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# REGULATORY GUIDE

DIRECTORATE OF REGULATORY STANDARDS

## REGULATORY GUIDE 1.90

# INSERVICE INSPECTION OF PRESTRESSED CONCRETE CONTAINMENT STRUCTURES WITH GROUTED TENDONS

## 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, "Licensing of Production and Utilization Facilities," requires, in part, that the containment be designed to permit (1) appropriate periodic inspection of all important areas and (2) an appropriate surveillance program. This guide describes a basis acceptable to the Regulatory staff for developing an appropriate surveillance program for prestressed concrete containment structures of light-water-cooled reactors with grouted tendons made up of parallel wires or strands (bar-type tendons are not covered).

## B. DISCUSSION

This guide is applicable to current "typical" prestressed concrete containments having a shallow-domed roof on cylindrical walls about 150 feet in diameter and an overall height of about 200 feet and for which the number of tendons is approximately as follows: 200 in the dome (either three families of tendons 60° apart or two families of tendons 90° apart), 200 vertical (in wall), and 500 complete hoops (in wall).

For containment that differ from the "typical" described above, the model program presented in this guide should serve as the basis for development of a comparable inservice inspection program which the Regulatory staff will evaluate on a case-by-case basis.

This guide covers inservice inspection of containments using grouted wire tendons of all sizes (up to an ultimate strength of approximately 1300 tons) and all types, for example, tendons with parallel wires, with one or several strands, and with different systems of anchors. The inservice inspection program should cover the tendons, the anchor hardware, and protection features intended for corrosion prevention including grout. Bar-type tendons are not covered in this guide, and, if used, will be reviewed by the Commission's Regulatory staff on a case-by-case basis to determine inservice inspection requirements.

In service inspection of the structural integrity of prestressed concrete containment structures with grouted tendons is needed because any deterioration of the prestressing tendons may not become evident until the containment is loaded as a result of a loss-of-coolant accident. Even though grouted tendons are a proven technology in other types of structures, there is as yet no real experience to adequately define the long-term characteristics of containment structures with grouted prestressing systems. Various types of corrosion may occur in the tendon, depending on age, temperature variation, degree of exposure, and other environmental factors, as well as the quality of workmanship. Of particular importance is the quality of the grouting.

The prestressing force in a tendon can be indirectly checked by measuring the level of prestress in the structure. Any eventual decrease in the tendon prestressing force is due to the interaction of several time-dependent factors such as:

1. Stress relaxation in the wire;
2. Shrinkage and creep in concrete;
3. Differential thermal expansion or contraction between the tendon, grout, and concrete; and
4. Reduction in cross section of the wires due to corrosion, including possible fracture of the wires.

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The effects of corrosion on the tendons are of greatest concern, but they cannot be isolated from other effects. Therefore, tolerance limits for the loss of prestressing force which are established to monitor corrosion must also take into account all prestress losses. An inservice inspection program is needed to ensure that these limits are not exceeded. It should be noted, however, that this program will not detect minor losses in tendon prestress due to corrosion but will instead provide a means of tracking changes in the containment prestress level which will initiate investigative actions if the prestress losses become significantly greater than the estimated losses.

Many hoop tendons are anchored on buttresses located partially inside the building adjacent to the containment. Unless the anchors are installed with consideration for inspection, they will not be easily accessible for inspection, especially during operation. The original layout of tendons should address itself specifically to this accessibility problem. Any architectural treatment or environmental protection provided for the anchors should not preclude access for inspection purposes.

The recommendations outlined in this guide are applicable to all containments with grouted wire (parallel or stranded) prestressing systems regardless of plant geographical location, but the following factors warrant special attention:

1. The tendons may need protection from moisture and salt intrusion at coastal sites and other sites having high moisture levels and significant temperature cycles of short duration.
2. For sites in industrial areas, tendons should be guarded against fume releases containing $SO_2$, $H_2S$, $NO_x$, or chlorides.
3. Chemical constituents of grout and placement methods can influence the vulnerability of grouted tendons to corrosive attack.
4. Where environmental conditions make electrochemical phenomena a consideration, grounding of grouted tendons against stray electrical currents, and possibly cathodic protection of the tendons, could be needed. It should be recognized, however, that cathodic protection can, under some circumstances, be detrimental to the tendons.

The inservice inspection program outlined in this guide consists of three major parts. Some test tendons are left ungrouted and are environmentally protected with a grease. The effects on these test tendons are not intended to represent the environmental or physical effects (with respect to corrosion) on the grouted tendons. Instead, acting as compensating gauges, these tendons will be used to evaluate the extent of concrete creep and shrinkage as well as relaxation of the tendon steel. This information will then assist in interpreting gross changes in the readings obtained from the instrumentation which is measuring the available level of prestressing in the structure. This instrumentation, composed of either strain gauges or stress meters, will provide prestress level readings in representative areas of the structure. The instrumentation can be either embedded permanently in the structure as it is being built or else installed so that it is possible to remove and replace it. The combined evaluation of the test tendons and instrumentation readings will be supported by a visual examination of the overall structure specifically including some representative critical locations (such as anchorages). Information from the test tendons, instrumentation, and visual examination will be used to evaluate the overall structural condition of the containment.

Because of the nature of the program described above, decisions must be made early in the design process as to the nature and acceptability of the system to be used and the components to be installed as noted below. In order to ensure timely review, the proposed inservice inspection program should be presented in the preliminary safety analysis report (PSAR); it should include:

1. A description of the instruments that will be installed in the structure and the data collecting system that will be used;
2. A description of the planned erection procedure of the system, including the instrument calibration procedure to be used and also the locations of the instruments, the data collecting system, and the ungrouted tendons;
3. Identification of which tendons will not be grouted and how these tendons will be protected against corrosion;
4. Discussion on the accessibility of the end anchorages; and
5. A description of the overall inservice inspection program utilizing instruments, ungrouted tendons, and visual observations.

Later, at the time of submittal of the final safety analysis report (FSAR), with construction well advanced, sufficient information will be available to submit a correct and expanded study. The FSAR should incorporate all changes that occurred during construction as well as:

1. A description of the provisions made to ensure that only properly calibrated gauges have been used;
2. A numerical estimate of the expected theoretical indication level of the gauges presented as a function of time for the entire life of the plant. This estimate should include all necessary estimated corrections, including concrete creep and shrinkage and tendon relaxation which will be checked by the ungrouted test tendons;
3. An indication of the reasons and tolerances for possible discrepancies between the measurements and the actual prestress;

4. An evaluation of the maximum probable error in the results and the accuracy expected;
5. A discussion of the probable influences of temperature on the results due to changes in the length of the wires, in the size of the structure, and in friction values;
6. A description of actions that should be taken as a result of anomalous gauge readings or indications that numerous gauges are defective; and
7. The visual observations to be made, the procedures for checking the ungrouted tendons, and the integration of these data with gauge data to form inservice inspection conclusions regarding continued structural integrity.

The FSAR should also contain a certification that the installation and the calibration of the instruments are correct. If the installation of the instrumentation is not yet completed, this certification may be submitted later, but not less than 3 months before issuance of an operating license.

The use of the Regulatory Position described below does not eliminate the requirement for compliance with "Capability for Containment Leakage Rate Testing," of Appendix A to 10 CFR Part 50, General Design Criterion 52, which requires that the containment be designed so that periodic integrated leakage rate testing can be conducted at containment design pressure.

## C. REGULATORY POSITION

### 1. Inservice Inspection Program–General

Each "typical" prestressed concrete containment structure with grouted tendons, as described in Section B, should be subjected to an inservice inspection program that includes:

a. Liftoff tests of ungrouted test tendons;
b. Periodic reading of instrumentation for determining concrete prestress level; and
c. Visual examination.

### 2. Ungrouted Test Tendons

a. The following ungrouted test tendons[1] should be installed:

(1) Three vertical tendons.
(2) Three hoop tendons, and
(3) Two dome tendons if the design utilizes two 90° families of tendons or three dome tendons if the design utilizes three 60° families of tendons.

b. At the intervals given for visual examinations in C.4.a below, the ungrouted test tendons should be subjected to liftoff testing to measure the effects of concrete shrinkage and creep and relaxation of the tendon steel. These data should be evaluated in conjunction with concurrent instrumentation readings and visual examinations. If instrumentation readings indicate a need for further checking, additional liftoff tests of the ungrouted test tendons may be needed.

### 3. Instrumentation

#### a. Characteristics

(1) Instrumentation provided for the determination of concrete prestress level should be capable of effective use over the life span of the containment structure within specified operational limits under the following conditions, unless otherwise defined by the designer and approved by the Regulatory staff:

(a) Humidity: 0% to 100%;
(b) Temperature: 0°F to 200°F; and
(c) Cyclic loading: 500 cycles of 600 psi stress variation in compression.

(2) The instruments should be protected against adverse effects of the expected environment in which they will be located, e.g., electrolytic attack, including the effects of stray electric currents of a magnitude that may be encountered at the particular site and structure. They should be protected against temperature extremes to which they may be exposed while the containment is under construction.

(3) The sensitivity of strain gauges should be specified, and the drift or stability under the conditions in C.3.a.(1) and (2) above should be accounted for in the specified limits, or the gauges should be subject to recalibration in service.

(4) The range of stress meters should be from 500 psi in tension to 2500 psi in compression.

(5) A numerical estimate of the expected theoretical indication level of the gauges or meters, including permissible deviations of readings, presented as a function of time, should be incorporated in the design specifications and the FSAR.

#### b. Installation

The prestressed cylindrical wall and the dome should be instrumented. The base mat need be instrumented only if it is prestressed. This instrumentation may be either embedded in the concrete or inserted into the structure so that it can be maintained and/or replaced. Instrument types, locations, and quantities should be selected to provide the best representation of prestress levels in the structure. Generally, these locations are presumed to be at the mid-depth of the thickness of the wall and dome, unless specified otherwise by the designer, at locations around the structure that match the locations at which deflection readings (in a prototype structure, deflection and strain readings) are taken during the structural acceptance test.

[1] For the purposes of this guide, a tendon is defined as a separate continuous tensioned element consisting of wires or strands anchored at each end to an end anchorage assembly.

If redundancy is required to achieve reliability at a measurement point, six strain gauges or six stress meters should be installed. Three gauges should measure the prestress in the direction of the meridian and three the prestress in the hoop direction. This would permit evaluation of anomalous readings and isolation of a malfunctioning gauge.

c. **Reading Frequency**

Every month for the first six months following the structural integrity test, all strain gauges or stress meters should be read. At the option of the designer, earlier readings may be initiated following completion of prestressing, but such readings are supplementary to those necessary following the structural integrity test and should not be substituted for them. Each gauge whose indication deviates from its initially predicted level by more than the preestablished amount contained in the design specifications should be listed in a special table with an indication of its location and all additional pertinent information. After the first six months, the reading frequency can be changed to reflect the deviation from the predicted readings. Those points whose measured strains have not deviated more than the preestablished amount from their initially predicted levels may be read once a year for the rest of plant life if their readings continue to approximate the predicted levels. Gauges whose strains have deviated from their predicted levels by more than the preestablished amount should continue to be measured once each month until, during six-month span of monthly readings, a pattern of no excessive deviations develops. These measurement points may then be read once a year. However, local conditions or special circumstances may dictate a continuation of once a month readouts.

All gauges should be read during the periodic Type A leakage tests required by Appendix J to 10 CFR Part 50, and the results should be evaluated against other data gathered during the overall inservice inspection program.

When the number of gauges listed in the special table of deviations described above reaches the predetermined fraction of the total contained in the design specifications or if there are other indications of possible loss of prestress, this event should be considered as an abnormal occurrence and reported in accordance with C.5 below.

If anomalous readings are received, it should be determined whether they result from defective gauges, and the basis for such a determination should be justified.

**4. Visual Examination**

a. A visual examination of the entire concrete containment structure should be performed 1, 3, and 5 years after the initial containment structural integrity test and every 5 years thereafter. As a part of this visual examination, the tendon anchorage assembly hardware (such as bearing plates, stressing washers, shims, wedges, and buttonheads) of 21 selected tendons should be visually examined to the extent practical without dismantling load-bearing components of the anchorage. These selected tendons[1] should include:

(1) Six dome tendons; two located in each 60° group (three families of tendons) and randomly distributed to provide representative sampling, or three located in each 90° group (two families of tendons),

(2) Five vertical tendons, randomly but representatively distributed.

(3) Ten hoop tendons, randomly but representatively distributed.

For each succeeding examination, the tendons should again be selected on a random but representative basis, so the sample group will change somewhat each time.

b. The inservice inspection program should define the defects the inspector should look for during visual examination of the anchorage system and should establish the corresponding limits and tolerances. Special attention should be given to the concrete supporting the anchor assemblies, and the crack patterns at these points should be observed, analyzed, and reported.

c. A visual examination of concrete cracking and deformations should be scheduled during integrated leakage testing while the containment is at its maximum test pressure, even if visual examinations have been conducted at other times.

d. Regulatory practice is to consider grouted tendons as unbonded for load-carrying purposes, and the anchor hardware is therefore considered to be a principal load carrying element requiring periodic visual examination. Consequently, containments should be designed so that the prestressing anchor hardware is accessible for periodic examination.

**5. Reporting**

If the specified limits of the inservice inspection program are exceeded, a possible abnormal degradation of the containment structure (a boundary designed to contain radioactive materials) is indicated. In such cases, the reporting program of Regulatory Guide 1.16, "Reporting on Operating Information–Appendix A Technical Specifications," should apply. A description should be furnished of the condition of the concrete (especially at tendon anchorages) and all examined tendon hardware, the inspection procedures, the tolerances on concrete cracking and hardware corrosion, the measures to be used when the specified limits or

tolerances are exceeded, and a description of procedures to be used following completion of corrective measures to verify the satisfactory condition of the structure.

## D. IMPLEMENTATION

For applicants choosing to implement the Commission's regulations by the methods described in this guide, the following guidance is provided:

1. Construction permit reviews for applications docketed after July 1, 1975, will be evaluated on the basis of this guide.
2. Construction permit and operating license reviews for plants whose construction permit applications were docketed prior to July 1, 1975, will be evaluated on a case-by-case basis. If practical, the applicant and designer in such cases may choose to follow the recommendations of this guide.