

# REGULATORY GUIDE

OFFICE OF STANDARDS DEVELOPMENT

## REGULATORY GUIDE 1.103

## POST-TENSIONED PRESTRESSING SYSTEMS FOR CONCRETE REACTOR VESSELS AND CONTAINMENTS

### A. INTRODUCTION

General Design Criterion 1, "Quality Standards and Records," of Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50, "Licensing of Production and Utilization Facilities," requires that structures, systems, and components important to safety be designed, fabricated, and erected to quality standards commensurate with the importance of the safety functions to be performed. This guide identifies the post-tensioned prestressing systems that have been reviewed and approved by the NRC staff for use in concrete reactor vessels and containments. It also describes qualifications acceptable to the NRC staff for new post-tensioned prestressing systems.

### B. DISCUSSION

A post-tensioned prestressing system is composed of a prestressing tendon combined with a method of stressing and anchoring the tendon to the hardened concrete. The word "system" is commonly associated with the different proprietary post-tensioned prestressing systems on the market and is understood to include the type of tendon, anchorage device, and stressing equipment associated with a given system.

It is not practical to discuss the details of all of the many post-tensioned prestressing systems available in the United States. Moreover, new post-tensioned prestressing systems are being developed, and existing ones are being modified. For these reasons, the descriptions in this guide are limited to systems listed in Table A, all of which have been used or proposed for use.

Some examples of use are presented in order to identify more specifically the system being discussed and provide a reference to some plants for which the systems in Table A have been proposed or approved. The examples cited are not intended to indicate any restric-

tion or preference in size of the tendon for a given system. Nor is this guide intended to discourage the development of refinements of current systems or the development of new prestressing systems or concepts.

The qualifications that a post-tensioned prestressing system should meet in order to be acceptable to the NRC staff are identified in the regulatory position. Rock anchorage systems are not covered by this guide.

#### Types of Systems

The type of tendon selected usually dictates the choice of stressing equipment and also affects the choice of end anchorages.

Basically, post-tensioned prestressing systems can be separated into three general categories according to the types of tendon in use: wire, strand, and bar systems. End anchorages for these tendons are based on either wedge or direct-bearing principles; sometimes a combination of the two is used. Post-tensioned prestressing systems are described below in terms of types of tendons and end anchorages.

**Wire Systems.** Wire systems use a number of parallel wires grouped to form a tendon. Wires manufactured in the United States conform to ASTM Specification A-421, "Uncoated Stress-Relieved Wire for Prestressed Concrete."\* This specification provides for wires of two types (BA or WA), depending on whether they are to be used with buttons or wedge anchorages.

The BBRV system, developed in Switzerland by Birkenmaier, Brandestini, Ros, and Vogt, is a wire system used in both concrete reactor vessels and

\*Copies of this and other ASTM specifications referenced in this guide may be obtained from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.

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Comments and suggestions for improvements in these guides are encouraged at all times, and guides will be revised, as appropriate, to accommodate comments and to reflect new information or experience. This guide was revised as a result of substantive comments received from the public and additional staff review.

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containments built in the United States. The main feature of this system is the use of cold-formed buttonheads for direct bearing at each end of the wire. The prestressed concrete reactor vessel (PCRV) of the Fort St. Vrain station in Colorado uses the BBRV system with 169-wire tendons developing approximately 2000 kips capacity each. A number of containments using the BBRV system with 90, 163, 169, 170, and 186 wires per tendon have been built in the United States. The wire diameter is 1/4 inch (6.35 mm) in all cases except for the 163-wire tendon, which uses 7-mm (0.28 inch) wire.

A wire-winding system was used to provide hoop prestress for the Hartlepool PCRVs in England. This method of providing hoop prestress is similar to that for conventional prestressed concrete tanks.

*Strand Systems.* Strand systems use a number of "strands" that are bundled into a tendon. A strand is made up of a number of factory-twisted wires. Stress-relieved strand is made in two forms. The first is the seven-wire strand, which conforms to ASTM Specification A-416, "Uncoated Seven-Wire Stress-Relieved Strand for Prestressed Concrete." The second form consists of larger strands that are made of larger individual wires and may consist of more than seven wires per strand. The larger strands are not covered by ASTM specifications and have not been used for the construction of nuclear power plants in the United States.

Strand systems have been introduced in the construction of nuclear power plants by Strand-Wrap, VSL, (Vorspann System Losinger), Stressteel, Freyssinet, and SEEE (Societe d'Etudes et d'Equipements d'Enterprises). The last two systems were considered but have not yet been used in the United States in nuclear power plants. Both the Freyssinet and SEEE systems have been used in Europe on concrete reactor vessels.

The Strand-Wrap system has been reviewed and approved only for applying hoop prestressing to some PCRVs in the United States. The basic principles of applying hoop prestressing to the PCRV by the Strand-Wrap system are the same as those of a wire-winding system. In one of the design methods, steel-lined circumferential precast concrete channels are anchored to the outer cylindrical surface of the vessel by reinforcing bars extending radially inward from the precast channels. The strand is anchored at one end by means of a tapered wedge grip in the rib between adjacent channels and then wound around the vessel at the design tension for a number of turns and anchored in the next adjacent rib. Each band of circumferential prestressing consists of multiple layers of strand wound onto these channels. Each layer consists of one contin-

uous length of strand. A maximum hoop prestressing force of about 6600 kips per linear foot of vessel height was to have been used in the design of the PCRV head region of the Delmarva Summit Power Station.\*\*

The VSL strand system, which was developed in Switzerland, uses a wedge anchorage for strands. Each strand is drawn through the openings of both the bearing plate and the anchor head and is held by a two-piece split cone wedged tightly against the inner surface of the anchor head. As an example, the containment of the Rancho Seco Nuclear Generating Station in California uses the VSL system with tendons consisting of 55 strands, each tendon developing 2250 kips capacity. (The Freyssinet, SEEE, and VSL systems were formally presented as alternatives to the previously approved BBRV system. The VSL system was chosen by the applicant. Consequently, the Freyssinet and SEEE systems were not reviewed by the NRC staff with regard to their acceptability for use in nuclear power plant containments.)

The Stressteel S/H multistrand system, which was developed in the United States by Stressteel Corporation in cooperation with Howlett Machine Works, is characterized by a three-piece slotted wedge cone that grips three strands in its serrated teeth, with a number of wedges in a single anchor plate making up a multistrand tendon of the desired size. As an example, the containment of the Three Mile Island Nuclear Station Unit No. 2 in Pennsylvania uses a Stressteel S/H multistrand system consisting of tendons with 54 1/2-inch, Grade 270K, 7-wire strands per tendon, each tendon developing 2230 kips capacity.

The Freyssinet system was named after the French engineer Eugene Freyssinet, who invented the anchorage device in 1939. The original anchorage device was for a wire system only. This is a commonly used commercial system. The anchorage consists of a male conical plug and a female conical recess. The plug, with the wires spaced evenly around its perimeter, anchors the wire by wedge action. As a result of market requirements and subsequent developments, the Freyssinet system now also has available anchorages for strand tendons and other shapes of anchorage devices different from the original one. The same wedge principle for anchoring the tendon is retained, however. Concrete reactor vessels have been built in Europe using the Freyssinet strand system with a maximum tendon capacity of about 2000 kips.

The SEEE system was developed in France by the Societe d'Etudes et d'Equipements d'Enterprises. The system features threaded anchorage fittings extruded onto the ends of a group of strands. An anchoring nut is then threaded onto the anchorage fitting and turned

\*Lines indicate substantive changes from previous issue.

\*\*The Delmarva Summit Power Station has been canceled.

tightly against the bearing plate. A tendon is composed of one or several such anchorage fittings on a common bearing plate.

**Bar Systems.** Bar systems use a number of high-tensile-strength steel bars that are bundled into a tendon. The bars are made from an alloy steel conforming to ASTM Specifications A-322 and A-29. A-322 is a general specification that covers only the chemical composition of many grade designations of alloy steel bars, and A-29 is a specification giving general requirements for hot-rolled and cold-finished carbon and alloy steel bars. The mechanical and physical requirements for the prestressing bars are covered by ASTM Specification A-722, "Uncoated High-Strength Steel Bar for Prestressing Concrete."

Bars are cold-stretched and also stress-relieved by heat treatment to produce the prescribed mechanical properties. Both deformed bars and smooth bars with threaded ends are available, but only smooth bars have been used for nuclear power plant construction in the United States.

The Stressteel Corporation in the United States uses a bar system. The bars are stressed by means of a hydraulic jack that consists of a coupler and pulling bar. The normal commercial technique for anchoring uses anchor nuts. During stressing, the anchor nuts are continuously screwed down on washers and bearing plates, and the prestressing force is then transferred to the anchorage assembly by releasing the force in the jack. Wedge and grip-nut anchorages are also available to anchor the bar; they have the advantage of being able to grip the bar at any point along its length.

The containment structure of H.B. Robinson Unit No. 2 in Hartsville, S.C., uses the Stressteel bar system anchored with Howlett Grip Nuts. The tendon, which is composed of six 1-3/8-inch-diameter Stressteel bars, develops a capacity of 1428 kips.

#### **Grouted and UngROUTED Tendons**

All of the concrete reactor vessels and containments designed and built in the United States use ungrouted tendons except for H.B. Robinson Unit 2 (bar tendons), Three Mile Island Unit 2 (strand tendons), and Forked River (strand tendons), all of which were designed for grouted tendons. On none of these, however, has design credit been given for any bond of the grouted tendons.

Whether grouted or ungrouted tendons are used, a means of determining the functional capability of the structure during its lifetime should be available. This results in a need for reliable quality assurance procedures for the tendon installations and in a need for a reliable structural inservice inspection program.

### **C. REGULATORY POSITION**

This regulatory guide covers the generic qualifications of post-tensioned prestressing systems used in concrete reactor vessels and containments, with no attempt to extend its scope to design aspects. The acceptability of any post-tensioned prestressing system in conjunction with a specific structure design would have to be evaluated on a case-by-case basis. Any proposed system submitted for NRC approval should address the following:

1. Post-tensioned prestressing systems that have been approved in previous nuclear power plant license applications are regarded as accepted systems. See Table A for identification. When the claim is made by an applicant that the prestressing system proposed is an accepted system, sufficient information should be provided with each application to demonstrate that the system proposed is the same as the one that was approved in previous nuclear power plant license applications. Prior approval of any system does not relieve the applicant of the responsibility for demonstrating that its system meets all the requirements of the Code for Concrete Reactor Vessels and Containments.\*

2. Changes in prestressing element materials or in anchorage items of previously accepted systems that may require repeating the system performance tests are identified in Subsections CB and CC, Article 2466 of the Code for Concrete Reactor Vessels and Containments.

3. Any new post-tensioned prestressing system should meet the requirements set forth in the Code for Concrete Reactor Vessels and Containments.

4. The use of any post-tensioned prestressing system should permit the application of an inservice inspection program that will verify the continued functional capability of the structure. Implementation of this program should not degrade the quality and reliability of the post-tensioned prestressing system. Regulatory Guides 1.35, "Inservice Inspection of UngROUTED Tendons in Prestressed Concrete Containment Structures," and 1.90, "Inservice Inspection of Prestressed Concrete Containment Structures with Grouted Tendons," should be consulted for recommendations concerning the use of ungrouted and grouted concrete containments, respectively.

\*ASME Boiler and Pressure Vessel Code, Section III, Division 2 (the latest version, plus addenda, as endorsed by the Nuclear Regulatory Commission). This Code is currently under review for endorsement by the NRC staff. Copies may be obtained from the American Society of Mechanical Engineers, United Engineering Center, 345 East 47th Street, New York, N.Y. 10017.

#### D. IMPLEMENTATION

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

This guide reflects current NRC staff practice. Therefore, except in those cases in which the applicant proposes an acceptable alternative method for comply-

ing with specified portions of the Commission's regulations, the procedure described herein is being and will continue to be used in the evaluation of submittals for construction permit applications until this guide is revised as a result of suggestions from the public or additional staff review.

**TABLE A**  
**STATUS OF POST-TENSIONED PRESTRESSING SYSTEMS**  
**AS OF MAY 1976**

<u>System</u>	<u>Submitted For Licensing Review</u>	<u>Reviewed For Licensing Acceptability</u>	<u>Approved By the NRC Staff</u>	<u>Used In U.S. Nuclear Power Plants To Date</u>
BBRV 90, 169, 170, 186 Wires (1/4 in $\phi$ ) 163 Wires (7 mm $\phi$ )	X	X	X	X
VSL (55 strands)	X	X	X	X
Stressteel S/H (54 strands)	X	X	X	X
Freyssinet (strand)	X	—	—	—
SEEE (strand)	X	—	—	—
Stressteel (6 1-3/8 in. bars)	X	X	X	X
PCRV Strand- Wrap	X	X	X	—