TENNESSEE VALLEY AUTHORITY

Division of Engineering Design

Civil Engineering and Design Branch

Posttensioned Anchor Tendons in Rock

Installation and Testing of Tendons by Stressteel Corporation

R. E. Bullock

December 11, 1973

POSTTENSIONED ANCHOR TENDONS IN ROCK

INSTALLATION AND TESTING OF TENDONS
BY STRESSTEEL CORPORATION

Summary

Three multistrand tendons were installed in holes drilled into rock at the Bellefonte Nuclear Plant site. They were first-stage grouted and subjected to load testing. The loads were adequately transferred to the rock.

Introduction

As a test of anchorage for the proposed prestressed concrete containment vessel, two contracts were awarded for the installation and testing of posttensioned anchor tendons in rock at the Bellefonte Nuclear Plant site. The first contract was for wire tendons with button-head anchorages, and the second contract was for strand tendons with wedge anchorages. This report relates only to the second contract which was with Stressteel Corporation. The contractor is also required to submit a report.

The tendons were installed September 18 and 19, and tested October 2, 3, and 4, 1973. At the site R. Bonomo and F. Selenski represented Stressteel. C. Kuhlo represented the Construction Services Branch. C. B. Phillips and R. E. Bullock represented DED during installation and testing. DED was also represented by J. H. Coulson during testing. Rock deformation test results from instruments installed by Mr. Coulson are covered in a separate report dated November 6, 1973.

Purpose

The tests were designed to provide documented evidence of the ability of grouted anchor tendons to transfer load to rock, to establish required length of grout, and to provide information on rock deformation.

Scope

Requirements are in Specification 1923 for Testing of Prestressed Grouted Rock Anchors, X-14 and X-15 Nuclear Plant, and details are on drawing 41N714-2[illegible] for Bellefonte Nuclear Plant. Three multistrand tendon assemblies were to be installed in holes drilled by TVA through a concrete bearing pad on which the bearing plates were to bear. Two tendons, designated A and B, were to extend 40 feet below the top of the bearing plate and one tendon, designated C, was to extend 20 feet. Tendons A and B were to have approximately 20 feet of first-stage grout, and tendon C was to have approximately 7 feet. First-stage grout is placed and permitted to harden before tensioning. Second-stage grout is installed after tensioning for corrosion protection.

Tendon A was to be loaded twice to 80 percent of its rated ultimate while load and deformation measurements were made on the tendon and the rock. Tendon B was to be cycled 100 times between 60 and 70 percent of ultimate with periodic load and deformation measurements. Tendon C was to be loaded three times to 80 percent of ultimate and then to 95 percent of ultimate.

The contractor's drawings as approved provided a protective cap over the bearing for only tendon A. Therefore, only tendon A was second-stage grouted.

Tendon Description

The preassembled tendons arrived on the site by truck on September 17, 1973. They are composed of 54 twisted 7-wire strands of 1/2-inch nominal diameter and of ASTM A 416 Grade 270 steel. The rated ultimate capacity of each tendon is 2230 kips. All details are on Stressteel drawing S1 for TVA contract 74K53-84861.

At the lower end of each tendon the strands are fitted into an elliptical dome-shaped forged steel pipe fitting. Through the center of the fitting and welded to it is a 3-foot length of 1-inch pipe which serves as the lower end of the grout system. The strands are bundled around this pipe with steel banding similar to that which is used on packaging. Over a distance of approximately 2 feet, the strands are spread and fitted around a short length of 6-inch-diameter pipe to which they are held with banding. Over the next approximately 2 feet of distance, the strands are bundled to a minimum diameter and held with banding. This process is repeated over the length to be incased in first-stage grout. Starting 1 foot above that the strands are greased and over the remaining length intended to be incased in second-stage grout the individual strands have plastic tubing slipped over them. As a tendon support, just above the plastic tubing a 3-foot length of rebar was placed perpendicular to the tendon between the strands and held with banding so that it would be horizontal just above the bearing plate when the tendon was installed. Two of the tendons required assembly repair because the banding and the pipe fitting had slipped and repair was delayed until a banding tool was obtained. After repair the banding frequently slipped as the tendon was handled by a crane or after it was supported in the hole by the rebar. When the tendons were suspended by the crane they were not straight but were somewhat curved and twisted.

Tendon Installation

All three holes were drilled with an 8-5/8-inch drill but were approximately 9 inches in diameter. Sounding revealed that the holes for tendons A and B lacked about 1 foot in clear depth. With this type tendon it was thought that this would not be critical since the stressing jack can be fitted anywhere along the tendon. However, when the tendons were installed, the grout pipes plugged. The tendons were removed and both holes had approximately 2 feet of clay and rock dust flushed from them.

The grout mixer was a 55-gallon drum equipped with a flat circular plate which rotated at high speed. When charged with grout, a vortex formed and effective mixing appeared to result. The mixer drained out a side valve into a rectangular hopper mounted over and draining into a pump. The hopper was shallow with a virtually flat bottom and had no agitator. A short distance from the drain the grout would become sufficiently still to form a temporary gel so that handscraping was required to get the grout into the pump.

No gage was provided to measure pumping pressure. Mr. Bonomo insisted that the pump would develop 150 psi. (In previous grouting of the wire tendons a pressure gage indicated 200 psi.) Mr. Bonomo complained about grout stiffness and ten pounds of water per sack of cement was added to the design mix for tendon C. Five pounds of water per sack was added for tendons A and B.

Final grout proportions and significant test results are as follows:

	Tendon C	Tendons A and B
Cement	94 pounds	94 pounds
Fly ash	19 pounds	19 pounds
Sand	71 pounds	71 pounds
Water	60 pounds	55 pounds
Sika DP 23-37	0.5 pound	0.5 pound
Expansion (CRD-C81)	1.8 percent	2.7 percent
Bleeding	.8 percent	None
Cube strength - 28 days	4900 psi	6400 psi

Grout was pumped through an internal sleeve coupling into a 1-inch plastic pipe down the center of the tendon and through another internal sleeve coupling to the 3-foot length of steel pipe at the bottom of the tendon. The tendons were grouted in the order: C, A, B. Both tendons C and A blocked shortly after grouting was initiated and had to be withdrawn from the hole and the lower end of the grout system cleaned. In my opinion the blockage started at the lowest internal sleeve. The sleeve, the 3-foot length of pipe, and the forged fitting were removed from tendon B and discarded. This introduced the grout above the tendon bottom but should not have affected the critical bonding length. During the grouting of tendon B an occasional bubble of air was observed at the surface of water in the hole. This appeared to result from trapping air in the pump by handscraping of the hopper.

Load results on tendon B do not exhibit any non-linearity. An estimate of slip and plastic deformation at the wedges, from tendon A results, is subtracted from the tendon B load curve slope and used in calculating the nominal bond length. The 100 cycles of loading did not significantly increase tendon deformation.

When test requirements for tendons A and B were completed, the wedges were placed in the wedge plate, the wedges at the jack reset, and the tendons again tensioned. Load results for both tendons are linear.

Test measurements on tendon C are shown in figure 2. This tendon was specified as 20 feet long with 13 feet of free length but sounding revealed only 11.5 feet. Thus the first-stage grout column had 8.5 feet in contact with and bonding to the rock but only 8 feet bonding to strand which was not incased in plastic tubing. The tendon exhibited some non-linearity just above 0.7 f_{pu} (specified ultimate strength of the tendon material) and had not quite achieved 0.9 f_{pu} when loading was terminated due to multiple breaks in individual wires within the strands. (The wire tendons showed non-linearity at a lower stress but achieved almost 0.95 f_{pu}. The rated capacity of the strand tendon was 11 percent greater than the wire tendon, and the strand tendon developed 1950 kips compared to the 1800 kips developed by the wire tendons when the tests were terminated.) Neither system will develop specified material ultimate under these field conditions. It is believed that this is due primarily to the short free length making unequal load distribution between individual strands or wires critical.

Published research indicates that bond stress distribution along the strands will be approximately uniform near the upper portion of the grout column where the strand has developed some slip and then increase to a maximum value near the final portion of the actual bond length. Since the calculations used to determine bond length assumed uniform strain in the strand, which is equivalent to instantaneous bond development, the actual bond length will be somewhat greater than the nominal bond length calculated on figures 1 and 2. Although the actual bond length can not be determined from our data, the 8 feet of bond length in the 8.5 feet of grout column for tendon C developed the actual strength of the tendon.

Conclusions

1. Posttensioned anchor tendons will transfer either a steady or cyclic load through grout to the rock at the Bellefonte Nuclear Plant site.

2. A column of sanded grout approximately 8.5 feet in length by 9 inches in diameter transferred a steady load of 1950 kips from a 54-strand tendon to the rock.

It was intended to sound or probe for the plastic grout surface in the holes. Probes could be worked down by the tubing around the strands, but so much friction developed that the grout surfaces could not be determined until after the grout hardened.

Stressing Procedures

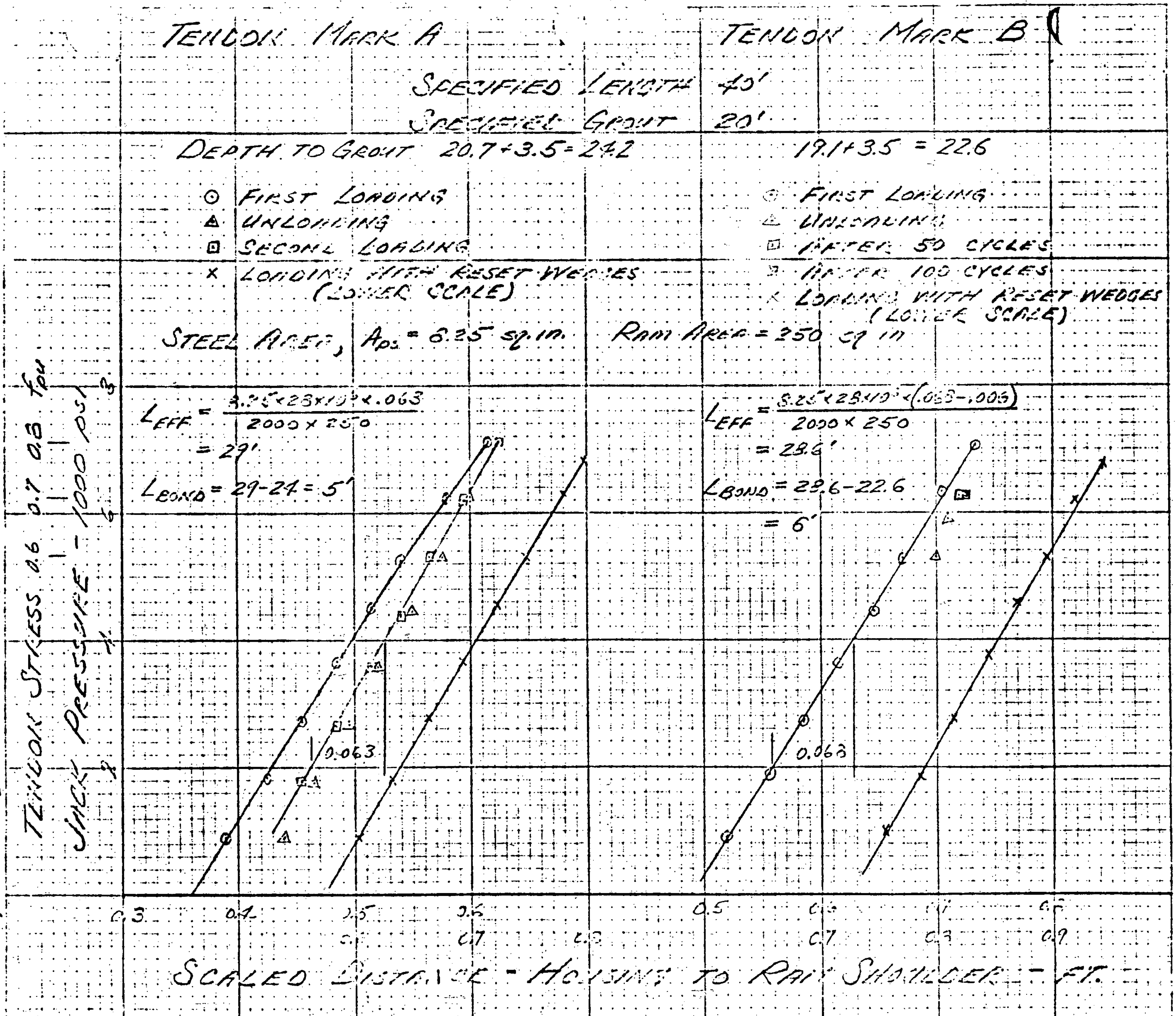
The stressing equipment, hydraulic jack, gage, and gasoline engine driven pump, were adequate. The jack and pressure gage combination had been calibrated by Lehigh University. The only method of measuring elongation was by holding a scale from the jack housing to the upper end of the ram.

Before stressing, the strands must be threaded through a splay plate, a wedge plate, and the jack. The strands are individually threaded through holes in the 5/8-inch-thick splay plate and then in groups of three through the 3-1/2-inch-thick wedge plate. The splay plate is designed to make the strands parallel to each other and perpendicular to the wedge plate which transfers the tendon force to the bearing plate when the tendon is anchored. It was necessary to suspend the jack by a crane during the threading operation and slightly different strand lengths or bent strands complicated the process. Three-part wedges were then fitted around each strand group at the top of the jack ram. It was a rather slow process. When the tendon is to be anchored off, wedges are also installed at the wedge plate before threading the strand through the jack. These wedges were not placed until testing was completed because they would have interfered with the required load cycling.

Test Results

The jack pressure versus scaled distance curves for tendons A and B are shown on figure 1 together with some associated calculations. Both tendons were specified as 40 feet long with 20 feet of free length from the bearing plate to the grout. Actual depths to grout from sounding have the 3.5-foot length of jack added to them to obtain the free length of strands to use in calculations.

Only the first loading of tendon A shows any non-linearity. The non-linearity may be due to some of the strands in this tendon having residual bends from excessively rough handling. Tendon deformation includes not only elongation of the strands but also slip, and plastic and elastic deformations at the wedges. The second loading of tendon A should have eliminated slip and plastic deformations at the wedges, and is used for calculating the nominal bond length. The effective length is equal to the area of the steel times the modulus of elasticity times the slope of the loading curve. The effective length minus the free length is the nominal bond length. The offset between the first and second loading is probably primarily caused by friction preventing the length of tendon over which bond slip has occurred from sliding back into the grout column.



TENDON MARK A
TENDON MARK B
SPECIFIED LENGTH 40'
SPECIFIED GROUT 20'
DEPTH TO GROUT 20.7+3.5=24.2
19.1+3.5 = 22.6
⊙ FIRST LOADING
△ UNLOADING
⊡ SECOND LOADING
× LOADING WITH RESET WEDGES (LOWER SCALE)
⊙ FIRST LOADING
△ UNLOADING
⊡ AFTER 50 CYCLES
AFTER 100 CYCLES
× LOADING WITH RESET WEDGES (LOWER SCALE)
STEEL AREA, Aps = 6.25 sq.in.
RAM AREA = 250 sq in
LEFF = 6.25×28×10³×.063 / 2000×250 = 29'
LBOND = 29-24 = 5'
LEFF = 6.25×28×10³×(.068-.005) / 2000×250 = 28.6'
LBOND = 28.6-22.6 = 6'
0.063
0.063
TENDON STRESS 0.6 0.7 0.8 fpu
JACK PRESSURE - 1000 psi
0.3
0.4
0.5
0.6
0.7
0.5
0.7
0.9
SCALED DISTANCE - HOUSING TO RAIL SHOULDER - FT.
11/5/73

3. An adequate free length of tendon, that between grout and jacking point, is necessary to minimize the affect of unequal load distribution between individual strands. This appears to be in excess of 16 feet.

TENDON: MARK C

SPECIFIED LENGTH 20'
SPECIFIED GROUT 7'
DEPTH TO GROUT 11.5+3.5=15'
DEPTH TO BONDING 12+3.5=15.5'

STEEL AREA, A_{ps} = 8.25 sq. in. RAM AREA = 250 sq. in.