(2), for each type of tendon is equal to or greater than the minimum required prestress specified at the anchorage for that type of tendon;

(b) the measured force in each individual tendon is not less than 95% of the predicted force unless the following conditions are satisfied:

(1) the measured force in not more than one tendon is between 90% and 95% of the predicted force;

(2) the measured forces in two tendons located adjacent to the tendon in IWL-3221.1(b)(1) are not less than 95% of the predicted forces; and

(3) the measured forces in all the remaining sample tendons are not less than 95% of the predicted force.

IWL-3221.2 Tendon Wire or Strand Samples. The condition of wire or strand samples is acceptable if:

(a) samples are free of physical damage;

(b) sample ultimate tensile strength and elongation be not less than minimum specified values.

IWL-3221.3 Tendon Anchorage Areas. The condition of tendon anchorage areas is acceptable if:

(a) there is no evidence of cracking in anchor heads, shims, or bearing plates;

(b) there is no evidence of active corrosion;

(c) broken or unseated wires, broken strands, and detached buttonheads were documented and accepted during a preservice examination or during a previous inservice examination;

(d) cracks in the concrete adjacent to the bearing plates do not exceed 0.01 in. in width.

IWL-3221.4 Corrosion Protection Medium. Corrosion protection medium is acceptable when the reserve alkalinity, water content, and soluble ion concentrations of all samples are within the limits specified in Table IWL-2525-1.

IWL-3222 Acceptance by Evaluation

Items with examination results that do not meet the acceptance standards of IWL-3221 shall be evaluated as required by IWL-3300.

IWL-3223 Acceptance by Repair or Replacement

Repairs or replacements to reestablish acceptability of the condition of an item shall be completed as required by IWL-3300. Acceptable completion of the repair or replacement shall constitute acceptability of the item.

IWL-3300 EVALUATION

IWL-3310 EVALUATION REPORT

Items with examination results that do not meet the acceptance standards of IWL-3100 or IWL-3200 shall be evaluated by the Owner. The Owner shall be responsible for preparation of an Engineering Evaluation Report stating the following:

(a) the cause of the condition which does not meet the acceptance standards;

(b) the acceptability of the concrete containment without repair of the item;

(c) whether or not repair or replacement is required and, if required, the extent, method, and completion date for the repair or replacement;

(d) extent, nature, and frequency of additional examinations.

IWL-3320 REVIEW BY AUTHORITIES

The Engineering Evaluation Report shall be subject to review by the regulatory and enforcement authorities having jurisdiction at the plant site.

ARTICLE IWL-4000 REPAIR PROCEDURES

IWL-4100 GENERAL

IWL-4110 SCOPE

This Article provides rules and requirements for repair of concrete containments.

IWL-4120 REPAIR/REPLACEMENT PROGRAM

(a) Repairs shall be performed in accordance with the Repair/Replacement Program required by IWA-4140.

(b) Repairs shall be completed in accordance with the Repair Plan of IWL-4200.

(c) The Repair/Replacement Program shall address concrete material control.

IWL-4200 REPAIR PLAN

The Repair Plan shall be developed under the direction of a Responsible Engineer (IWL-2500).

IWL-4210 CONCRETE REPAIR

(a) The Repair Plan shall specify requirements for removal of defective material.

(b) The affected area shall be visually examined to assure proper surface preparation of concrete and reinforcing steel prior to placement of repair material.

(c) When removal of defective material exposes reinforcing steel, the reinforcing steel shall receive a VT-1 visual examination. Reinforcing steel is acceptable when the Responsible Engineer determines that there is no evidence of damage or degradation sufficient to warrant further evaluation or repair. When required, reinforcing steel shall be repaired in accordance with IWL-4220. Repair of exposed-end anchors of the post-tensioning system shall be in accordance with IWL-4230.

(d) Repair material shall be chemically, mechanically, and physically compatible with existing concrete.

(e) When detensioning of prestressing tendons is required for repair of the concrete surface adjacent to the tendon, the Repair Plan shall require the following:

(1) selection of repair material to minimize stress and strain incompatibilities between repair material and existing concrete;

(2) procedures for application of repair material;

(3) procedures for detensioning and retensioning of prestressing tendons.

(f) The Repair Plan shall specify requirements for in-process sampling and testing of repair material.

IWL-4220 REPAIR OF REINFORCING STEEL

Damaged reinforcing steel shall be repaired by any method permitted in the original Construction Code or in Section III, Division 2, with or without removal of the damaged reinforcing steel.

IWL-4230 REPAIR OF THE POST-TENSIONING SYSTEM

(a) Weld repair of bearing plates and shim plates of the post-tensioning system shall meet the applicable requirements of IWA-4000. The corrosion protection medium shall be restored following the repair.

(b) Procedures for detensioning and retensioning of prestressing tendons shall be specified in the Repair Plan.

IWL-4300 EXAMINATION

The repaired area shall be examined in accordance with IWL-2000 to establish a new preservice record and shall meet the acceptance standards of IWL-3000.

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ARTICLE IWL-5000
SYSTEM PRESSURE TESTS

IWL-5100 SCOPE

This Article provides requirements for pressure testing concrete containments following repair or replacement.

IWL-5200 SYSTEM TEST REQUIREMENTS

IWL-5210 GENERAL

A containment pressure test shall be performed following repair or replacement unless any of the following conditions exist:

(a) The Engineering Evaluation Report (IWL-3310) demonstrates that the structural integrity of containment in the existing unrepaired condition has not been reduced below that required by the original design criteria.

(b) The repair or replacement affects only the cover concrete external to the outermost layer of structural reinforcing steel or post-tensioning tendons.

(c) The repair or replacement involves only exchange of post-tensioning tendons, tendon anchorage hardware, shims, or corrosion protection medium.

IWL-5220 TEST PRESSURE

The pressure test shall be conducted at the design basis accident pressure, P_a.

IWL-5230 LEAKAGE TEST

If the repair or replacement penetrated the containment metallic liner, or otherwise breached containment leak-tight integrity, a leakage rate test shall be conducted as required by IWE-5000.

IWL-5240 SCHEDULE OF PRESSURE TEST

If the repair or replacement is performed with the plant shutdown, the pressure test shall be conducted prior to resumption of operation. If the repair or replacement is performed with the plant in operation, the pressure test may be deferred until the next scheduled integrated leak-rate test.

IWL-5250 TEST PROCEDURE AND EXAMINATIONS

The pressure test shall be conducted in accordance with a detailed procedure prepared under the direction of the Responsible Engineer. The surface of all containment concrete placed during repair or replacement operations shall be examined by VT-1 examination prior to start of pressurization, at test pressure, and following completion of depressurization. Extended surface examinations, additional examinations during pressurization, other examinations, and measurements of structural response to pressure shall be conducted as specified by the Responsible Engineer.

IWL-5260 CORRECTIVE MEASURES

If the surface examinations of IWL-5250 cannot satisfy the requirements specified by the Responsible Engineer, the area shall be examined to the extent necessary to establish requirements for corrective action. Repairs shall be performed in accordance with IWL-4000, and pressure testing shall be repeated in accordance with IWL-5200, prior to returning the containment to service.

IWL-5300 REPORT

A pressure test report shall be prepared under the direction of the Responsible Engineer. This report may be an addition to a previously-prepared Engineering Evaluation Report (IWL-3310). The report shall describe pressure test procedures and examination results and shall state whether or not the repair or replacement is acceptable. If the repair or replacement is not acceptable, the report shall specify corrective measures.

ARTICLE IWL-7000
REPLACEMENTS

IWL-7100 GENERAL REQUIREMENTS

IWL-7110 SCOPE

(a) This Article provides rules and requirements for reinstallation and replacement of post-tensioning system items for concrete containments.

(b) Grease caps and installation screws are exempt from the requirements of this Article.

IWL-7120 REPLACEMENT PROGRAM

The following items, as applicable, shall be contained in the Replacement Plan:

(a) requirements for removal of items that are to be replaced;

(b) surface preparation required prior to installation of replacement items;

(c) examinations required prior to installation of replacement items;

(d) detensioning and retensioning requirements for tendons affected by installation of replacement items;

(e) requirements and procedures applicable to installation of replacement items;

(f) in-process sampling and testing requirements to be performed during installation of replacement items.

U.S. NUCLEAR REGULATORY COMMISSION
Revision 3
July 1990

REGULATORY GUIDE

OFFICE OF NUCLEAR REGULATORY RESEARCH

REGULATORY GUIDE 1.35
(TASK SC 810-4)

INSERVICE INSPECTION OF UNGROUTED TENDONS IN PRESTRESSED CONCRETE CONTAINMENTS

A. INTRODUCTION

General Design Criterion 53, "Provisions for Containment Testing and Inspection," of Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," requires, in part, that the reactor containment be designed to permit (1) periodic inspection of all important areas and (2) an appropriate surveillance program. This guide describes a basis acceptable to the NRC staff for developing an appropriate inservice inspection and surveillance program for ungrouted tendons[1] in prestressed concrete containment structures of light-water-cooled reactors.

The Advisory Committee on Reactor Safeguards has been consulted concerning this guide and has concurred in the regulatory position.

Any information collection activities mentioned in this regulatory guide are contained as requirements in 10 CFR Part 50, which provides the regulatory basis for this guide. The information collection requirements in 10 CFR Part 50 have been cleared under OMB Clearance No. 3150-0011.

B. DISCUSSION

Following the issuance for public comment of the proposed Revision 3 of this regulatory guide (Task SC 810-4) and of the accompanying proposed Regulatory Guide 1.35.1 (Task SC 807-4) in April 1979, the NRC Office of Research awarded a contract to Oak Ridge National Laboratory (ORNL). The contract work included evaluating actual inspections performed by licensees, the methods of implementing Revision 2 of this guide, and the opinions and problems of utilities, A/Es, vendors, etc., related to Revision 2 of this regulatory guide. The contractor also considered the pertinent portion of the January 1982 draft version of "Inservice Inspection of Concrete Pressure Components," developed by a Working Group of ASME Section XI, in making final suggestions for modifying this guide. These suggestions were published in NUREG/CR-2719.[2]

This guide has been revised to reflect public comments, suggestions from ORNL, and additional staff review.

Regulatory Position 1 provides general information on the applicability of the guide, frequency of inservice inspections, and inspections when there are two containments at a site.

Regulatory Position 2 delineates the method of determining sample size and emphasizes random sampling. If random sampling can not be assured, it is acceptable to select representative samples from

[1]For the purpose of this guide, a tendon is defined as a separate continuous multiwire or multistrand tensioned element anchored at both ends to an end anchorage assembly.

[2]NUREG/CR-2719, "Evaluation of Inservice Inspections of Greased Prestressing Tendons," by J. R. Dougan, Nuclear Regulatory Commission, September 1982. Available for sale from the U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20013-7082, or from the National Technical Information Service, Springfield, VA 22161.

between the pairs of buttresses and from various heights. The samples for each inspection may be selected any time prior to the inspection. Since inspections can be performed when the plant is operating, there may be certain areas where inspection of a randomly selected tendon might result in some radiological exposure to the inspecting personnel. The position provides for substituting a readily accessible tendon for such a tendon.

Regulatory Position 3 describes the areas and extent of visual examinations during each inspection.

Regulatory Position 4 presents the criteria for performing prestress monitoring tests.

Regulatory Position 5 states the extent and scope of tendon material testing.

Regulatory Position 6 lists items that should be considered in the inspection of sheathing filler grease. In order to assess the potential grease leakage, a recommendation is made to compare the amount of sheathing filler grease removed with that being replaced.

Regulatory Position 7 discusses the individual criteria for evaluating inspection results as follows:

In Regulatory Position 7.1, prestress monitoring criteria have been developed to ensure that any signs of systematic tendon force degradation are detected and investigated. Acceptance of 95% of the predicted force for two tendons out of three in Regulatory Position 7.1.3 is a slightly relaxed criterion from Revision 2 of the guide. It should be recognized, however, that the primary objective is to compare the measured tendon forces against the predicted forces at the time of the lift-off testing. Regulatory Guide 1.35.1 provides guidance on establishing the predicted forces.

A provision has been added to check the average of measured forces against the minimum required force in an average (hypothetical) tendon in a group. This provision is added as a result of a suggestion from the contractor (ORNL) and public comments. It should be recognized that each individual tendon force (measured) will have to be modified to reflect the condition of an average tendon. The contributing modifying factors would be the difference in installation forces and in the elastic shortening losses, assuming the time-dependent characteristics remain essentially the same for the group of tendons.

The loss of prestress from creep and shrinkage of concrete and stress relaxation of the tendon steel are time-dependent and are predicted on such a basis. The predicted tendon force may be represented by a sloped line in a semi-logarithmic graph. The trend of the actual effective tendon force is obtained by joining the points on the graph representing the measured tendon forces in two or more surveillances of the same tendon or tendons in a group. By extending the trend line, one can determine when the effective tendon force will be below the minimum required.

Regulatory Position 7.2 provides a means of tracking elongations during lift-off testing. The 10% tolerance in elongations at specific loads of retensioned tendons should include the effect of differential friction (from fully greased vs. coated tendons) and errors attributed to calibration, measurement procedures, and equipment.

Regulatory Position 7.4 provides detailed guidance on the results of the grease examination.

The incident of tendon anchor head failures at Farley demonstrated that the free water in grease was the main source of hydrogen for hydrogen stress cracking of high-hardness anchor heads. High-hardness anchor heads are used in large-size tendon systems (i.e., $\geq$750 tons). Since the small-size ($\leq$750 tons) tendons have not exhibited such characteristics, two limits for water are provided. It should be recognized that these limits are not the threshold limits for distress in anchor heads. When these limits are exceeded, it is advisable to detension the tendon and look for cracks on the shim side of the anchor heads.

An assessment of a base number for filler grease has been proposed for new grease in ASME Section III, Division 2, and for new and old grease in ASME Section XI. The grease used in many operating plants tends to have a low base number ($\leq$5). The newer grease formulations tend to have base numbers in excess of 20. Hence, two acceptance limits have been provided.

At least two plants that implemented the detailed grease examination criteria experienced problems with the void limit of 5%. Further inquiry into the matter revealed that when the injection pressure was very high (twice the pressure used during installation of grease), the amount of grease replaced was 10 to 15% higher than that removed. The staff discourages this practice, as there is a likelihood of tearing the sheathing joints at such pressures, opening a way for grease to seep into the concrete. Hence, Regulatory Position 7.4 has been revised to reflect this consideration.

The NRC staff encourages operating plant licensees to review their existing tendon inservice inspection programs and evaluate them from the standpoint of operating convenience, safety improvements, and cost reduction potential.

The NRC staff recognizes that in some older plants (plants operating before the initial issuance of Regulatory Guide 1.35 in 1974), adopting all provisions of this revised guide may not be feasible without extensive retrofitting. In such cases, licensees are advised to present their revised inservice inspection programs with any necessary exemptions from the specific provisions of this guide. If licensees adopt this Revision 3 to Regulatory Guide 1.35, it should be adopted in its entirety, not just segments of the guide.

C. REGULATORY POSITION

1. GENERAL

1.1. The inservice inspection program described in this guide should be used with the following types of prestressed concrete containment structures:

a. Prestressed concrete containments having a shallow-dome roof on cylindrical walls with the cylinder prestressed in hoop and vertical directions and the dome prestressed by three families of tendons at 60°.

b. Prestressed concrete containments having a hemispherical-dome roof on cylindrical walls with two families of inverted U tendons placed at 90° to each other and hoop tendons located in the cylinder and dome.

1.2. For containments that differ from these two types, the program described should serve as the basis for the development of a comparable inservice inspection program.

1.3. The inservice inspection should be performed 1, 3, and 5 years after the initial structural integrity test (ISIT) and every 5 years thereafter.

1.4. Containments should be designed and constructed so that the prestressing anchor hardware is accessible for inservice inspection.

1.5. All containment structures with ungrouted tendons should be inspected in accordance with this guide. However, the liftoff force comparison may be performed as shown in Figure 1 if any two containments at the same site are shown to satisfy all three of the following conditions:

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

b. Their ISITs were performed within two years of each other.

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

For both containments, the visual and filler grease inspection should be performed according to Regulatory Positions 3 and 6 at frequencies described in Regulatory Position 1.3.

2. SAMPLE SELECTION

2.1. For the inspections at 1, 3, and 5 years, 4% of the population of each group (vertical, hoop, dome, and inverted U) of tendons should be selected randomly with a minimum of four tendons from each group. The sample size from any group need not exceed ten.

2.2. If the inspections performed at 1, 3, and 5 years indicate no abnormal degradation of the post-tensioning system, 2% of the population of each group (vertical, hoop, dome, and inverted U) of tendons or five tendons, whichever is less, may be selected for the subsequent inspection with a minimum of three tendons for each group.

2.3. The fraction obtained as a percentage of a tendon population should be rounded off to the nearest integer.

2.4. The tendons to be inspected should be randomly selected from each group during each inspection. However, to develop a history and to correlate the observed data, one tendon from each group should be kept unchanged after the initial selection, and these unchanged tendons should be identified as control tendons.

2.5. If, owing to plant operating conditions, a randomly selected tendon from a group cannot be inspected during a scheduled inspection, another sample from the group should be randomly selected. The tendon that was selected but not inspected should be inspected during the following plant shutdown and accepted (or rejected) on an individual tendon basis.

2.6. Tendons, except the control tendons, that had been inspected and found intact during previous inspections should be excluded from the group population during subsequent inspections.

3. VISUAL INSPECTION

3.1. The exterior surface of the containment should be visually examined to detect areas of large spall,[3] severe scaling, D-cracking in an area of 25 square feet or more, other surface deterioration or disintegration, or grease leakage.

3.2. Tendon anchorage assembly hardware (such as bearing plates, stressing washers, shims, wedges, and buttonheads) of all tendons selected as described in Regulatory Position 2 should be visually examined. For those containments for which only visual inspections need be performed, tendons selected as described in Regulatory Position 2 should be visually examined to the extent practical without dismantling load-bearing components of the anchorage or removing grease caps.

3.3. Bottom grease caps of all vertical tendons should be visually inspected to detect grease leakage or grease cap deformations. Removal of grease caps is not necessary for this inspection.

[3]The terms "large spall," "severe scaling," "D-cracking," "deterioration" and "disintegration" are as defined in the American Concrete Institute publication, ACI 201.1R-68, "Guide for Making a Condition Survey of Concrete in Service." The publication can be obtained from the American Concrete Institute, Redford Station, Detroit, Michigan 48219.

5.4. Concrete surrounding visually inspected tendon anchorages should also be checked visually for indications of abnormal material behavior.

4. PRESTRESS MONITORING TESTS

Tendons selected as described in Regulatory Position 2 should be subjected to liftoff or other equivalent tests to monitor their prestress. Additionally, the tests should include the following:

4.1. One tendon, randomly selected from each group of tendons during each inspection, should be subjected to necessary detensioning in order to identify broken or damaged wires or strands.

4.2. The simultaneous measurement of elongation and jacking force during retensioning should be made at a minimum of three approximately equally spaced levels of force between zero and the lock-off force.

5. TENDON MATERIAL TESTS AND INSPECTIONS

5.1. A previously stressed tendon wire or strand from one tendon of each group should be removed for testing and examination over its entire length to determine if evidence of corrosion or other deleterious effects is present. At each successive inspection, the samples should be selected from different tendons. The tendon selected may be the same as that selected for detensioning. In addition, all wires or strands identified as broken should be removed for tensile testing and visual examination.

5.2. Tensile tests should be made on at least three samples cut from each removed wire or strand, one at each end and one at mid-length. The samples should be the maximum length practical for testing and the gauge length for the measurement of elongation should be in accordance with the relevant ASTM specification. The following information should be obtained from each test:

1. Yield strength
2. Ultimate tensile strength
3. Elongation at ultimate tensile strength

6. INSPECTION OF FILLER GREASE

A sample of sheathing filler grease from each of the sample tendons should be taken and analyzed according to the following national standards.

1. To determine water content, ASTM D95, "Standard Test Methods for Water in Petroleum Products and Bituminous Materials by Distillation."[4]
2. To determine reserve alkalinity, ASTM D974, "Standard Test Methods for Neutralization Number by Color-Indicator Titration."[4,5]
3. To determine the concentrations of water-soluble chlorides, ASTM D512, "Standard Test Methods for Chloride Ion in Water."[4]
4. To determine nitrates, ASTM D3867, "Standard Test Methods for Nitrite-Nitrate in Water"[4] (formerly ASTM D992).
5. To determine sulfides, APHA 428, "Standard Methods for Examination of Water and Waste Water."[6]

In addition, the amount of sheathing filler grease removed and replaced should be compared to assess grease leakage within the structure.

7. EVALUATION OF INSPECTION RESULTS

7.1. The prestressing force measured for each tendon in the tests described in Regulatory Position 4 should be compared with the limits predicted for the time of that test. Regulatory Guide 1.35.1 provides further information on the determination of these limits.

7.1.1. If the measured prestressing force of the selected tendon in a group lies above the prescribed lower limit, the liftoff test is considered to be a positive indication of the sample tendon's acceptability.

7.1.2. If the measured prestressing force of a selected tendon in a group lies between 95% of the prescribed lower limit and 90% of the prescribed lower limit, two additional tendons, one on each side of the first tendon, should be checked for their prestressing forces. If the prestressing forces of each of the second and third tested tendons are above 95% of the prescribed lower limits for the tendons, all three tendons should be restored to the required level of integrity and the tendon group should be considered acceptable.

7.1.3. In Regulatory Position 7.1.2, if the prestressing force of any two adjoining tendons falls below 95% of the prescribed lower limits of the tendons, additional lift-off testing should be done to detect the cause and extent of such occurrence. The condition should be considered reportable.

7.1.4. If the measured prestressing force of the selected tendon lies below 90% of the prescribed lower limit, the defective tendon should be fully investigated and a determination should be made as to the extent and cause of such occurrence. Such an occurrence should be considered a reportable condition.

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[4]ASTM Standards can be obtained from the American Society of Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

[5]Modified by Note 3 of Table CC-2422-1 of the ASME B&PV, Section III, Div. 2, 1982 Winter Addenda.

[6]APHA Standards can be obtained from the American Public Health Association, 1015 Eighteenth Street NW., Washington, DC 20036.

the average of all measured tendon forces for each group (corrected for average condition) is found to be less than the minimum required prestress level (as defined in the plant's Technical Specifications) at anchorage location for that group, the condition should be considered reportable.

7.1.6. If from consecutive surveillances the measured prestressing forces for the same tendon or tendons in a group indicate a trend of prestress loss larger than expected and the resulting prestressing forces will be less than the minimum required for the group before the next scheduled surveillance, additional lift-off testing should be done to determine the cause and extent of such occurrence. The condition should be considered reportable.

7.2. During detensioning and retensioning of tendons (Regulatory Position 4.2), if the elongation corresponding to a specific load differs by more than 10% from that recorded during installation of the tendons, an investigation should be made to ensure that the difference is not related to wire failures or slip of wires in anchorages. A difference of more than 10% should be considered reportable.

7.3. Failure in the tensile test at a strength or elongation value less than the minimum requirements of the tendon material should be considered reportable. Other conditions that indicate corrosion (metal reduction) found by visually examining wire or strands should be considered reportable.

7.4. Reportable conditions for sampled sheathing filler grease include:

a.	Water content	Exceeding 10% by wt
b.	Chlorides	Exceeding 10 ppm
c.	Nitrates	Exceeding 10 ppm
d.	Sulfides	Exceeding 10 ppm
e.	Reserve alkalinity (Base numbers)	Less than 50% of the installed value or less than zero when the installed value was less than 5

f. Amount of grease replaced exceeds 5% of the net duct volume, when injected at the original installation pressure.

g. Grease leakage detected during general visual examination of the containment exterior surface.

h. Presence of free water.

8. REPORTING TO THE NRC

The reportable conditions listed in Regulatory Positions 7.1.3, 7.1.4, 7.1.5, 7.3, or 7.4 could indicate a possible abnormal degradation of the containment structure (a boundary designed to contain radioactive materials). Any such condition should be reported to the NRC in accordance with the recommended reporting program of Regulatory Guide 1.16, "Reporting of Operating Information—Appendix A Technical Specifications."

The NRC staff recognizes that for some containment designs, adoption of all provisions of this guide may not be feasible. In those cases, licensees should present alternatives for those provisions of the guide they are unable to implement.

D. IMPLEMENTATION

The purpose of this section is to provide information to applicants and licensees regarding the NRC staff's plans for using this regulatory guide.

Except in those cases in which the applicant or licensee proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the methods described herein will be used in the evaluation of inservice inspection and surveillance programs for the following nuclear power plants using prestressed concrete containments with ungrouted tendons:

1. Plants for which the construction permit or design approval is issued after July 31, 1990.
2. Plants for which the licensee voluntarily commits to the provisions of this guide.

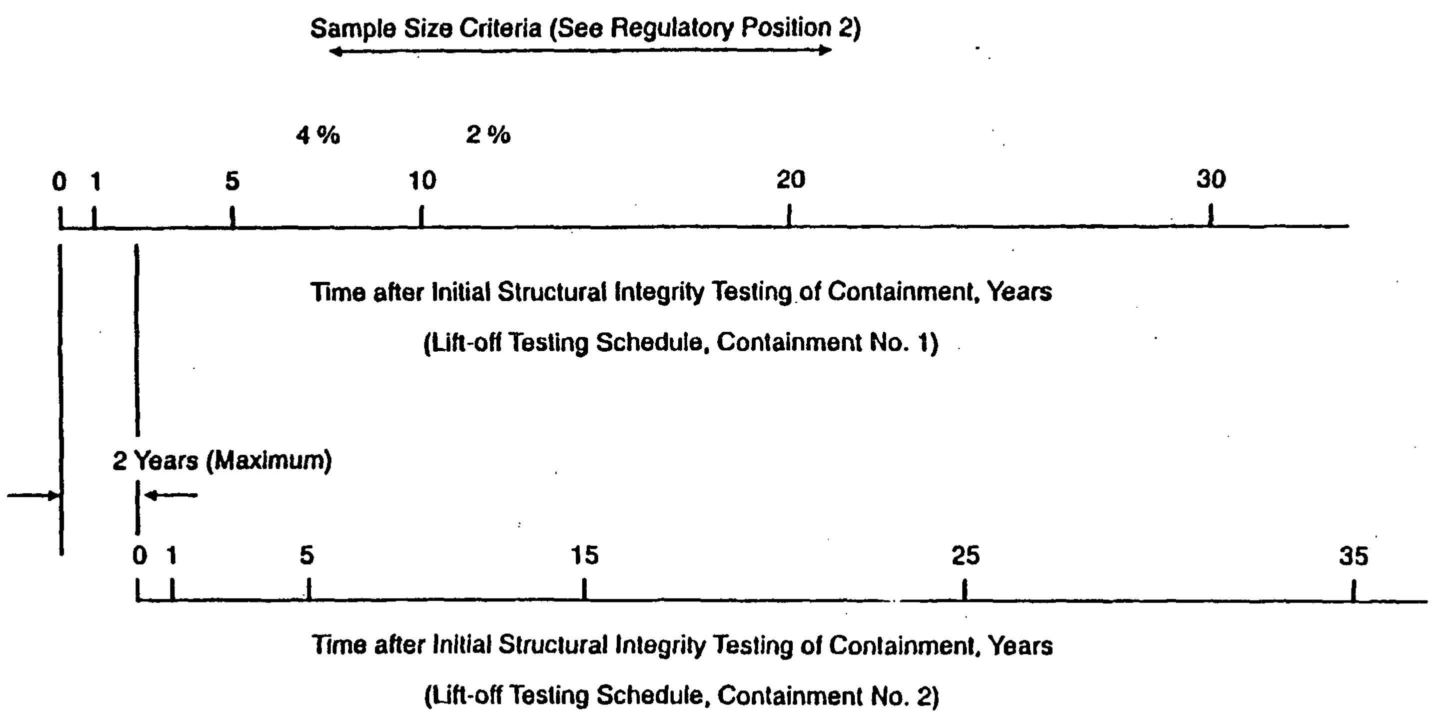

Figure 1. Schedule of Lift-off Testing for Two Containments at a Site
(See Regulatory Position 1.5)

REGULATORY ANALYSIS

A separate regulatory analysis was prepared for this Revision 3 to Regulatory Guide 1.35. The regulatory analysis is contained in NUREG/CR-4712, "Regulatory Analysis of Regulatory Guide 1.35 (Revision 3, Draft 2)—In-Service Inspection of Ungrouted Tendons in Prestressed Concrete Containments" (February 1987), and is available for inspection or copying for a fee in the Commission's Public Document Room, 2120 L Street NW., Lower Level, Washington, DC. NUREG/CR-4712 is also for sale at the U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20013-7082, and at the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

U.S. NUCLEAR REGULATORY COMMISSION

July 1990

REGULATORY GUIDE

OFFICE OF NUCLEAR REGULATORY RESEARCH

REGULATORY GUIDE 1.35.1 (Task SC 807-4)

DETERMINING PRESTRESSING FORCES FOR INSPECTION OF PRESTRESSED CONCRETE CONTAINMENTS

A. INTRODUCTION

General Design Criterion 53, "Provisions for Containment Testing and Inspection," of Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," requires, in part, that the reactor containment be designed to permit (1) periodic inspection of all important areas and (2) an appropriate surveillance program. Regulatory Guide 1.35, "Inservice Inspection of Ungrouted Tendons in Prestressed Concrete Containment Structures," describes a basis acceptable to the NRC staff for developing an appropriate inservice inspection and surveillance program for ungrouted tendons in prestressed concrete containment structures of light-water-cooled reactors. This guide expands and clarifies the NRC staff position on determining prestressing forces to be used for inservice inspections of prestressed concrete containment structures.

The Advisory Committee on Reactor Safeguards has been consulted concerning this guide and has concurred in the regulatory position.

Any information collection activities mentioned in this regulatory guide are contained as requirements in 10 CFR Part 50, which provides the regulatory basis for this guide. The information collection requirements in 10 CFR Part 50 have been cleared under OMB Clearance No. 3150-0011.

B. DISCUSSION

The inspections of prestressed concrete containment structures (with greased or grouted tendons) are performed with the objective of ensuring that the safety margins postulated in the design of containment structures are not reduced under operating and environmental conditions. Of particular concern in the case of prestressed concrete containment structures is the possible degradation of the prestressing tendon system by corrosion. The recommended inservice inspection programs of Regulatory Guides 1.35 and 1.90, "Inservice Inspections of Prestressed Concrete Containment Structures with Grouted Tendons," are formulated to achieve this basic objective. The extent to which the programs can perform their intended function depends on the method of their implementation.

Review of reports of some of the inspections performed by licensees on greased tendons indicates that there are various ways (simple but imprecise) of combining the losses in prestressing forces, giving a wide band of tolerance in comparing the measured results. Such a practice is not acceptable to the NRC staff because a real and substantial degradation of the tendon system may remain undetected.

Regulatory Guide 1.35 recommends the comparison of measured prestressing forces with the predicted forces of randomly selected tendons. The predicted forces at a given time are based on the measurement of prestressing forces during installation minus the losses in the prestressing forces that were predicted to have occurred since that time because of material and structural characteristics.

As various complex interacting phenomena are involved in the prediction of these losses, the chance is small that the measured prestressing force will agree quite closely with the predicted value. Hence, Regulatory Position 2.2 of this regulatory guide recommends the determination of limits (upper and lower) of prestressing force as a function of time. Revision 1 of Regulatory Guide 1.90 discusses this aspect briefly, as it is also relevant to the recommended inspection alternatives in that guide.

This supplementary guide is intended to clarify the NRC staff's position on the construction of tolerance bands for groups and subgroups of tendons so that the small-sample inspection program of Regulatory Guide 1.35 can provide better confidence in the integrity of prestressing tendons. The regulatory position of this guide recommends the factors to be evaluated and a method of using these factors in the construction of a tolerance band for a group of tendons having approximately the same time-dependent characteristics. The methods for evaluating the effects of these factors are discussed in this section of the guide.

The "Code for Concrete Reactor Vessels and Containments" (Ref. 1) enumerates the factors to be considered in determining the effective prestress (see Section CC–3542 of Ref. 1). However, it does not provide detailed consideration of these factors.

The methods suggested here are based on a search of relevant literature and on information provided to the NRC staff by applicants and their contractors. However, the listing of references in this guide does not constitute a blanket endorsement of the content of these references by the NRC staff.

1. MEASUREMENT OF PRESTRESSING FORCE

In general, the requirements of Section CC–4464 of the Code (Ref. 1) are adequate for measuring and verifying the seating force. However, the allowable discrepancy of ±10% of the force calculated from the measured elongation and that obtained by a dynamometer or a pressure gauge is excessive. If the load/elongation curve for the tendon system is based on a thorough evaluation of the prior tests using tensioning and measuring equipment similar to that proposed for use in construction, such a high discrepancy level is unwarranted. The NRC staff believes that this discrepancy level should not exceed ±5%. This recommendation is in agreement with the practice adopted by the American Concrete Institute (Ref. 2) and the Post-Tensioning Institute (Ref. 3).

During an inservice inspection, the liftoff (or load cell) measurements are compared against the initially measured forces. If the equipment used to make the measurements during the tensioning operation and during an inservice inspection have identical characteristics, the errors introduced by contributing factors such as reading accuracy or friction in the jacking system can be reduced to a minimum. The objective should be to use well-calibrated, accurate measuring equipment with sufficient sensitivity during both construction and inservice inspections to reduce the comparative errors caused by measurement to a negligible amount.

2. DETERMINATION OF PRESTRESSING LOSSES

The losses in prestressing force after the application of the force can be classified as follows:

1. Initial losses caused by:
   - Slip at anchorages
   - Friction between the tendon and the tendon duct at areas of contact
   - Elastic shortening and effect of sequence of stressing the various tendons.
2. Time-dependent losses caused by:
   - Shrinkage of concrete
   - Creep of concrete
   - Relaxation of prestressing steel.
3. Other losses caused by:
   - Failure of tendon elements from corrosion or material deficiency
   - Effects of variations in temperature.

These losses are discussed in Regulatory Position 2 together with the methods of determining their magnitude. Regulatory Position 2 pertains only to the prestressed concrete containment structures typically used for light-water reactors. For containments that operate at sustained high temperatures, the time-dependent characteristics need to be evaluated at correspondingly high temperatures.

C. REGULATORY POSITION

The following minimum standards should be followed in the design and construction of prestressed concrete containment structures for the inspection programs described in Regulatory Guide 1.35 (Revision 3).

1. MEASUREMENT OF PRESTRESSING FORCE

The procedure of Code Section CC–4464 (Ref. 1) should be followed in measuring loads and extensions during tensioning, as supplemented by the following:

1. A minimum of three readings of loads and extensions at approximately equally spaced levels of load should be recorded before the final seating of the tendon.

2. If the discrepancy between the measured extension at the final seating force and the extension determined from the average tendon force along the length of a tendon exceeds 5%, the cause of such discrepancy and the corrective actions taken should be recorded. The extension corresponding to the average tendon force may be determined by calculation or from a tendon load-extension diagram provided by the tendon manufacturer.

The objective should be to use well-calibrated, accurate measuring equipment with sufficient sensitivity during both construction and inservice inspections to reduce the comparative errors caused by measurement to a negligible amount.

2. DETERMINATION OF PRESTRESSING LOSSES

The following regulatory positions apply only to the prestressed concrete containment structures typically used for light-water reactors. For containments that operate at sustained high temperatures, the time-dependent characteristics need to be evaluated at correspondingly high temperatures.

2.1 Initial Losses

The initial seating force (F_o) should be modified to allow for the following influences:

1. A known amount of slip at anchorage (if any)
2. A loss caused by elastic shortening of the structure, including the effects of sequence of tensioning by the method discussed here or by any other appropriate method.
3. Influence of wire breakage during construction. The extent of wire breakage should not exceed the allowance made in the design.

Loss from slip at anchorages should be determined based on prior experience and the testing history of the prestressing system to be used. The influence of slip at anchorages should be allowed for in the computation of initial prestressing forces.

Coefficients for determining the losses from friction should be determined before the start of the installation and should be verified and modified (if necessary) during the construction. In comparing the liftoff (or load cell) forces for ungrouted tendons, friction loss need be considered only for the fixed ends of tendons that have been tensioned from one end. For the purposes of inspecting (or monitoring) ungrouted tendons, consideration of this loss can be avoided by comparing forces at tensioned ends.

If all tendons in a specific direction (hoop, vertical, etc.) are prestressed simultaneously, the loss of prestressing force from elastic shortening (F_{LES}) can be given by:

$$F_{LES} = \frac{F_o}{A_{cn}E_c + A_sE_s + A_pE_p + A_lE_l + A_dE_d} \times E_pA_p$$

where

F_o	is the initial seating force
A_{cn}	is the net concrete area
A_s, A_p, A_l, A_d	are the areas of reinforcing steel, prestressing steel, liner, and duct, respectively
E_c, E_s, E_p, E_l, E_d	are the moduli of elasticity of concrete, reinforcing steel, prestressing steel, liner, and duct, respectively.

However, the number of tendons to be prestressed is large, and the prestressing operation is performed in a systematic sequence so that the structure is more or less symmetrically prestressed during the process. Thus, the first tendons that are tensioned undergo a full loss from the subsequent elastic shortening of the structure, while the tendons that are tensioned last undergo almost no loss from elastic shortening. For all practical purposes, the loss of prestressing force from elastic shortening can be estimated and accounted for by using the following linear relationship:

$$F^n_{LES} = \frac{n_r}{N} F_{LES}$$

where N represents the total number of tendons in a particular direction, n represents the sequential number of a randomly selected tendon to be tensioned in that direction, and n_r represents the number of tendons to be tensioned after the n^{th} tendon, i.e., n_r = N−n.

If the sequences of tensioning tendons in different directions are intermingled, the stresses produced in one direction by the tendons tensioned in the other directions must be considered.

Thus it is essential that the complete history of tensioning a tendon be recorded, including its seating force F_o, the number of tendons tensioned before and after it, and any provision to account for the slip at anchorages. The modified initial prestressing force F_i at the tensioned end can be calculated and recorded as:

$$F^n_i = F^n_o - F^n_{LES} - F_{LSA}$$

where F_{LSA} is the loss of prestressing force due to slip at anchorages.

2.2 Time-Dependent Losses

Limits (high and low) on expected time-dependent losses at the end of the service life of the structure (generally 40 years), as well as those at one year after prestressing, should be established considering the variations in the following factors:

1. The extent of shrinkage of the structure contributing to the prestress losses. Table 1 may be used in the absence of specific data.
2. The effect of creep deformation on prestressing force. The method given in Appendix A of this guide or a similar method may be used to determine the creep deformation.
3. The effect of relaxation of stress in prestressing tendons. Reference 1 states that a minimum of three 1000-hour relaxation tests should be performed for the prestressing steel proposed for use.

Table 1. Variation of Shrinkage Strain With Relative Humidity

Mean Daily Relative Humidity,[1] Annual %	40-Year Shrinkage Strain[2]
Under 40%	130×10^{-6}
40 to 80%	100×10^{-6}
Above 80%	50×10^{-6}

[1]Mean daily relative humidities for various areas in the U.S. can be found on Map 46 of Reference 4.

[2]These values are applicable to containments in which inside operating temperatures do not exceed 120°F (49°C) and that are subject to the ambient outside environment. The maximum value of 130×10^{-6} may be substantially increased if the containment is exposed to a controlled dry high-temperature environment after completion of prestressing.

2.2.1 Effect of Shrinkage of Concrete

The schedule of construction of a typical prestressed concrete containment is such that a substantial portion of the expected long-term shrinkage will have taken place before the structure is prestressed. Reference 5 presents formulas for predicting the long-term shrinkage based on the assumption that the shrinkage approximately follows the laws of diffusion and supports the formulas by experimental investigation. An appropriate extrapolation of these formulas (for the volume-to-surface ratio of the structure in excess of 24 in. (60 cm) and the contributing shrinkage as that occurring 100 days after the average time of construction of the structure) would yield a value of 100×10^{-6}, which is considered to be a reasonable value at a temperature of 70°F (21°C) and a relative humidity of 50%. The safety analysis reports of several plants[1] indicate that a 40-year shrinkage value of 100×10^{-6} has been used by the applicants.

This value, however, needs to be modified to account for the significantly higher shrinkage in a low-humidity environment and the significantly lower shrinkage in a high-humidity environment. Table 1 provides typical shrinkage values that could be used for computation of prestressing losses caused by shrinkage.

2.2.2 Effect of Concrete Creep

One of the most significant and variable factors in the computation of time-dependent losses in prestressed concrete containment structures is the influence of concrete creep. Creep is thought to consist of two components: basic creep and drying creep. Drying creep, also sometimes termed stress-induced shrinkage, is thought to be due to the exchange of moisture between the structure and its environment. Its characteristics are considered to be similar to those of shrinkage, except that they represent an additional moisture movement resulting from the stressed condition of a structure. The amount of drying creep depends mainly on the volume-to-surface ratio of the structure and the mean relative humidity of the environment. For prestressed concrete containment structures having a volume-to-surface ratio in excess of 24 in. (60 cm), the relative influence of drying creep (compared to basic creep) is negligible as indicated by Figure 9 of Reference 5.

The significant parameters that influence the magnitude of basic creep can be summarized as follows:

1. Concrete mix—cement and aggregate type; proportion of cement, water, and aggregates; and the influence of admixtures.
2. Age at loading—The basic creep value is a function of the degree of hydration that has taken place at the time of loading.
3. The magnitude of the average sustained stress.
4. Temperature.

Almost all investigators support the assumption that basic creep varies linearly with the intensity of sustained stress, as long as the average stress level in the concrete is not greater than 40% of the ultimate strength of the concrete. The specific creep is thus defined as the ratio of total creep to the average stress intensity.

A literature review of the effect of temperature on basic creep (sealed or water-stored concrete specimens) is compiled in Reference 6. The average temperature of a prestressed concrete containment structure could vary between 40°F (5°C) and 100°F (38°C). Basic creep is shown to vary linearly with

[1]Turkey Point, Midland, Bellefonte, Three Mile Island.

temperature in this range of temperatures. Hence, if the basic creep is evaluated at approximately 70°F (21°C), it should represent overall deformation caused by creep of concrete.

An acceptable method of determining basic creep at various times for a given concrete mix as a function of age at loading is provided in Appendix A to this guide. The method is based on concepts and equations derived by Hansen (Ref. 7) from a rheological model representing creep of concrete. Reference 8 uses the method of Reference 7 in determining long-term creep for a given concrete mix. Most investigators agree that there is no one formula that can be generally applicable in determining the long-term creep for various concrete mixes. Hence Appendix A recommends a method of predicting the long-term basic creep from the results of short-term creep tests. Other methods such as those described in References 9, 10, and 11 may be used if demonstrated to be appropriate for predicting long-term basic creep.

Short-term creep tests are generally performed during the construction of a nuclear power plant. The extrapolated creep values consistent with the average time of the loading of the structure may not be available during the preliminary design stages. A conservative estimate of creep values may be obtained from previous experience or from creep tests on similar concretes. However, these values should be modified to estimate the tolerance band for the prestressing force to be used for comparison of the measured prestressing forces during inservice inspections. The modifications should include the extrapolated creep values in light of the actual average age of the concrete at the time the containment is prestressed.

2.2.3 Effect of Relaxation of Prestressing Steel

The stress relaxation properties of prestressing steel vary with its chemical composition and thermal/mechanical treatment. Manufacturers should be able to provide data on the long-term loss in prestressing steel stress from pure relaxation. Section CC-2424 of Reference 1 requires a minimum of three 1000-hour relaxation tests for the prestressing steel proposed for use. There should be a sufficient number of data points in each of the three tests to extrapolate the 1000-hour pure relaxation data to the life of the structure. An appropriate model (Refs. 12, 13, 14) should be selected for the determination of the "best-fitting" line for the purpose of extrapolation.

2.3 Losses Caused by Tendon Degradation

Most applicants make allowance for breakage of wires on an overall basis as well as on a localized basis. Such an allowance in the design of the containment would allow a breakage of a few wires during construction without need for replacing these wires. For a tendon with a few broken wires, care should be taken not to overstress intact wires to bring the tendon force to a prescribed value. Instead, the tendon should be extended to the same level as other similar tendons (without broken wires). The procedure will leave the tendon at a prestress level lower than the prescribed (generally 70% of the guaranteed ultimate tensile strength (GUTS)) level. This is acceptable provided the design includes an allowance for the breakage of wires.

2.4 Effects of Variations in Temperature

Of particular importance for the purpose of comparing the prestress forces is the effect of differences between the average temperature of the structure during installation and that during inspections. Localized hot spots and temperature variations along the length of a tendon can cause variations in the force along the length of the tendon. The differences between the coefficients of expansion or contraction of concrete and steel can also cause modifications of tendon forces. These effects, as appropriate, should be considered in comparing the measured prestressing forces with the predicted forces.

3. GROUPING OF TENDONS

3.1 Basic Grouping of Tendons

The basic grouping of tendons for the purpose of developing tolerance bands should consider:

1. The geometric configuration of tendons with respect to the structure, e.g., vertical, hoop, dome, inverted U, and
2. The similarity in time-dependent characteristics. This may involve dividing the above configuration group (e.g., vertical, hoop, dome, and inverted U) into additional groups.

The significant variable affecting the time-dependent prestressing force of tendons would be the effect of concrete creep. If the concrete mix characteristics and the curing conditions are assumed to be about the same during the entire period of construction of a containment structure, the parameters introducing variations in creep are (1) average compressive stress and (2) age of concrete at the time of prestressing. For example, in a shallow-dome containment structure, if the design requires that the meridional compressive stresses in the cylinder be half those in the hoop direction, the creep strains affecting the losses in prestressing would be proportional to their compressive stresses. Similarly, at the time of prestressing, the dome concrete might have aged three months, while the cylinder concrete might have aged six months or more. These parameters would affect the losses in prestressing forces in tendons and should be considered in grouping the tendons according to the similarity of their time-dependent characteristics and in prescribing the tolerance band for prestressing forces in these tendons.

3.2 Subgroups of Tendons

The basic groups may be divided further into subgroups to account for the differences in instantaneous elastic shortening during the transfer of prestressing force and to account for the differences in initial prestressing forces (F_i) caused by differences in instantaneous elastic shortening during transfer. To account for the differences in initial prestressing forces F_i, a tabulation of F_i for each tendon in a group may serve the same purpose as subgrouping.

In short, the intent of any adopted procedure should be to track the individual prestressing forces as precisely as possible with the current state of the art in predicting these forces, so that when a tendon is selected randomly during an inspection its measured values can be compared with its prescribed tolerance band.

4. CONSTRUCTION OF TOLERANCE BANDS

Tolerance bands for groups and subgroups of tendons should be constructed and should be used for comparison of measured prestressing forces with the forces predicted for the time of inspection.

It is recognized that each of the factors affecting the time-dependent characteristics of tendon forces are subject to variations. To account for these variations in prescribing the tolerance band, the following method is recommended:

1. Determine Shrinkage. Table 1 provides the 40-year shrinkage strains in relation to the humidity level at the location of the structure. To allow for the associated uncertainty in the assumed values, strain should be varied by ±20%. The shrinkage strains at any time between the time of prestressing (consider zero shrinkage at t = 10 days) and 40 years can be estimated by considering shrinkage strain to vary linearly with the logarithm of time.

2. Determine Creep. The creep strains at any time after prestressing can be determined by the method of Appendix A. The high and low creep strains can be determined by increasing the extrapolated creep values by 25% and decreasing them by 15%, respectively (see Appendix B for illustrative example).

3. Determine Relaxation of Prestressing Steel. Provide a ±15% variation in relaxation values obtained by extrapolation of 1000-hour tests.

The first inservice inspection needs to be performed one year after the Initial Structural Integrity Testing (ISIT) of the containment. Hence, the period of interest from the point of view of inservice inspection is nominally between 1 year and 40 years after prestressing.

The upper and lower bounds for prestressing forces at 1 year and 40 years after prestressing can be found by adding up the low and high losses and subtracting them from F_i. For the purpose of constructing tolerance bands for various groups of tendons, it is sufficiently accurate to consider prestressing force to vary linearly with the logarithm of time.

In lieu of the variations indicated above, the designer may use the conservatively estimated design values as the base values for the time-dependent factors. In that case, the individual predicted tendon prestressing force at 1 year and 40 years can be determined using the base value as illustrated in Appendix B. The line drawn using these values should be considered as the lower bound. The upper bound can be arbitrarily drawn by plotting a line parallel to the lower bound and starting at $0.93F_i$ at 1 year. This method can be used for the operating plants.

The upper line of the tolerance band is not critical from a safety point of view. However, this line allows the designer to establish a maximum variation line. If the prestressing of a tendon lies above this line, it is prudent to investigate the measurement technique and the pattern of losses in adjoining tendons.

D. IMPLEMENTATION

The purpose of this section is to provide information to applicants and licensees regarding the NRC staff's plans for using this regulatory guide.

Except in those cases in which the applicant or licensee proposes an acceptable alternative method for complying with specified portions of the Commission's regulation, the methods described herein will be used in the evaluation of inservice inspection and surveillance programs for the following nuclear power plants using prestressed concrete containments with ungrouted tendons:

1. Plants for which the construction permit or design approval is issued after July 31, 1990.

2. Plants for which the licensee voluntarily commits to the provisions of this guide.

APPENDIX A

DETERMINATION OF BASIC CREEP STRAINS FOR PRESTRESSED CONCRETE CONTAINMENT STRUCTURES

Recommended creep formula

$$\frac{\epsilon_c}{f_c} = A\left[1 - e^{-\frac{1}{30}(t-t_o)}\right] + B\log_{10}\frac{t}{t_o}$$

where

- t = time (after average time of concrete placement) when creep value is desired, in days
- t_o = time of loading after average time of concrete placement, in days
- f_c = average sustained concrete stress
- ϵ_c = creep strain at time t when the age of concrete at loading is t_o
- A,B are constants to be determined from tests.

To determine the value of constants A and B, the following short-term creep tests are recommended:

Age at loading	**Minimum Observations at**					
t_o	t_o	t_1	t_2	t_3	t_4	t_5
30	30	31	45	90	150	210
90	90	92	110	150	210	270
180	180	185	210	240	300	360

The constants A and B should be determined from creep strains at t_1, t_2, t_3, t_4, and t_5 for each t_o by plotting the measured specific creep $\frac{(\epsilon_c)}{f_c}$ against t on a semi-logarithmic paper (see Figure 1). The value of B would essentially remain the same for all values of t_o. The value of A for various values of t_o can be determined as shown in Figure 1. For t_o values greater than 365 days, the A value determined at 365 days should be used.

The short-term creep tests should be performed according to the test method of Reference 15. To make the creep test results representative of creep deformations in a containment structure, the referenced test method should be used with the following specific provisions:

a. Section 3.1: The length of specimens should be 16 ± 1/16 in. (40 ± 0.16 cm).

b. Section 3.2: The concrete mix should be the same as that proposed for use in the construction of the containment.

c. Section 3.3: Companion identical specimens corresponding to each t_o may be used to observe the deformations of unloaded specimens.

d. Section 4.2: Mass curing (sealed specimen) conditions should be used during storage and testing. (The method used for the "as cast" condition in Reference 16 is a good example.)

e. Section 5.1: Load the specimens to maintain a sustained stress of 30% of the design compressive strength of concrete.

f. Section 6.1: Subtract the instantaneous elastic strain taken at time t_o and the strain on the unloaded specimen from the subsequent total strain measurements to arrive at creep strain (ϵ_c).

1.35.1-8

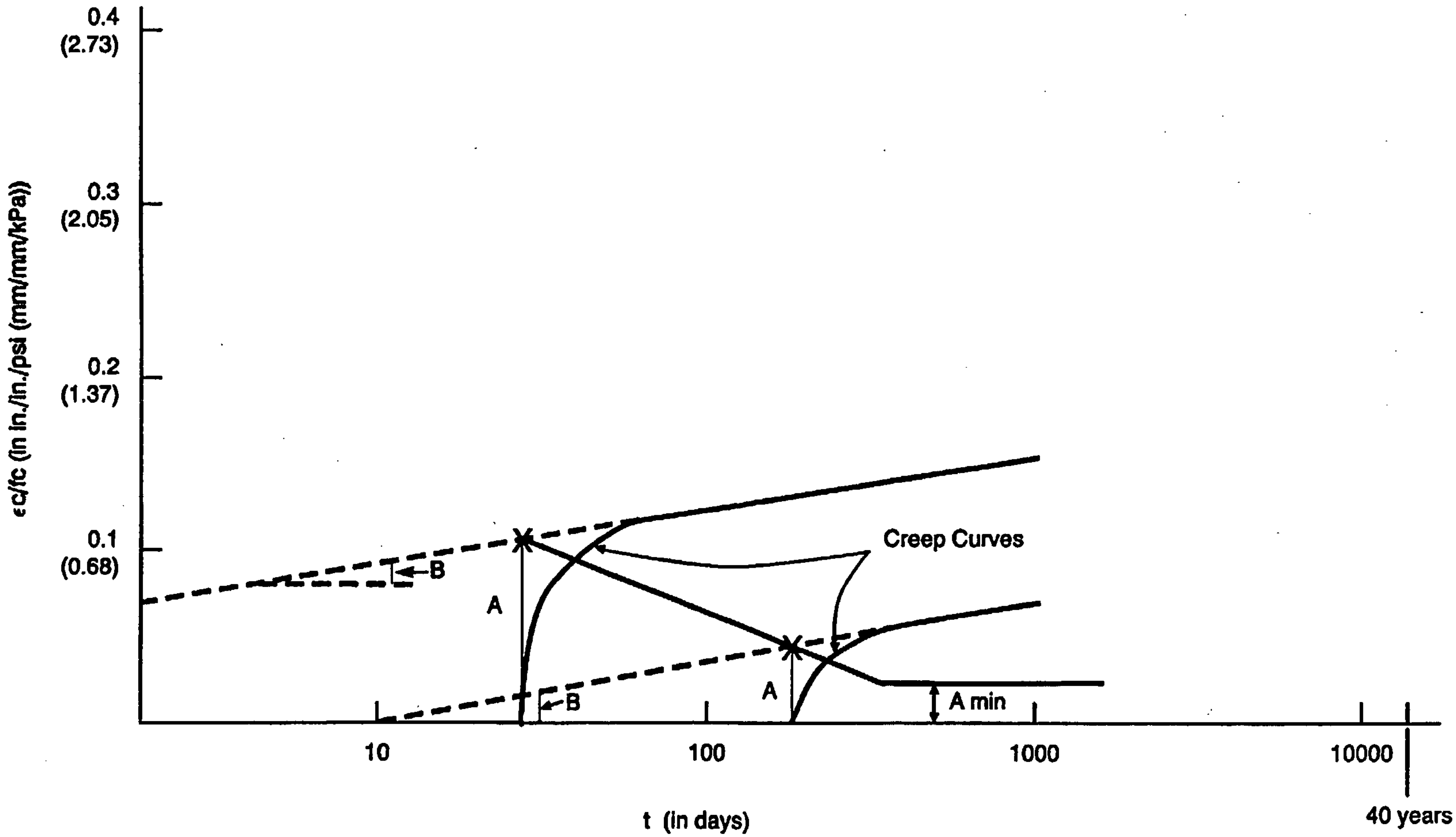

Figure 1. Specific Creep Curves

Note: The creep curves are plotted from actual short-term creep test data — Communication from J.F. Fulton, Gilbert/Commonwealth Associates.

APPENDIX B

CONSTRUCTION OF TOLERANCE BAND (EXAMPLE)

Consider the following values for time-dependent influences:

Time-Dependent Factors	Base Value at 40 Years	1 Year High	1 Year Low	40 Years High	40 Years Low
Shrinkage (ϵ_c) at 70% Relative Humidity x 10^6 Variation: ±20%	100	72	50	120	80
Creep $\frac{\epsilon_c}{(f_c)}$ x 10^6 for t_o = 180 days					
per psi	0.3	0.193	0.073	0.375	0.255
per kPa	2.05	1.32	0.50	2.56	1.75
Variation: +25% −15%					
Stress Relaxation of Prestressing Steel in % of F_i Variation: ±15%	7	5.8	4.2	8.1	5.9

Prestressing Losses in % of F_i

Assume Eps = 28 x 10^3 ksi (193 x 10^3 MPa)

fps = 168 ksi (1.158 x 10^3 MPa)

Shrinkage $\epsilon_s \times \frac{Eps}{fps} \times 100$	1.7	1.2	0.8	2.0	1.3
Creep for f_c = 1500 psi (10350 kPa) $\frac{\epsilon_c}{f_c} \times f_c \times \frac{Eps}{fps} \times 100$	7.5	4.8	1.8	9.4	6.4
Stress Relaxation of Prestressing Steel	7	5.8	4.2	8.1	5.9
Total Losses	16.2	11.8	6.8	19.5	13.6
Remaining Prestressng Force in Tendon[1]	0.84 F_i	0.88 F_i	0.93 F_i	0.8 F_i	0.86 F_i

[1]These values are used for constructing the tolerance band in Figure 2.

1.35.1-10

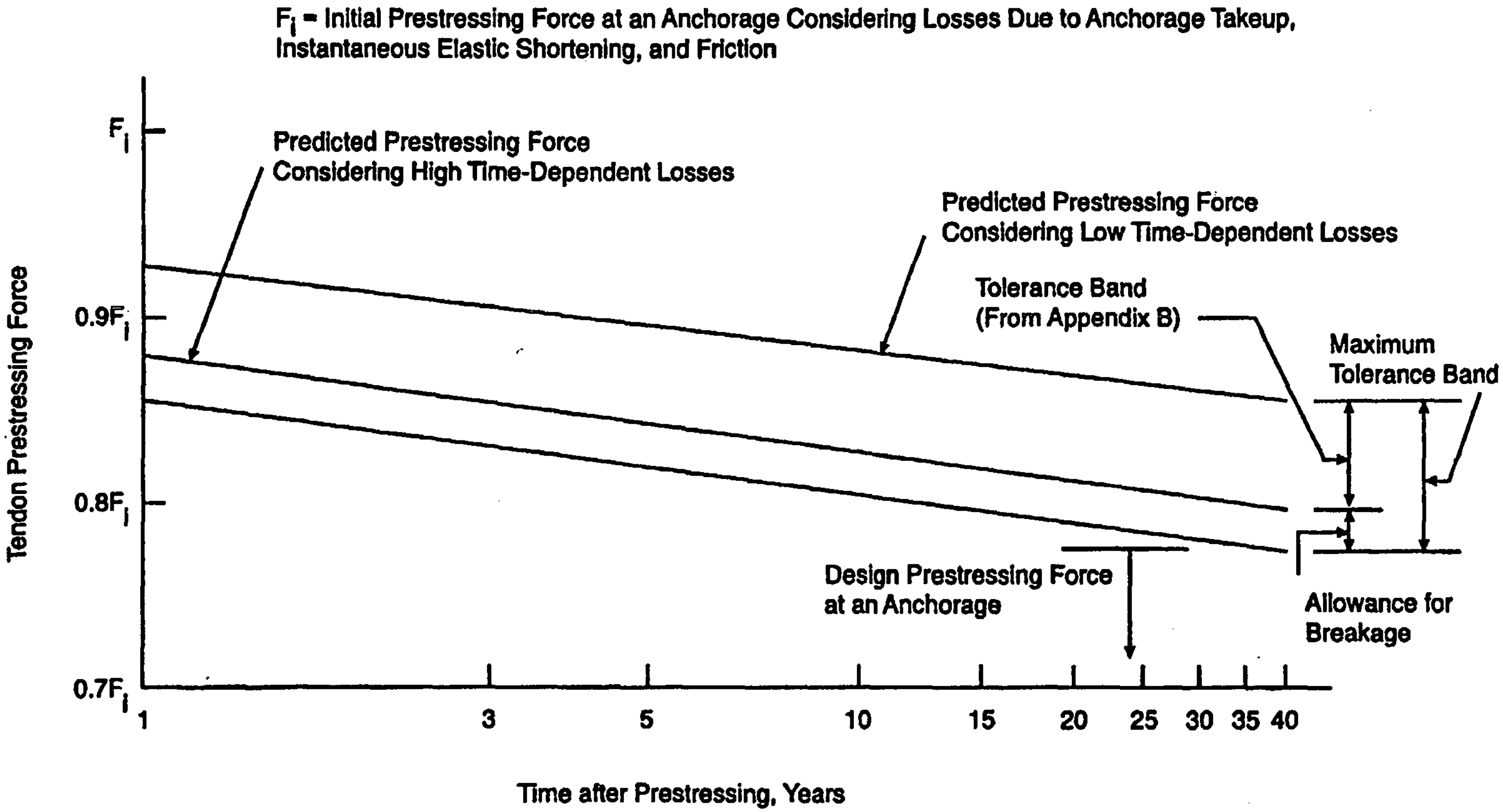

Figure 2. Tolerance Band of Acceptable Prestress

REFERENCES

1. American Concrete Institute and American Society of Mechanical Engineers Subcommittee on Nuclear Power, "Code for Concrete Reactor Vessels and Containments," ACI-359, 1986.

2. American Concrete Institute, "Building Code Requirements for Reinforced Concrete," ACI-318, Revised periodically.

3. Post-Tensioning Institute, "Post-Tensioning Manual," Phoenix, AZ, 1986.[1]

4. J. L. Baldwin, "Climates of the United States," U.S. Department of Commerce, Washington, DC, December 1974.[2]

5. T. C. Hansen, A. H. Mattock, "Influence of Size and Shape of Member on the Shrinkage and Creep of Concrete," *Journal of the American Concrete Institute*, Proceedings Vol. 63, February 1966. Also published as PCA Development Bulletin D103.

6. H. G. Geymayer, "Effect of Temperature on Creep of Concrete, A Literature Review," Paper 31 of ACI SP-34, "Concrete for Nuclear Reactors," Vol. 1, American Concrete Institute, 1972.

7. T. C. Hansen, "Creep and Stress Relaxation of Concrete," Swedish Cement and Concrete Research Institute, Stockholm, 1960.[3]

8. "Report on Recommended Concrete Creep and Shrinkage Values for Computing Prestressing Losses," by Schupack and Associates. This nonproprietary report is filed in the NRC Public Document Room as Appendix 5J in Amendment 2 of the "Preliminary Safety Analysis Report for the Three Mile Island Nuclear Power Station, Unit 2," June 1968, Docket No. 50-320.[4]

9. I. J. Jordann, C. L. England, M. M. A. Khalifa, "Creep of Concrete: A Consistent Engineering Approach," *Journal of the Structural Division of the American Society of Civil Engineers*, March 1977.

10. E. Cinlar, Z. P. Bazant, E. Osman, "Stochastic Process for Extrapolating Concrete Creep," *Journal of the Engineering Mechanics Division of the American Society of Civil Engineers*, December 1977.

11. J. W. Chaung, T. W. Kennedy, E. S. Perry, "An Approach to Estimating Long-Term Multiaxial Creep Behavior from Short-Term Uniaxial Creep Results," Union Carbide Report #2864-3, TID 25795, Department of Civil Engineering, University of Texas at Austin, June 1970.[5]

12. D. D. Magura, M. A. Sozen, C. P. Siess, "A Study of Stress Relaxation in Prestressing Reinforcement," *Prestressed Concrete Institute Journal*, April 1964.

13. T. Cahill, C. D. Branch, "Long-Term Relaxation Behavior of Stabilized Prestressing Wires and Strands," Group D, Paper 19 of Conference Papers on Prestressed Concrete Pressure Vessels, The Institution of Civil Engineers, 1968.[6]

14. R. J. Batal, T. Huang, "Relaxation Losses in Stress-Relieved Special Grade Prestressing Strands," Fritz Engineering Laboratory, Report No. FEL-339.5, NTIS PB200668, April 1971.[5]

15. American Society for Testing and Materials, "Standard Test Method for Creep of Concrete in Compression," ANSI/ASTM C512-76, 1976.

16. A. Hijazi, T. W. Kennedy, "Creep Recovery of Concrete Subjected to Multiaxial Compressive Stresses and Elevated Temperatures," Research Report 3661-1, TID-26102, Department of Civil Engineering, The University of Texas at Austin, March 1972.[5]

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[1]Copies may be obtained from the Post-Tensioning Institute, 301 West Osborn, Suite 3500, Phoenix, AZ 85013.

[2]Copies may be obtained from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20013.

[3]Copies in English may be obtained from the Swedish Cement and Concrete Research Institute, Royal Institute of Technology, Stockholm, Sweden.

[4]A copy may be obtained from the Public Document Room, U.S. Nuclear Regulatory Commission, 2120 L Street, NW., Washington, DC.

[5]Copies may be obtained from the National Technical Information Service, Springfield, Virginia 22161.

[6]Copies may be obtained from The Institution of Civil Engineers, Thomas Telford Ltd., 26-34 Old Street, London, ECIV, 9AD, England.

VALUE/IMPACT STATEMENT

A draft value/impact statement was published with the draft of Regulatory Guide 1.35.1 (Task SC 807-4) when the draft guide was published for public comment in April 1979. No changes were necessary, so a separate value/impact statement for the final guide has not been prepared. A copy of the draft value/impact statement is available for inspection and copying for a fee at the Commission's Public Document Room at 2120 L Street NW., Washington, DC, under Task SC 807-4.

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NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

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Florida Power CORPORATION

DESIGN ANALYSIS/CALCULATION

Crystal River Unit 3

DOCUMENT IDENTIFICATION NO.	REVISION
Calculation S-95-0082	

ATTACHMENT G

CONCRETE CREEP REFERENCE DATA

NOTE:
The following data was extracted from the Reference 10 and 11 calculations and included herein for reference.

Gilbert/Commonwealth ENGINEERS/CONSULTANTS CALCULATION	SUBJECT CR 3 TENDON LOSS CALCS	IDENTIFIER 5500-528-1	PAGE 13 OF 48 PAGES
	REV. 0 / 1 / 2 / 3		
	MICROFILMED		
	ORIGINATOR D Krauss		
	DATE 1-30-87		

Verified E. Pagan 2-9-87

CREEP LOSS:

HOOP TENDONS
Ref. p. 8 GT DeMoss Calc.

From Ref 10 CALC

HOOP

	TENDON SURV. PERIOD										
	1½	3	5	10	15	20	25	30	35	40	
SPEC. CR. μ"/in/psi	.09	.110	.133	.150	.167	.181	.190	.200	.209	.215	
UNIAX. CONC. CREEP STRAIN $\times 10^{-4}$	1.56	1.91	2.13	2.50	2.89	3.13	3.29	3.46	3.62	3.72	
BIAXIAL CONC. CREEP STRAIN $\times 10^{-4}$	1.4	1.72	1.92	2.34	2.61	2.8	2.95	3.12	3.26	3.36	
UNIAXIAL TEND. STRESS LOSS	4524	5539	6177	7540	8381	9077	9541	10,034	10498	10788	
BIAXIAL TEND STRESS LOSS	4060	4988	5568	6786	7569	8120	8555	9048	9454	9744	
BIAX. TEND. FORCE LOSS	39.5	48.5	54.1	66	73.6	78	83.2	88	91.9	94.7	⟸

UNIAX. CR. STRAIN = SPEC. CREEP $\times 10^{-6}$ $\times$ AVE. STRESS ON TRANSFORMED AREA OF CONC. (1732 psi)

BIAX. CREEP STRAIN = UNIAX. STRAIN FOR HOOP — poisson ratio $\times$ UNIAX STRAIN FOR VERT (.17)

STRESS LOSS = CR. STR (UNI OR BIA) $\times$ Es (29×10^6)

FORCE LOSS = BIAX TEND STRESS LOSS $\times$ TENDON AREA 9.7230 [1]

Gilbert/Commonwealth
ENGINEERS/CONSULTANTS
CALCULATION

SUBJECT: CR 3 TENDON LOSS CALCS
IDENTIFIER: 5500-528-1
PAGE 14 OF 48 PAGES
REV. 0 1 2 3
MICROFILMED
ORIGINATOR: [illegible signature]
DATE: 1-20-87
Verified: [illegible] 2-4-87

CREEP LOSS (CONT)
Ref. p.9 GT Demoss Calcs

VERTICAL

	TENDON SURV. PERIOD (YR)										
	1	3	5	10	15	20	25	30	35	40	
SPEC. CREEP μ"/in/psi	.096	.117	.130	.157	.173	.188	.197	.207	.216	.221	⇐ Input to Lotus
UNIAX CONC. CR. STRAIN $\times 10^{-4}$	.93	1.13	1.36	1.52	1.67	1.81	1.90	2	2.09	2.14	
BIAX. CONC. CR. STRAIN $\times 10^{-4}$	.66	.8	.90	1.08	1.18	1.29	1.34	1.41	1.47	1.51	
UNIAX. TEND ~~Los~~ STRESS LOSS	2697	3277	3659	4408	4843	5299	5510	5800	6001	6204	
BIAX. TENDON STRESS LOSS	1914	2320	2610	3132	3422	3712	3886	4089	4263	4379	
BIAXIAL TEND FORCE LOSS	18.6	22.6	25.4	30.5	33.3	36.1	37.8	39.8	41.5	42.6	⇐ Input to Lotus

CALCULATED SIMILAR TO HOOP EXCEPT USE ~~AT~~ HOOP FOR BIAX. CR. STRAIN CALC. AND AVE STRESS ON CONC. SEC. (TRANSFORMED) = 967 PSI

GAI-446 7-84

Gilbert/Commonwealth ENGINEERS/CONSULTANTS CALCULATION	SUBJECT CR 3 TENDON LOSS CALCS	IDENTIFIER 5500-528-1	PAGE 15 OF 48 PAGES
	REV. 0	1	2	3
	MICROFILMED			
	ORIGINATOR [signature]			
	DATE 1-30-87			

CREEP (cont)
Dome:

Ref. pp. 4, 4a, 16

INPUT TO LUTUS

INSP. PERIOD	DAYS FROM CONC. PLCMENT TO PERIOD	(YRS)	SPECIFIC CREEP SC_1 198 Day (10^{-6})	SC_3 908 Day (10^{-6})	$\epsilon_c(t)$	F_{CR} (K)
1	1270	3.56	.16	.064	3.28×10^{-4}	92.5
3	2000	5.62	.19	.09	3.86	108.8
5	2730	7.67	.208	.112	4.21	118.7
10	4560	12.8	.23	.14	4.62	130.3
15	6380	17.9	.26	.165	5.21	146.9
20	8210	23.1	.27	.18	5.39	152
25	10030	28.2	.28	.19	5.59	157.6
30	11860	33.3	.29	.20	5.78	163
35	13680	38.4	.30	.205	5.98	168.6
40	15510	43.6	.31	.215	6.18	174.3

$\epsilon_c(t) = 2123\ sc_1 - 188\ sc_3$

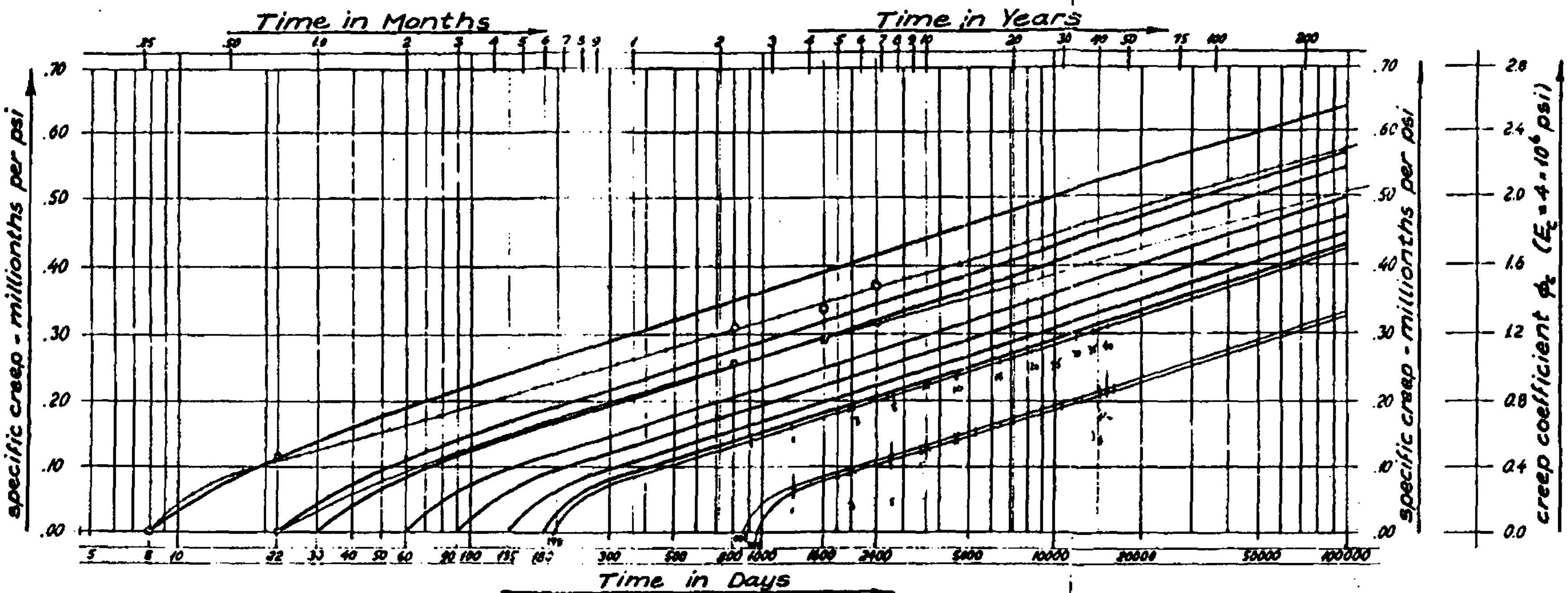
$F_{CR}(t) = \epsilon_c(t) \times E_S \times A_T \times \text{Wire factor} = 281.967 \times 10^6 \times \epsilon_c(t) \times WF$

$E_S = 29 \times 10^6$
$A_T = 9.723$

FM 6.5 Exhibit 4

From Ref 11 Calc

Basic Creep for 5000 psi Concrete



—o———o— Total creep @ cgs ...., Port Hueneme Tests[1]; age @ loading: 8 days;

—o———o— Differential creep, top fibre, —"— —"— —"— [1]; —"— @ —"— : 22 —"—;

———— Estimated basic creep[2] for loading ages: 8 & 22 days and 1, 2, 3, 4½ & 6 months.

[1] Technical Report R212, U.S. Naval Civil Engineering Laboratory, see also Appendix B.

[2] Formula for basic creep: $\frac{\varepsilon_{creep}}{\sigma} \cdot 10^6 =$ [illegible] $(1-e^{-(t-t_0)/30}) + 0.6\ln(\frac{t}{t_0})$, ref. equation [6], Appendix A.

MARKED FOR CR #3

195 DAYS FOR DOME TENDONS
934 DAYS FOR VERTICAL TENDONS
964 DAYS FOR HOOP TENDONS

SCHUPACK & ASSOCIATES
CONSULTING ENGINEERS - STAMFORD, CONN.
Job: Oyster Creek Unit 2
By: C.B. Date: May 10, 1968

APPENDIX C

SPECIFIC CREEP CURVES
G. T. DeMoss
1/13/60 PAGE 4
00-4763-099

Calculation S-95-0062
Attachment G
Page C5

Gilbert Associates, Inc.
Reading, Pennsylvania

ANALYSIS/CALCULATION

SUBJECT: Creep Losses - Hoop Tendons
CISID: 04-4762-099
PAGE: 8

REV.	0	1	2	3
MICROFILMED		Corrected for ungrouted stress value		
ORIGINATOR	D. T. De Moss	D. T. De Moss		
DATE	1/16/80	4/8/80		

VERIFIED BY: J. Hafiz

HOOP TENDONS

	TENDON SURVEILLANCE PERIOD									
	1 YR	3 YR	5 YR	10 YR	15 YR	20 YR	25 YR	30 YR	35 YR	40 YR
SPECIFIC CREEP $\times 10^{-6}$ (N"/"/PSI)	.09	.110	.123	.150	.167	.181	.190	.200	.209	.215
UNIAXIAL CONC. CREEP STRAIN $\times 10^{-4}$	1.56 ~~1.37~~	1.68	2.13 ~~1.88~~	2.29	2.55	2.76	2.90	3.05	3.19	3.72 ~~3.28~~
BIAXIAL CONC CREEP STRAIN $\times 10^{-4}$	-~~.14~~ .16 1.40 ~~1.23~~	-.17 1.51	-~~.19~~ .21 1.92 ~~1.69~~	-.23 2.06	-.25 2.30	-.28 2.48	-.29 2.61	-.30 2.75	-.32 2.87	-~~.33~~ .36 3.36 ~~2.96~~
UNIAXIAL TENDON STRESS LOSS	4524 ~~3973~~	4872	6177 ~~5457~~	6641	7395	8004	8410	8845	9251	10788 ~~9512~~
BIAXIAL TENDON STRESS LOSS	4060 ~~3567~~	4379	5568 ~~4901~~	5974	6670	7192	7569	7975	8323	9744 ~~8584~~
BIAXIAL TENDON FORCE LOSS	39.5 K ~~34.7~~	42.6 K	54.1 ~~47.7~~ K	58.1	64.9 K	69.9 K	73.6 K	77.5 K	80.9 K	94.7 ~~83.5~~

Uniaxial creep strain = specific creep $\times 10^{-6}$ $\times$ average stress on transformed area of concrete (1732)

Biaxial creep strain = uniaxial strain for HOOP tendons − poisson's ratio $\times$ uniaxial strain for VERT tendons. (Poisson's ratio = .17)

Stress losses = creep strain (uniaxial or biaxial) $\times E_s (29 \times 10^6)$

Force loss = biaxial tendon stress loss $\times$ tendon area (A_s) of 9.7230 ⊡.

Creep values as entered in tendon loss table are adjusted by multiplying by wire factor.

Gilbert Associates, Inc. Reading, Pennsylvania
ANALYSIS/CALCULATION

SUBJECT: Creep Losses - Vert. Tendons
CISID: 04-4762-099
PAGE 9 OF —

REV.	0	1	2	3
MICROFILMED		Corrected for concrete strain value		
ORIGINATOR	D. J. DeMoss	D. J. DeMoss		
DATE	1/16/80	4/8/80		

VERIFIED BY [illegible]

VERTICAL TENDONS

	TENDON SURVEILLANCE PERIOD									
	1 YR	3 YR	5 YR	10 YR	15 YR	20 YR	25 YR	30 YR	35 YR	40 YR
SPECIFIC CREEP $\times 10^{-6}$ (in/in/psi)	.096	.117	.130	.157	.173	.188	.197	.207	.216	.221
UNIAXIAL CONC. CREEP STRAIN $\times 10^{-4}$	.93 ~~.83~~	1.01	1.26 ~~1.12~~	1.36	1.49	1.62	1.73	1.79	1.87	2.14 ~~1.91~~
BIAXIAL CONC. CREEP STRAIN $\times 10^{-4}$	- ~~.25~~ .26 .67 ~~.60~~	-.29 .72	- ~~.33~~ .36 .90 ~~.80~~	-.39 .97	-.43 1.06	-.47 1.15	-.49 1.24	-.51 1.27	-.54 1.33	- ~~.56~~ .63 1.51 ~~1.35~~
UNIAXIAL TENDON STRESS LOSS	2697 ~~2407~~	2929	3654 ~~3248~~	3944	4321	4698	5017	5191	5423	6206 ~~5539~~
BIAXIAL TENDON STRESS LOSS	1943 ~~1740~~	2088	2610 ~~2320~~	2813	3074	3335	3596	3683	3857	4379 ~~3915~~
AXIAL TENDON FORCE LOSS	18.9 ~~16.9^K~~	20.3^K	25.4 ~~22.6^K~~	27.4^K	29.9^K	32.4^K	35.0^K	36.8^K	37.5^K	42.6 ~~38.1^K~~

Uniaxial creep strain = specific creep $\times 10^{-6}$ $\times$ average stress on transformed area of concrete (967)

Biaxial creep strain = uniaxial strain for VERTICAL tendons − poisson's ratio $\times$ uniaxial strain for HOOP tendons. (Poisson's ratio = .17)

Stress losses = creep strain (uniaxial or biaxial) $\times E_s (29 \times 10^6)$

Force loss = biaxial tendon stress loss $\times$ tendon area (A_s) of 9.7230 [1].

Creep values as entered in tendon loss table are adjusted by multiplying by wire factor.

Calculation S-95-0082
Attachment G
Page G8

GILBERT ASSOCIATES, INC. ENGINEERS AND CONSULTANTS READING, PA.	DEPARTMENT NAME	DEPT. NO. 0414	FILING CODE
	PROJECT NAME CR #3	W.O. NUMBER 04-4762-099	PAGE 3 18
SUBJECT Creep Loss Calculations – Regular Dome Tendons			ORIGINATOR G. T. DeMoss DATE 2/15/80
			VERIFIER DATE

From J. Fulton's Calculations (APPENDIX B):

$$\epsilon_c(t) = .83\left[sc_1(\sigma_1 + \Delta\sigma_1) - sc_3(\Delta\sigma_2)\right]$$

$$\sigma_1 + \Delta\sigma_1 = 2558 \text{ psi}$$
$$\Delta\sigma_2 = 227 \text{ psi}$$

$$\therefore \epsilon_c(t) = .83\, sc_1(2558) - .83\, sc_3(227)$$

$$\epsilon_c(t) = 2123\, sc_1 - 188\, sc_3$$

For 1 year period, $\epsilon_c(1) = 2123(.16\times10^{-6}) - 188(.064\times10^{-6})$
$= 3.397\times10^{-4} - .120\times10^{-4}$
$\epsilon_c(1) = 3.28\times10^{-4}$

$$F_{CR}(1) = \epsilon_c(1) \times E_s \times A_T \times \text{wire factor (WF)}$$

$$E_s = 29\times10^6$$
$$A_T = 9.723$$

$F_{CR}(1) = (3.28\times10^{-4})\times(29\times10^6)\times 9.723 \times WF$
$= 92{,}485^{\#} \times WF = 92.5^{K} \times WF$

For 5 year period $\epsilon_c(5) = 2123(.208\times10^{-6}) - 188(.112\times10^{-6})$
$= 4.205\times10^{-4}$
$F_{CR}(5) = (4.205\times10^{-4})\times(29\times10^6)\times 9.723 \times WF$
$= 118{,}567^{\#} \times WF = 118.6^{K} \times WF$

For 40 year period $\epsilon_c(40) = 2123(.31\times10^{-6}) - 188(.215\times10^{-6})$
$= 6.18\times10^{-4}$
$F_{CR}(40) = (6.18\times10^{-4})\times(29\times10^6)\times 9.723 \times WF$
$= 174{,}256^{\#} \times WF = 174.3^{K} \times WF$

These apply to non-retensioned tendons only.

GAI 350 REV. 3-77

GILBERT ASSOCIATES, INC. ENGINEERS AND CONSULTANTS READING, PA.	DEPARTMENT NAME	DEPT. NO. 0414	FILING CODE
	PROJECT NAME CR#3	W.O. NUMBER 04-4762-099	PAGE 18a
SUBJECT Creep Loss Calculations – ALL DOME TENDONS			ORIGINATOR D. T. DeMoss DATE 2/25/80 VERIFIER DATE

Non-retensioned dome tendons

For 3 year period $\epsilon_c(3) = 2123(.188\times10^{-6}) - 188(.093\times10^{-6})$
$= 3.82\times10^{-4}$

$F_{CR}(3) = \epsilon_c(3)\times 2.82\times10^{8}$
$= 107.7^{K}\times WF$

For 10 year period $\epsilon_c(10) = 2123(.237\times10^{-6}) - 188(.144\times10^{-6})$
$= 4.76\times10^{-4}$

$F_{CR}(10) = \epsilon_c(10)\times 2.82\times10^{8}$
$= 134.3^{K}\times WF$

For Retensioned Dome Tendons (18)

(see page 19 for explanation)

3 year period

$F_{CR}^{(3)} = (3.82\times10^{-4} - 2.95\times10^{-4})\times 2.82\times10^{8}$
$= 24.5^{K}\times WF$

10 year period

$F_{CR}(10) = (4.76\times10^{-4} - 2.95\times10^{-4})\times 2.82\times10^{8}$
$= 51.0^{K}\times WF$

Calculation S-95-0082
Attachment G
Page G10

GILBERT ASSOCIATES, INC. ENGINEERS AND CONSULTANTS READING, PA.	DEPARTMENT NAME	DEPT. NO. 0414	FILING CODE
	PROJECT NAME CR #3	W.O. NUMBER 04-4762-099	PAGE 3a 19

SUBJECT: Creep Loss Calculations - Reduced Force DOME TENDONS

ORIGINATOR: G. T. DeMoss
DATE: 2/19/80
VERIFIER:
DATE:

For the 18 retensioned dome tendons the creep losses will be the values for non-retensioned tendons less $.83[SC_1(\sigma_1+\Delta\sigma_1)]$

$\sigma_1 + \Delta\sigma_1 = 2558$ psi

SC_1 = value at 908 days measured on 198 day curve $= .139 \times 10^{-6}$

$\epsilon_c(0) = .83 \times .139 \times 10^{-6} \times 2558 = 2.95 \times 10^{-4}$

Therefore losses are:

1 year period $\epsilon_c(1) = 3.28 \times 10^{-4} - 2.95 \times 10^{-4}$
$= .33 \times 10^{-4}$

$F_{CR} = .33 \times 10^{-4} \times 2.82 \times 10^{8} = \underline{9.3^{K} \times WF}$

5 year period $\epsilon_c(5) = 4.205 \times 10^{-4} - 2.95 \times 10^{-4}$
$= 1.26 \times 10^{-4}$

$F_{CR} = 1.26 \times 10^{-4} \times 2.82 \times 10^{8} = \underline{35.5^{K} \times WF}$

40 year period $\epsilon_c(40) = 6.18 \times 10^{-4} - 2.95 \times 10^{-4}$
$= 3.23 \times 10^{-4}$

$F_{CR} = 3.23 \times 10^{-4} \times 2.82 \times 10^{8} = \underline{91.1^{K} \times WF}$

FILING CODE

B-1

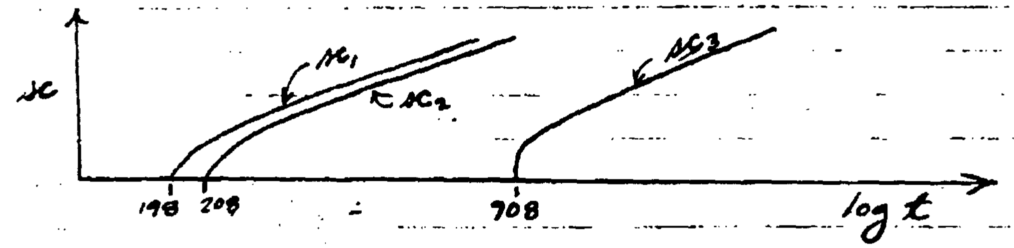
Gilbert Associates, Inc. Reading, Pennsylvania ANALYSIS/CALCULATION	SUBJECT: CR3 Dome Creep Losses			CISID	PAGE CR 1 OF PAGES
	REV. 0	1	2	3	
	MICROFILMED				
	ORIGINATOR: J Fulton				
	DATE: 2-11-80				

APPENDIX B - DOME TENDON CREEP LOSSES

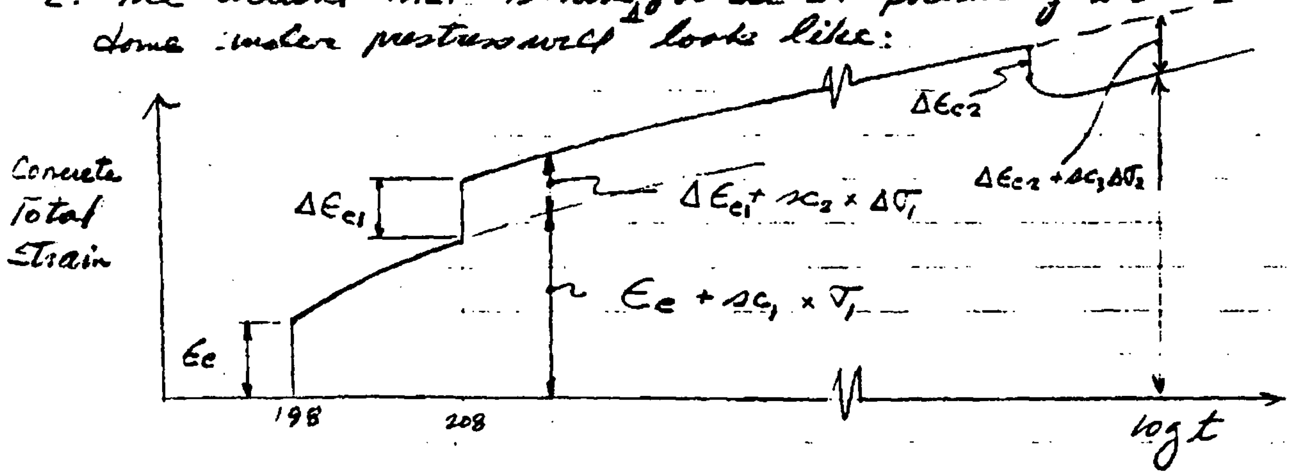
Ave. dome const. date 5-6-74 } 198 days
Ave. stressing date 11-23-74 } 10 days
Dome delamination date 12-4-74 } say 700 days
Detension and Partially Retension 18 tendons 10-25-76

Concrete Age at Ave. Stressing Date - 198 days
Concrete Age at Dome Delamination - 208 days
Concrete Age at Deten/Reten 18 - 908 days

1. Below are specific creep versus log time curves for concrete ages of 198, 208, and 908 days, from Schupack curves. (Note that this data will probably indicate that one curve will suffice for 198 and 208 ages)



2. The actual total strain history for the 24" portion of the dome under prestressing looks like:



1) Ee = elastic strain due to tendons stressed in sequence 1 thru 27, computed for all these tendons having been stressed.

Gilbert Associates, Inc. Reading, Pennsylvania ANALYSIS/CALCULATION	SUBJECT		CISID		PAGE CK 2 OF PAGES
	REV.	0	1	2	3
	MICROFILMED				
	ORIGINATOR	J Fulton			
	DATE	2-11-80			

2) σ_1 = dome stress after all tendons in sequences 1 thru 27 stressed
3) $\varkappa c_1 \times \sigma_1$ = creep strain corresponding to σ_1

4) $\Delta\sigma_1$ = dome stress increment due to: (1) under the load due to stressed tendons in sequence 1 thru 27, the difference in stresses for the 36" and 24" dome plus (2) the stresses for the 24" dome under the load corresponding to sequences 28 thru 32.

5) $\Delta\epsilon_{e1}$ = elastic strain due to $\Delta\sigma_1$
6) $\varkappa c_2 \times \Delta\sigma_1$ = creep strain corresponding to $\Delta\sigma_1$
7) $\Delta\sigma_2$ = dome stress decrease due to 18 tendons being partially retensioned
8) $\Delta\epsilon_{e2}$ = elastic strain due to $\Delta\sigma_2$ (9) $\varkappa c_3 \times \Delta\sigma_2$ = creep strain due to $\Delta\sigma_2$

All the elastic strains are considered when calculating the elastic shortening of the tendons.

The creep strain at any time, t, are

$$\varkappa c_1(\sigma_1) + \varkappa c_2(\Delta\sigma_1) - \varkappa c_3(\Delta\sigma_2)$$

However, if there is no significant difference in the creep curves for 198 and 208 day old concrete then the creep strain, $\epsilon_c(t)$, is

$$\epsilon_c(t) = \varkappa c_1(\sigma_1 + \Delta\sigma_1) - \varkappa c_3(\Delta\sigma_2).$$

The stresses are

$\sigma_1 + \Delta\sigma_1$ = stress in 24" dome after all tendons stressed

$$\sigma_1 + \Delta\sigma_1 = \left(\frac{-2930\text{ psi}}{1.34} + -2930\right)\frac{1}{2} = -2558\text{ psi}$$

(from ES loss calcs)

assumed 40 yr loss factor. Taken from CR3 Delaminated Dome report, p. 4-3, as 168/125 = 1.34.

Gilbert Associates, Inc. Reading, Pennsylvania ANALYSIS/CALCULATION	SUBJECT		CISID		PAGE CR 3 OF PAGES
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	ORIGINATOR				
	DATE				

and $\Delta\sigma_2 = 227$ psi (from ES loss calcs)

The concrete strain, assuming approximately equal biaxial dome stresses, is

$$\epsilon_c = 0.83 \frac{\sigma_c}{E_c} = 0.83 \times \text{uniaxial strain}$$

$$\therefore \quad \boxed{\epsilon_c(t) = 0.83 \left\{ sc_1 (\sigma_1 + \Delta\sigma_1) - sc_3 (\Delta\sigma_2) \right\}}$$

where,
sc_1 and sc_3 are the specific creep curves for 200 day and 908 day old concrete. These curves are constructed from the Schupack curves.

$\sigma_1 + \Delta\sigma_1 = 2558$ psi

$\Delta\sigma_2 = 227$ psi

The tendon stress loss is

$$f_{CR}(t) = \epsilon_c(t) E_s$$

The corresponding force loss is

$$\boxed{F_{CR}(t) = f_{CR}(t) A_p = \epsilon_c(t) E_s A_p}$$

where A_p is the actual tendon area considering ineffective wires.

Gilbert Associates, Inc. Reading, Pennsylvania ANALYSIS/CALCULATION	SUBJECT		CISID		PAGE CR 4 OF PAGES
	REV. 0	1	2	3	
	MICROFILMED				
	ORIGINATOR				
	DATE				

Footnote: The dome stresses of 2930 psi and 227 psi for $(\sigma_1 + \Delta\sigma_1)$ and $\Delta\sigma_2$, respectively, take into account the actual tendon forces. Recall that the actual average lock off of all the dome tendons was calculated to be practically the same as the 0.7 F_{pu} theoretical value upon which 2930 psi dome stress corresponds. Also, $\Delta\sigma_2 = 227$ psi is based on the actual reduction in force for the 18 detensioned-partially retensioned tendons ($1516^k - 652^k = 864^k$, see ES loss calcs).

Florida Power CORPORATION

DESIGN ANALYSIS/CALCULATION

Crystal River Unit 3

DOCUMENT IDENTIFICATION NO.	REVISION
Calculation S-95-0082	

ATTACHMENT H

CONCRETE SHRINKAGE REFERENCE DATA

NOTE:

The following data was extracted from the Reference 10 and 11 calculations and included herein for reference.

Gilbert/Commonwealth ENGINEERS/CONSULTANTS CALCULATION	SUBJECT CR 3 TENDON LOSS CALCS	IDENTIFIER S500-528-1	PAGE 11 OF 48 PAGES
	REV. 0 / 1 / 2 / 3		
	MICROFILMED		
	ORIGINATOR D Krause		
	DATE 1-30-87		

WIRE STRESS RELAXATION (CONT)

FROM REF 10

DOME TENDONS.
Ref. p.20 G.T. DeMoss Calc.

Same as for HOOP AND VERT. WIRE FACTOR is NEGLIGIBLE FOR THIS LOSS THEREFORE DISREGARD.

SHRINKAGE:

HOOP & VERTICAL
REF. PP. 13 & 14 G.T. DEMOSS CALC

SHRINKAGE = .282 × difference on p.14.

PERIOD	Tab. Diff. × .282	= Shrink. loss (Kips)
1	6	1.69
3	8.5	2.40
5	10	2.82
10	13.5	3.81
15	15.5	4.37
20	17.5	4.94
25	19.5	5.50
30	20.4	5.75
35	21.5	6.06
40	22.5	6.35

INPUT TO LOTUS

Gilbert/Commonwealth ENGINEERS/CONSULTANTS CALCULATION	SUBJECT CR 3 TENDON LOSS CALCS		IDENTIFIER 5500-528-1		PAGE 12 OF 48 PAGES
	REV. 0	1	2	3	
	MICROFILMED				
	ORIGINATOR [signature]				
	DATE 1-30-87				

SHRINKAGE (CONT). (DOME TENDONS FULLY STRESSED) —
SEE. GT. DEMOSS CALC. pp. 21, 23

PERIOD	DIFF. x .282	=	SHRINKAGE LOSS (KIPS)
1	15	=	4
3	18	=	5
5	21	=	6
10	25	=	7
15	27.5	=	8
20	29	=	8
25	30.8	=	9
30	32	=	9
35	33	=	9
40	34	=	10

INPUT TO LOTUS

	TOT. SHRINK. AT SURV.	—	TOT. SHRINK. AT TEND. STRESS	= Δ	YRS. FROM STRESSING
1	81	—	66	= 15	3.5
3	84			= 18	5.5
5	87			= 21	7.5
10	91			= 25	12.5
15	93.5			= 27.5	17.5
20	95			= 29	22.5
25	96.8			= 30.8	27.5
30	98			= 32	32.5
35	99			= 33	37.5
40	100	↓	↓	= 34	42.5

↑

INPUT TO LOTUS

Calculation S-95-0082
Attachment H
Page H4

GILBERT ASSOCIATES, INC. ENGINEERS AND CONSULTANTS READING, PA.	DEPARTMENT NAME	DEPT. NO. 0414	FILING CODE
	PROJECT NAME CR#3	W.O. NUMBER 04-4762-099	PAGE 13

SUBJECT: Concrete Shrinkage Loss – Hoop & Vert Tendons

ORIGINATOR: D. T. DeMoss
DATE 1/19/80
VERIFIER: S. Holl
DATE 4/4/80

FROM REF 11

Shrinkage losses are plotted from chart on page 14 for inspection periods in terms of time since average concrete placement.

The number read from the table shall be the difference between the surveillance period being examined less the value at time of tendon stressing. This difference will be multiplied times E_s (29×10^6) times the nominal tendon area (9.723 $\square''$).

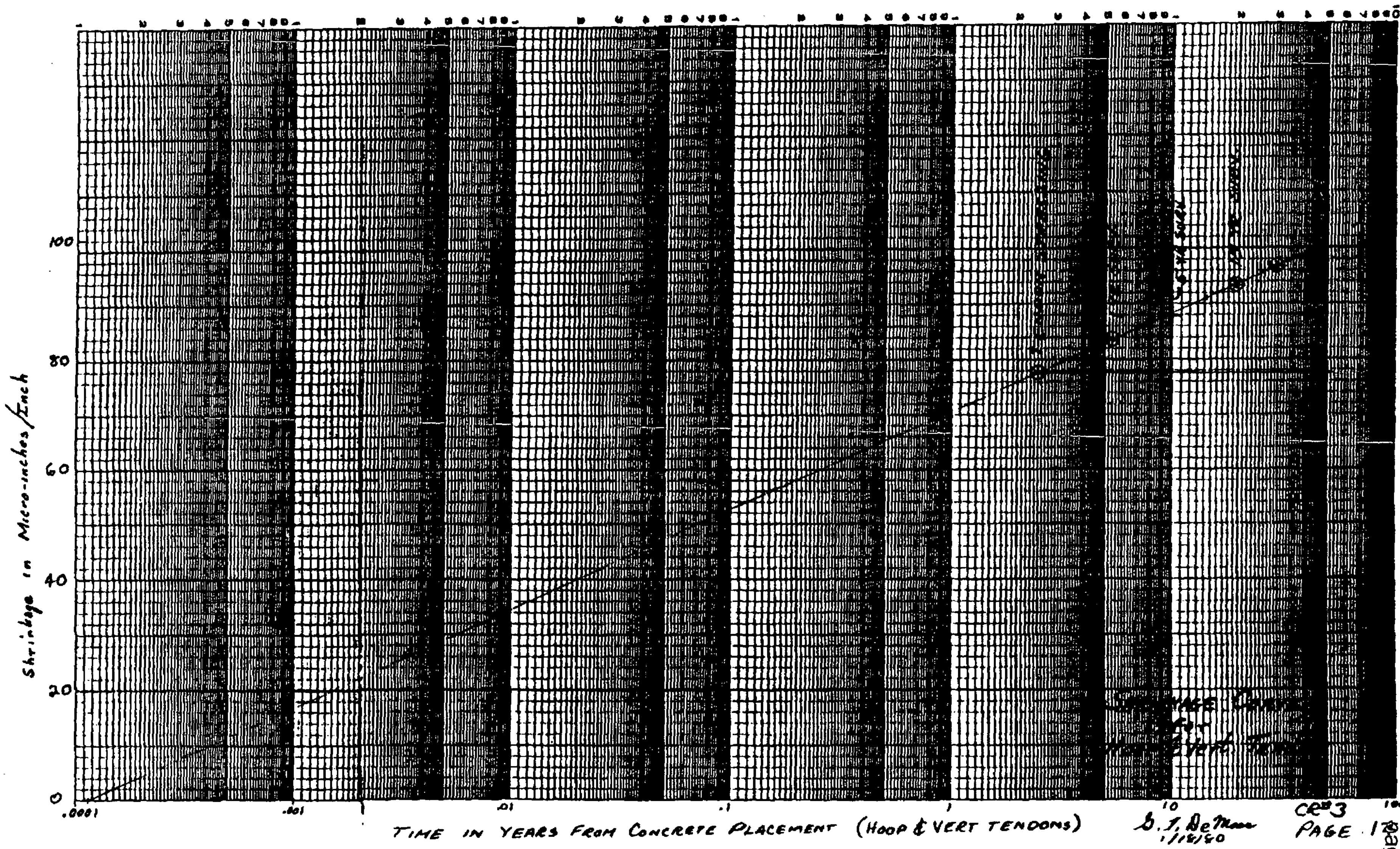
Diff. in Tabulated #'s $(\times 10^{-6}) \times (29 \times 10^6) \times 9.723 = .282^K \times$ diff.

Period	Tabulated Diff.	Shrinkage loss
1	6	1.7^K
5	10	2.8^K
15	15.5	4.4^K
25	19.5	5.5^K
40	22.5	6.3^K

The above losses will be applied to all hoop & vertical tendons.

CODE

FM 6.5 Exhibit 4



CR#3
PAGE 1

Calculation S-95-0082
Attachment H
Page H5

Calculation S-95-0082
Attachment H
Page H6

GILBERT ASSOCIATES, INC. ENGINEERS AND CONSULTANTS READING, PA.	DEPARTMENT NAME	DEPT. NO. 0414	FILING CODE
	PROJECT NAME CR #3	W.O. NUMBER 04-4762-099	PAGE 21

SUBJECT Shrinkage Loss Calculations — REGULAR DOME TENDONS

ORIGINATOR G. T. DeMoss
DATE 2/16/80
VERIFIER
DATE

Original concrete average placement date 5/6/74
Replacement concrete cap ave. date 10/12/76

Original average tendon stressing date 11/23/74

SIT performed on 11/3/76

age of original concrete at stressing $= \frac{198}{365} = .54$ yrs
" " " " " 1 yr. surv. $= \frac{1270}{365} = 3.5$ yrs
" " " " " 5 yr. surv. $= \frac{2730}{365} = 7.5$ yrs
" " " " " 40 yr surv. $= \frac{15510}{365} = 42.5$ yrs

3 yr = 5.5 yrs
10 yr = 12.5 yrs

age of replacement conc. at 1 yr surv. $= \frac{387}{365} = 1.1$ yrs
" " " " " 5 yr " $= \frac{1847}{365} = 5.1$ yrs
" " " " " 40 yr " $= \frac{14622}{365} = 40.1$ yrs

If all shrinkage is based on original concrete, shrinkage loss will be as follows:

$loss = Diff.\ from\ chart \times 10^{-6} \times (29 \times 10^{6}) \times 9.723 = .282 \times Diff.$

Period	Diff	Shrinkage loss
1	15 x1	4.23^k
5	21	5.9^k
40	34	9.6^k

The above apply to original fully stressed tendons only, not the 18 tendons partially retensioned at a later date

Calculation S-95-0082
Attachment H
Page H7

GILBERT ASSOCIATES, INC. ENGINEERS AND CONSULTANTS READING, PA.	DEPARTMENT NAME	DEPT. NO. 0414	FILING CODE
	PROJECT NAME CR #3	W.O. NUMBER 04-4762-099	PAGE 52 22

SUBJECT: Shrinkage Loss Calculations - Reduced Force DOME TENDONS

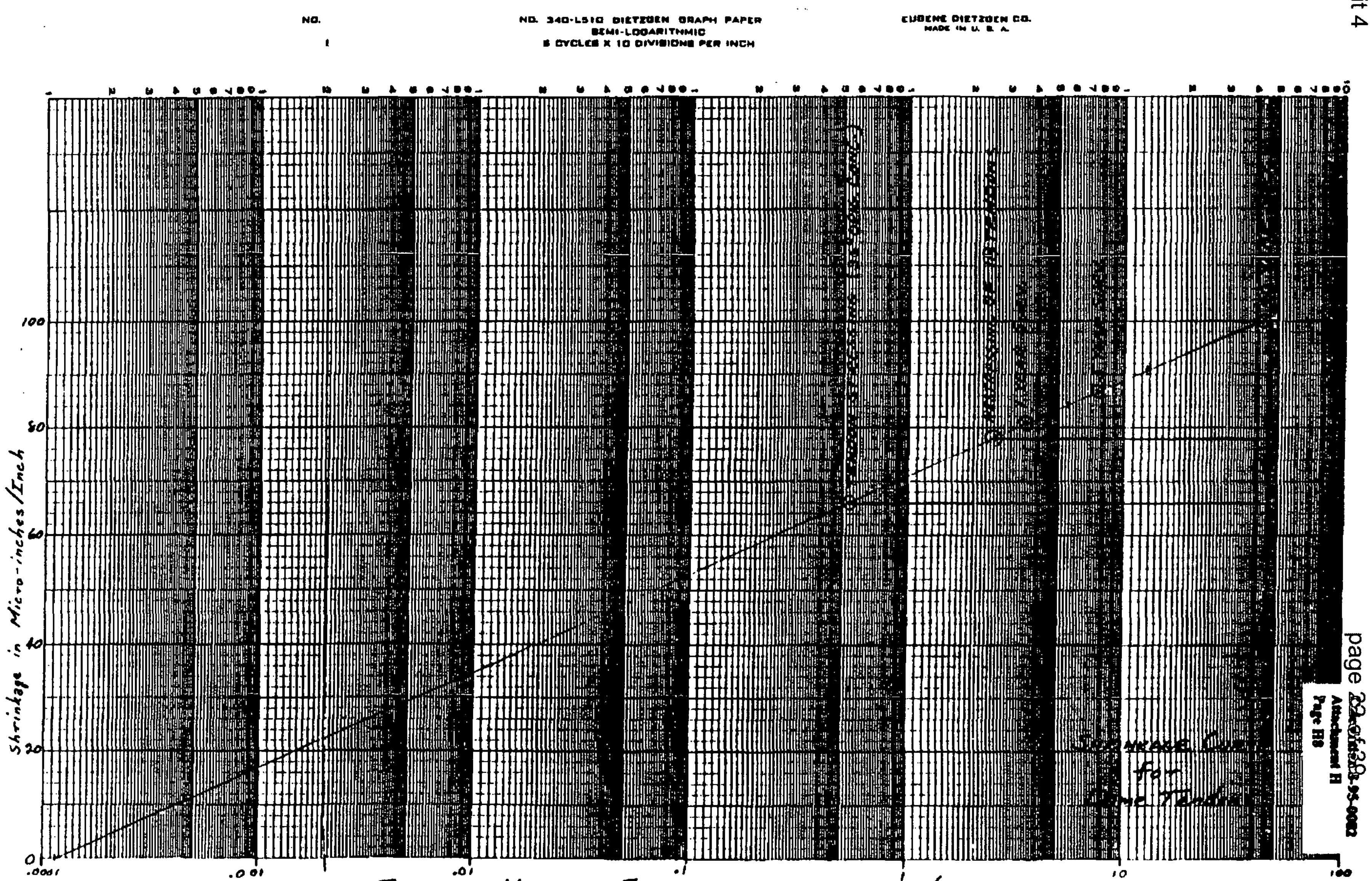
ORIGINATOR: G. T. DeMoss
DATE: 2/19/80
VERIFIER
DATE

18 Retensioned tendons

age of concrete at final stressing = 2.54 years (.54 + 2)

loss = diff. from chart $\times 10^{-6} \times (29 \times 10^{6}) \times 9.723 = .282 \times$ diff.

Period	Diff.	Shrinkage Loss
1	3	.8 k
5	9	2.5 k
40	22	6.2 k
3	6	1.7 k
10	13	3.7 k



TIME IN YEARS FROM CONCRETE PLACEMENT (Dome Tendons)

ATTACHMENT E

ELASTIC SHORTENING REFERENCE DATA

NOTE:

The following data was extracted from the Reference 10 calculation, page 9 and the Reference 11 calculation, pages 10, 23A & Appendix C and included herein for reference.

Gilbert/Commonwealth ENGINEERS/CONSULTANTS CALCULATION	SUBJECT CR 3 TENDON LOSS CALCS			IDENTIFIER 5500-528-1	PAGE 9 OF 48 PAGES
	REV. 0	1	2	3	
	MICROFILMED				
	ORIGINATOR D Kramer				
	DATE 1-30-87				

ELASTIC SHORTENING LOSSES

4TH SURV. CALC — REFERENCE 10

DOME TENDONS:

Ref. T. DeMoss Calcs. / √Fulton Calcs p. 23 a

A) FOR TENDONS IN SEQUENCES 1 THRU 27

$N = 27$ m = sequence of particular tendon

$$F_{LES} = \frac{N-m}{N}(82.7) + 75$$

B) FOR TENDONS IN SEQUENCES 28 THRU 32

$N = 5$ m = Sequence no. less 27

ie. 28 = 1
29 = 2
30 = 3
31 = 4
32 = 5

$$F_{LES} = \frac{N-m}{N}(47.4) - 13.7$$

HOOP AND VERTICAL TENDONS:

$$F^{n}_{LES} = \frac{N-m}{N} F_{LES} \times \text{wire factor}$$

Must add wire factor to a cell in lotus as an input. Change formula in the cell for F^{n}_{LES}.

Ref. p. 29, 10 6T DeMoss Calc.

from Ref 11

GILBERT ASSOCIATES, INC. ENGINEERS AND CONSULTANTS READING, PA.	DEPARTMENT NAME	DEPT. NO. 0414	FILING CODE	
	PROJECT NAME CR#3	W.O. NUMBER 04-4762-099		PAGE 10

SUBJECT: Basic Elastic Shortening Loss - Hoop & Vert. Tendons

ORIGINATOR: G. T. DeMove — DATE 1/17/80
VERIFIER: — DATE
Rev 1 J Fulton 4-9-80

Loss of prestressing force $F^n_{LES} = \frac{N-n}{N} \times \frac{\sigma^i_{cn}}{E_c} \times E_s \times A_p$

A_p = area of prestressed tendon = 9.723 [11]

σ^i_{cn} = ~~$\frac{F_i}{A_1}$ ...~~ = ~~915~~ 1042 psi for vert. tendons (from p. 7)

for vert. tendons $F^n_{LES} = \frac{N-n}{N} \times \frac{\text{~~915~~ } 1042}{4 \times 10^6} \times 29 \times 10^6 \times 9.723$

$F^n_{LES} = \frac{N-n}{N} \times$ ~~64.5~~ 73.5 K

for hoop tendons σ^i_{cn} = ~~1668~~ 1901 psi (from p. 7)

$F^n_{LES} = \frac{N-n}{N} \times \frac{\text{~~1668~~ } 1901}{4 \times 10^6} \times 29 \times 10^6 \times 9.723$

$F^n_{LES} = \frac{N-n}{N} \times$ ~~117.6~~ 134.0 K

Calc 04476209 pg 23 a

FLES CALCULATIONS FOR CR3 DOME

FOR TENDONS IN SEQUENCES 1 THROUGH 27

$N = 27$ n = sequence no. of tendon

$$F_{LES} = \frac{N-n}{N}(82.7) + 75$$

FOR TENDONS IN SEQUENCES 28 THROUGH 32

$N = 5$ n = sequence no. less 27
i.e.: 28 = 1
29 = 2
30 = 3
31 = 4
32 = 5

$$F_{LES} = \frac{N-n}{N}(47.4) - 13.7$$

Source of above: ~~4 page calculations by J. Fulton dated 2/7/80 to 2/12/80~~ REFER TO APPENDIX C

CR#3 Elastic Shortening Calculations – Dome Tende
G. T. DeMoss
2/13/80

APPENDIX C - DOME TENDON ELASTIC SHORT LOSSES C-1

GILBERT ASSOCIATES, INC. ENGINEERS AND CONSULTANTS READING, PA.	DEPARTMENT NAME	DEPT. NO.	FILING CODE
	PROJECT NAME	W.O. NUMBER	PAGE

SUBJECT: CR3 Dome P/S Stresses - Assuming No Delamination

ORIGINATOR: J Fulton
DATE: 2-8-80
VERIFIER:
DATE:

INITIAL (on 36" dome)

actual $T = 168 \times 9.723 = 1633^k$
$s = 30"$

From similar calcs for TMI-1, -2041 psi is the value of initial stress used.

OK, $E_c = 4 \times 10^6$ in KSHEL model

$\therefore$ For CR3, $\sigma = -2041\left(\frac{1633}{1394}\right)\left(\frac{24.5}{30}\right) = -1953$ psi

Use -1953 psi for concrete stress under initial P/S of 0.7 fpu at anch -

Use -1953 for ES calcs on 36" dome

NOTE the results come from a KSHEL analysis with liner included in model. Consequently, the transformed area calc should not include the liner -

~~FINAL (on 36" dome)~~

~~Using TMI-1 results for concrete stress of -1526 psi,~~ ok, $E_c = 2.2 \times 10^6$

~~For CR3 at 40 yrs $T = 140.0 ksi \times 9.723 = 1361^k$ and with s = 30"~~

~~$\sigma = -1526\left(\frac{1361}{1091}\right)\left(\frac{24.5}{30}\right) = -1554$ psi~~

~~ave over 40 yrs $= \frac{1}{2}(-1953 - 1554) = -1754$ psi~~

C-2

Gilbert Associates, Inc. Reading, Pennsylvania ANALYSIS/CALCULATION	SUBJECT CR 3 Tendon Surveillance Dome Losses - Delaminated Dome	CISIO		PAGE E3 of PAGES
	REV. 0	1	2	3
	MICROFILMED			
	ORIGINATOR J Fulton			
	DATE 2-7-80			

Elastic Shortening Based on lock off @ 0.7 and 163 wire tendon

Assume dome delaminated on date of "sonic boom" – 12/4/74 am
Calculate ES losses for two groups of tendons: those stressed in sequences 1 thru 27 and those in sequences 28 thru 32

DATA: (* assumes ave lock off for all tendons = $.7 \times 240 \times 9.72 = 1633^k$

σ_{c1} = stress in the 36" dome concrete if all tendons were stressed
σ_{c2} = " " " 24" " " " " " " "

(OK, $E_c = 4 \times 10^6$ in KSI E_s)

$\sigma_{c1} = -1953$ psi (gross concrete area)
$\sigma_{c1} =$ * (transformed area)
$\sigma_{c2} = -2930$ psi (gross concrete area)
$\sigma_{c2} =$ (transformed area)
(– indicates compression)

* Note: Obtaining σ_{c2} by proportioning σ_{c1} will be sufficiently accurate for ES loss calcs
$\therefore \sigma_{c2} = (36/24)\sigma_{c1}$

PART I
Tendons in Sequence 1 thru 27

1. ES losses just prior to delamination

$$F^n_{LES} = \frac{N-n}{N}\left(\frac{\sigma_c^i}{E_c} E_s A_p\right)$$

where $N = 27$
n = Sequence #
$\sigma_c^i = (\sigma_{c1}) \times \dfrac{\text{No of Tendons Stressed to 12/4/74}}{123}$

$\therefore \sigma_c^i = (89/123)\,\sigma_{c1} = -1413$ psi

$$F^n_{LES} = \frac{N-n}{N}\left(\frac{-1413}{4} \times 29 \times 9.723\right) = \left(\frac{N-n}{N}\right)(99.6^k)$$

2. ES losses due to delamination

$$F_{LES} = \frac{\overset{=2120}{[(89/123)\sigma_{c1}][36''/24'']} - \overset{-(-1413)}{(89/123)\sigma_{c1}}}{E_c} E_s A_p$$

$$F_{LES} = (-707)(29/4)(9.722) = 49.8^k$$

3. ES losses due to Stressing Tendons in sequences 28 thru 32

$$F_{LES} = \frac{\overset{-2930}{\sigma_{c2}} - \overset{-(-2120)}{[(89/123)\sigma_{c1}][36/24]}}{E_c} E_s A_p$$

$$= (-810)(29/4)(9.723) = 57.1^k$$

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	ORIGINATOR J Fulton				
	DATE 2-7-80				

The total ES losses for those tendons in sequence 1 thru 27 are the sum of F_{LES}'s in ① thru ⑤

Tendons in Sequence 28 thru 32

1. ES Losses (total)

$$F_{LES}^{n^*} = \frac{N^* - n^*}{N^*}\left\{\sigma_{c2} - [(89/123)\sigma_{c1}][36/24]\right\}\frac{E_s}{E_c}A_p \quad (-2930 - (-2120))$$

where

$N^* = 5$

$n^* = (\text{Sequence } \#) - 27$

$$F_{LES}^{n^*} = [(N^* - n^*)/n^*][-810\ (29/4)(9.723)] = \left(\frac{N^* - n^*}{n^*}\right)(57.1^k)$$

PART II

Elastic Shortening correction due to the reduced force in the 18 Retensioned on or about 10/25/76:

Ave Lift off for 18 tendons = 1516^k (based on Delam. Dome Rpt)
Ave retensioning lock off " " " " = -652^k (calculated)
864^k

This ave force reduction for 18 tendons results in a compressive stress and strain reduction of

$$\Delta\sigma_c = \frac{(2930\ psi)}{123 \times 1633^k} \times 18 \times 864^k = 227\ psi$$

$\Delta\epsilon = 227/4\times10^6 = 56.8\ \mu\ in/in$

$\Delta\sigma_s = 56.8 \times 29 = 1645\ psi \approx \underline{1.7\ ksi}$

($\Delta F_s = 1.7\ ksi \times A_p = 1.7 \times 9.723 = 16.5^k$ for all 163 wire tendons)

→ Reduce the tendon stress losses calculated in PART I by 1.7 ksi, or 16.5^k for 163 wire tendon

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	DATE 2-12-80				

Biaxial Effect

Assume that the concrete stresses obtained above for the various loading stages are equal biaxial. For such a stress state the strains are

$$\epsilon_\phi = \epsilon_\theta = \epsilon = \frac{(1-\nu_c)\,\sigma_c}{E_c} = \frac{1-.17}{E_c}\,\sigma_c = 0.83\,\frac{\sigma_c}{E_c}$$

Thus, the tendon force losses should be multiplied by 0.83 since they are proportional to concrete strain

FINAL

Tendons in Sequences 1 thru 27

$$F^n_{LES} = 0.83\left\{\left(\frac{N-n}{N}\right)(99.6^k) + 49.8^k + 57.1^k - 16.5^k\right\}$$

A | $F^n_{LES} = \left(\frac{N-n}{N}\right)(82.7^k) + 75^k, \quad 27 \le n \le 1 \quad + N = 27$

Tendons in Sequence 28 thru 32

$$F^{n^*}_{LES} = 0.83\left\{\left(\frac{N^*-n^*}{N^*}\right)57.1^k - 16.5^k\right\}$$

B | $F^{n^*}_{LES} = \left(\frac{N^*-n^*}{N^*}\right)(47.4^k) - 13.7^k$

$n^* = \text{Seq.}\ \# - 27$
$N^* = 5$

Use A + B

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	ORIGINATOR J Fulton				
	DATE 2-12-80				

<u>Elastic Shortening Based on Actual Average Lock Off</u>

Results of Actual Average Lock Off Calcs:

Tendons in Sequences 1 thru 27 (89): <u>Ave = 1634^k</u>

Tendons in Sequences 28 thru 32 (43): <u>Ave = 1638^k</u>

<u>Conclusion</u>: These values are close enough to the theoretical lock off value used previously of 1633^k which is for 0.7 F_{pu}.

Therefore, the only correction which should be made to the results on p ES 3 is for actual tendon area, using the wire factor

Florida Power CORPORATION

DESIGN ANALYSIS/CALCULATION

Crystal River Unit 3

DOCUMENT IDENTIFICATION NO.	REVISION
Calculation S-95-0082	

ATTACHMENT F

WIRE STRESS RELAXATION REFERENCE DATA

NOTE:
The following data was extracted from the Reference 10 and 11 calculations and included herein for reference.

Gilbert/Commonwealth ENGINEERS/CONSULTANTS CALCULATION	SUBJECT CR3 TENDON LOSS CALCS	IDENTIFIER 5500-528-1	PAGE 10 OF 48 PAGES
	REV. 0 / 1 / 2 / 3		
	MICROFILMED		
	ORIGINATOR D. Krause		
	DATE 1-30-87		

Verified A. Fagan 2-5-87

FROM REFERENCE 10 CALC

WIRE STRESS RELAXATION:

HOOP /VERT. TENDONS
Ref. p. 12 G.T. DeMoss Calcs.

TENDON AREA = 9.7556 □ WITH 163 WIRES

PERIOD	(1) INTERA % Loss	(1)x2.68= (2) Factored % Loss	(3) = 168 ksi x(2)	(4)=(3)x9.7556 Tendon Loss	(4) / 1638.9	(4) x Ave Lockoff STRESS Relax (kips) HOOP	VERT
1	.96	2.57	4.32	42.1	.0257	42	42.3
3	.975	2.61	4.38	42.7	.0260	42.5	42.7
5	1.00	2.68	4.50	43.9	.0268	43.8	44.1
10	1.03	2.76	4.64	45.3	.0276	45.1	45.4
15	1.05	2.81	4.72	46.0	.0281	45.9	46.2
20	1.07	2.87	4.82	47.0	.0287	46.9	47.2
25	1.075	2.88	4.84	47.2	.0288	47.1	47.3
30	1.085	2.91	4.89	47.7	.0291	47.6	47.8
35	1.092	2.93	4.92	48.0	.0293	47.9	48.2
40	1.10	2.95	4.96	48.4	.0295	48.2	48.5

INPUT TO LOTUS AS % (HOOP column)

Use for Dome Also (VERT column)

AVE LOCKOFF = 1644^{K} VERT.
= 1635^{K} HOOP.

Gilbert/Commonwealth ENGINEERS/CONSULTANTS CALCULATION	SUBJECT CR 3 TENDON LOSS CALCS			IDENTIFIER 5500-528-1	PAGE 11 OF 48 PAGES
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	ORIGINATOR D Kreuse				
	DATE 1-30-87				

WIRE STRESS RELAXATION (CONT)

From Reference 10 Calc

DOME TENDONS

Ref. p.20 G.T. DeMoss Calc.

Same as for HOOP AND VERT. WIRE FACTOR is NEGLIGIBLE FOR THIS LOSS THEREFORE DISREGARD.

SHRINKAGE:

HOOP & VERTICAL

REF. PP. 13 & 14 G.T. DEMOSS CALC

SHRINKAGE = .282 x difference on p.14.

PERIOD	Tab. Diff. x .282 =	Shrink. loss (Kips)
1	6	1.69
3	8.5	2.40
5	10	2.82
10	13.5	3.81
15	15.5	4.37
20	17.5	4.94
25	19.5	5.50
30	20.4	5.75
35	21.5	6.06
40	22.5	6.35

INPUT TO LOTUS

GILBERT ASSOCIATES, INC. ENGINEERS AND CONSULTANTS READING, PA.	DEPARTMENT NAME	DEPT. NO. 0414	FILING CODE
	PROJECT NAME CR#3	W.O. NUMBER 04-4762-099	PAGE 11
SUBJECT Wire Relaxation Loss – Hoop & Vert. Tendons			ORIGINATOR S. T. DeMoss DATE 1/18/80 VERIFIER DATE

Stress relaxation will be interpolated from the curve in figure 5-23 of the CR#3 FSAR with certain factors applied:
(Chart on page 11a)

From Reference 11 Calculation

Temperature Factor Since curve is based on 68°F and actual tendon wire long-term temperature is closer to, or over, 100°F, the interpolated values will be multiplied by $\frac{1.1}{.75} = 1.47$ (see attached telephone memo with Earl Cutler of Prescon).

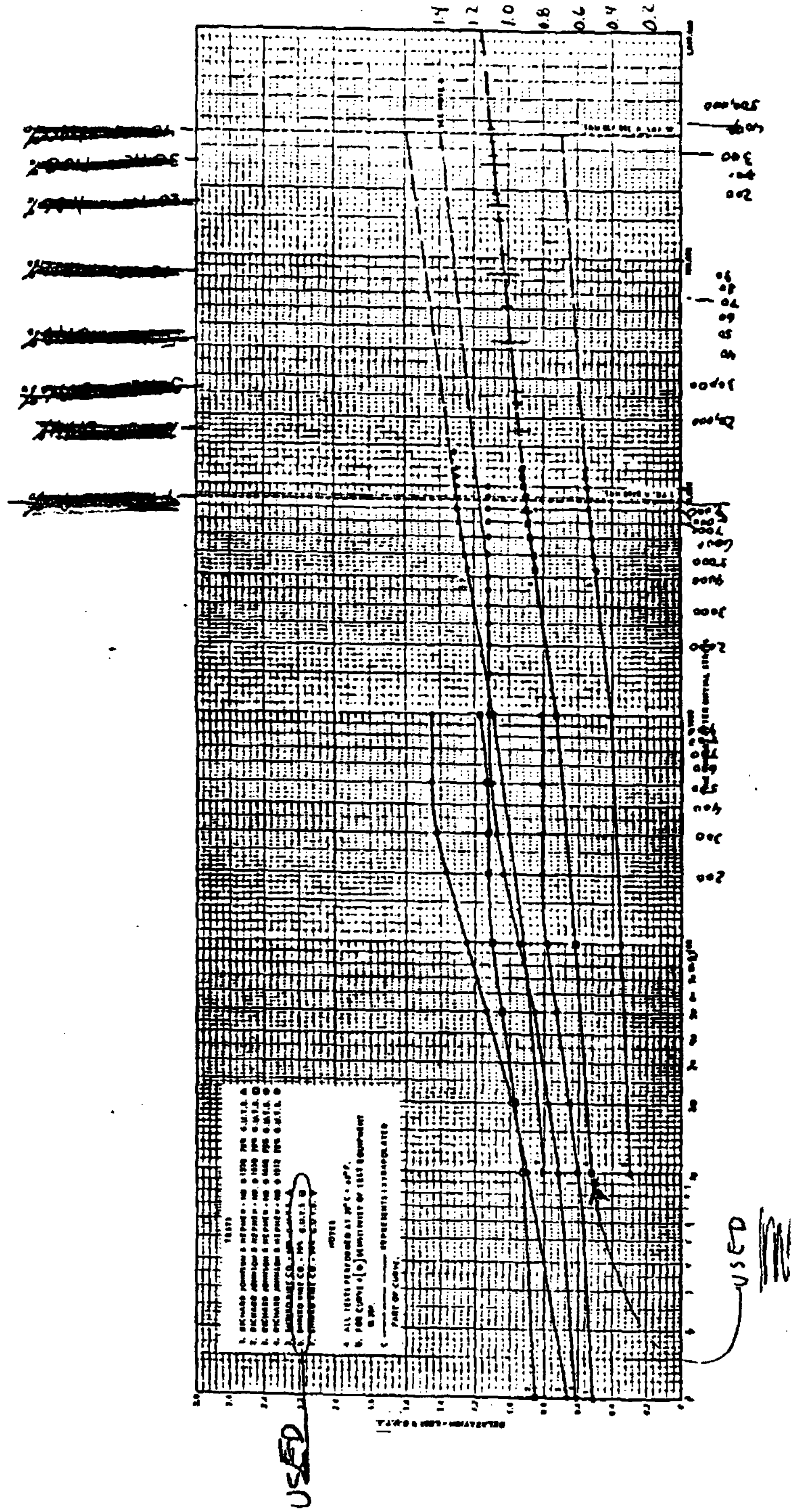
Conservatism Factor

Since, according to the Shinko catalog, "--- the relaxation test is complicated and aims to find very small values. The scatter of the relaxation values would be about 50 per cent when the values are small (say 1% ± .5%, 2% ± 1%) ----." Also, according to Earl Cutler of Prescon, a value of 2% relaxation would be conservative for this wire for the 40 year period. Accordingly, the interpolated values from curve 5-23 will be multiplied by $\frac{2.0}{1.1} = 1.82$.

Final multiplication factor = 1.47 × 1.82 = 2.68 = K

The interpolated values represent stress loss in wire in % of initial design stress (of .7 × G.U.T.S.) = .7 × 240,000 = 168,000 psi

PAGE 11



RELAXATION CURVES FOR LOW RELAXATION
PRESTRESSING WIRE
CRYSTAL RIVER UNIT 3
FIGURE 5-23

FIG 3

Wire Relaxation Cur
Hoop & Vert. Tendo
G. J. De More
1/18/80

11b

FILE

GILBERT ASSOCIATES, INC.
TELEPHONE AND CONFERENCE MEMORANDUM

DATE January 18, 1980

BY: G. T. DeMoss WORK ORDER NO. 04 4762-099

TELEPHONE CALL [X] CONFERENCE [ ]

WITH: Mr. Earl Cutler

COMPANY: Prescon Corporation, San Antonio, Texas Tel. 512-828-6264

SUBJECT: Prestress wire relaxation for CR #3 containment

NOTES:

I asked Mr. Cutler several questions regarding prestress wire relaxation. The questions and his answers are as follows:

1. Q:- The curves in the CR #3 FSAR (Figure 5-23) show the 40 year relaxation for the Shinko wire used in CR #3 to be about 1.1%. I asked if this appeared to be reasonable.

   A: Mr. Cutler feels the numbers reflect the average values of the tests, but feels that to be conservative, the curve should be shifted upward so that the 40 year period would give about 2.0% relaxation.

2. Q: Since the interior of the containment building normally operates above 100° F, and the structure is exposed to the Florida sunshine on the outside, I asked if we should not be assuming a higher temperature for the wire than the 20° C (68° F) on which the curve in the FSAR is based.

Copies To:

lk

A: Mr. Cutler stated that the selection of temperature criteria is not a Prescon responsibility but, if we wanted to use a higher lifttime temperature, the current Shinko catalog also gives a curve for 40° C (104° F). This curve roughly parallels the 20° C curve. At 1000 hours the 20° C curve indicates .75% relaxation, while the 40° C curve indicates about 1.1 %.

3. Q: I asked Mr. Cutler if the wire used was considered as "stress-relieved" or "stabilized".

A: He replied that it was "stabilized".

4. Q: I noted that the left hand scale on the curve in the CR #3 FSAR (Figure 5-23) indicates "Relaxation-Loss % G.U.T.S.", while the curves in the Shinko catalog indicate, for the same scale, "Relaxation-Loss in Per Cent". I asked Mr. Cutler if he felt our labelling was in error and what the relaxation was a percent of.

A: He replied that the percentages were given as a percent loss of original stressing value, which in our case is 70% G.U.T.S. He said that our labelling appeared to be inaccurate.

Mr. Cutler agreed to send a copy of the more recent Shinko tables or catalog to me for our reference.

cc: J. Fulton
J. Herr
K. Nodland
R. Eshbach
F. Moreadith

GILBERT ASSOCIATES, INC.
ENGINEERS AND CONSULTANTS
READING, PA.

DEPARTMENT NAME	DEPT. NO.	FILING CODE	
	0414		
PROJECT NAME: CR #3	W.O. NUMBER: 04-4762-099		PAGE: 12

SUBJECT: Wire Relaxation Loss — Hoop & Vert. Tendons

ORIGINATOR: D. T. DeMoss
DATE: 1/18/80
VERIFIER: S. Hoffa
DATE: 4/3/80

Wire Relaxation based on tendon area of 9.723 □"

(See page 3 for durations)

Period	Interpolate % Loss	Factored % Loss	Factored % loss × 168 K/in² (KSI)	Tendon Loss (KIPS)	Ave. stress date to period (HRS)
1 YR (1)	.96	2.57	4.32	42.0	25,300
3 (2)	.975	2.61	4.38	42.6	42,800
5 (3)	1.00	2.68	4.50	43.8	60,300
15 (5)	1.05	2.81	4.72	45.9	147,900
25 (7)	1.075	2.88	4.84	47.1	235,500
40 (10)	1.10	2.95	4.96	48.2	366,900
10	1.03	2.76	4.64	45.1	104,100

Wire stress relaxation losses as entered in the tendon loss table are adjusted to reflect actual lock off by multiplying by actual lock off and dividing by 1633 K (theoretical lock-off).

1 YR $F_{SR} = 42 \times \frac{\text{LOCK-OFF}}{1633} = .0257 \times$ lock-off

3 yr = .0261 × " "

5 YR $F_{SR} = 43.8 \times \frac{\text{LOCK-OFF}}{1633} = .0268 \times$ lock-off

10 yr = .0276 × " "

40 YR $F_{SR} = 48.2 \times \frac{\text{LOCK-OFF}}{1633} = .0295 \times$ lock-off

Period	Interpolated %	Factored %	Hrs. to period
10 yr (4)	1.03	2.76	104,100
20 yr (6)	1.07	2.87	191,700
30 yr (8)	1.085	2.91	279,300
35 yr (9)	1.092	2.93	323,100

CODE