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GROUTING TESTS ON LARGE POST-TENSIONING TENDONS FOR SECONDARY NUCLEAR CONTAINMENT STRUCTURES

Tests of sedimentation (bleeding) and expansion of neat cement grouts were made as part of a program to insure successful grouting of large capacity, long vertical post-tensioning tendons and large capacity tendons on sharp curvatures. Water reducing and expansion producing admixtures for grout are recommended, together with standpipes at all high points of the tendon, to assure elimination of voids.

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The typical secondary containment structure for a pressurized water reactor nuclear power plant of approximately 1000 Mwe capacity is illustrated in Fig. 1. In the United States the trend has been to prestress the containment structures if the accident pressure is over 45 psi (3 kg/cm^2), generally using unbonded tendons. Because of the potential maintenance problems in using unbonded tendons, which are accessible for monitoring, it has been the desire of some power companies to use bonded tendons to avoid what may be considerable maintenance problems in the future.

GROUTING PROBLEMS WITH LARGE TENDONS

Actual experience of grouting large capacity, long vertical tendons and large capacity tendons on sharp curvature with a large included angle, is somewhat limited. Experience to date has not revealed any particular problems, although in vertical tendons, two-stage grouting has been used in several known instances. To obtain confidence that large capacity tendons, with appreciable curvature and of lengths in excess of 200 ft. (60 m), could be grouted effectively to give a corrosion-free protection, considerable grout testing has been undertaken for several containment structures.

Assuming that good mixing and pumping equipment is used, there are basically only two concerns in insuring proper filling of a conduit with grout:

1. Sedimentation, sometimes called bleeding, has manifested itself in many ways in previous

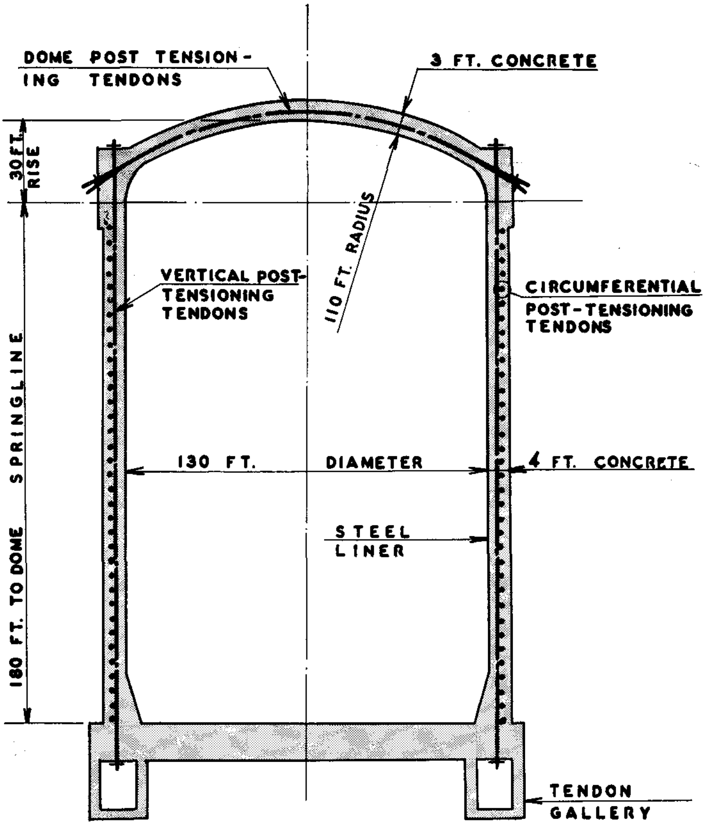


Fig. 1. Typical containment structure

grouting experience. In sections taken through moderate size horizontal tendons (see Fig. 2) a small void can be seen at the top of the cross-section. This void has generally been reported as an air bubble. However, by inspecting the formation of this void in the plastic tubes, it could be seen that this void is not an air void but is actually created by the water left on top of a suspension when the fine material has settled to the bottom. Some standards permit up to 4 per cent bleeding. For a 200 ft. (60 m) long vertical tendon, this would result in a substantial void. This amount of bleeding is realistic, but the specifications generally do not recommend methods of eliminating voids caused by sedimentation. It is the author's opinion that voids on top of a horizontal conduit are not consequential, whereas voids formed in tendons with any substantial vertical rise could be critical depending on the environment. Therefore, for long vertical tendons, the sedimentation characteristic of the grout has to be known and if sedimentation cannot be controlled, the space left by the top water lens must be eliminated.

2. On sharp curvature, where individual wires or strands are tightly bunched together, the question is raised whether it is possible to get grout through the grouped elements, particularly on

a radius of, say, 20-ft. (6 m). The testing to be described covers primarily these two items. All the tests performed in these programs were done with a neat cement grout which is the grout most commonly used in the United States. Since effective methods of grouting tendons were achieved with a neat cement grout, and a maximum alkali environment was desired for best corrosion protection, additional effort was not made to determine if inert fillers or flyash would have been beneficial. In this area, further work is definitely required.

TESTING FOR SEDIMENTATION AND EXPANSION

Some of the literature reports that bleeding phenomenon or sedimentation is practically negligible. These tests are generally based on use of very short cylinders with rather large diameters which are left open at the top and thus free to permit evaporation. We have found that to appreciate the amount of sedimentation that occurs, a 1-liter graduate is a convenient device, but for field work a transparent plastic tube about 2 to 4 in. (5 to 10 cm) in diameter and about 60 in. (1.5 m) high gives a more representative reading of the sedimentation. For convenience we place the grout to the 50-in. (1.3 m) mark in the pipe, using the flow cone as a funnel, so we can read the percentage of the expansion and sedimentation directly. In the metric system it is probably more convenient to use a 1.00 m (40 in.) column of grout, in which case readings in centimeters are directly in percent. This is suggested as a possible standard for evaluating expansion and sedimentation. It is important that the top of the cylinder be sealed to minimize evaporation. It is also important to remember that in the first 8 to 10 hr. after mixing, the free water at the top has to be observed because it has been found that re-absorption of the water occurs, and the bleeding phenomenon is obscured.

To evaluate the importance of different types of cements, admixtures, mixers, efflux time and water-cement ratio on expansion and sedimentation, information was gathered from various tests (Table 1). Though this is not an extensive tabulation, it gives a good picture of what can be expected. Note that bleeding ranges from 0.5 percent to 1.1 percent, and the expansion from 6 percent to 36 percent. From more extensive tabulations of grout characteristics it was concluded that sedimentation was not significantly affected by the above parameters. Speed of pumping and type of pump likewise had no significant effect.

It seems to be generally accepted that locking off the tendon under pressure (up to 100 psi) (7 kg/cm^2) is good practice. To check this, tests

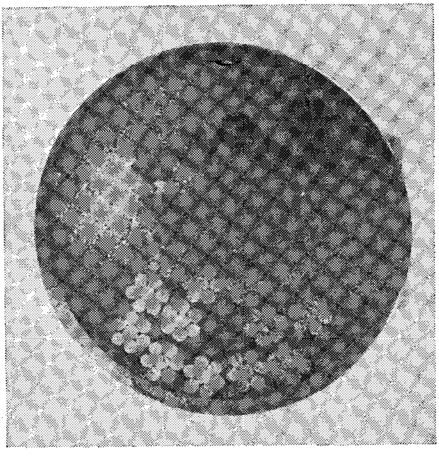


Fig. 2. 28-strand horizontal tendon with sedimentation void at top

Table 1. Typical neat cement grout characteristics

Type of cement	W/C ratio (gal/sack)	Mixer type and speed	Admixture	Efflux time, sec.	Maximum expansion, percent	Maximum sedimentation, percent
II 2800 to 3600 Fineness*	0.40 (4.5)	2—5 in. (12.7cm) ø, 3 blade propellers 1725 RPM	Intracrete	12	9	0.7
	0.41 (4.6)		Intrusion Aid	11	7	0.5
	0.39 (4.4)	2—5 in. (12.7cm) ø, 2 blade propellers 1400 RPM	Intraplast C	15	13	0.6
	0.42 (4.7)	1—4 blade propeller 290 RPM	Intracrete	13	6	0.9
	0.37 (4.2)		Intraplast RD-4 (w/.014%Al)†	15	18	0.6
	0.40 (4.5)		Intraplast RD-4 (w/.021% Al)†	14	17	1.1
	0.40 (4.5)		Intraplast RD-4 (w/.032% Al)†	17	36	0.7
III 3600 to 4500 Fineness*	0.47 (5.3)		Intraplast RD-4 (w/.014%Al)†	14	14	0.6
	0.53 (6.0)		Intraplast RD-4 (w/.021% Al)†	14	13	0.7
	0.47 (5.3)		Intraplast RD-4 (w/.032% Al)†	17	33	0.7

* By Blaine air permeability test
† By weight of cement

were made to determine the amount of sedimentation that occurs under pressure locked in and pressure from expansive admixtures. To make a test of this nature, the best visual observations could be made by using a clear plastic tube so that the actual sedimentation could be seen taking place over a period of time. These tubes were grouted by placing the grout in from the top to a specific height, and then the tops were sealed so they could support pressure. The grout then was pumped until a pressure of 50 to 100 psi (3.5 to 7.0 kg/cm^2) was obtained. Pressure gauges were installed in the grout pipes. Several interesting items appeared from this test. One was that expansion caused by the aluminum powder will appreciably increase the pressure within the conduit. Because of the limitation of pressure that could be taken by the plastic tubing, additional pressure caused by the expansion admixture of only up to 50 psi (3.5 kg/cm^2) was permitted on the conduit, and then the pressure was released. Of particular interest, it was noted that settlement occurred under pressure and left a void at the top of some of the cylinders. Also, intermediate sedimentation occurred. The material above apparently arched, and water lenses occurred through the cross-section of the conduit (Fig. 3). Seven tests in the 10-ft. (3 m) plastic tubes were made using different admixtures and no admixtures. Five of the seven tests had water at the top and at some intermediate locations.

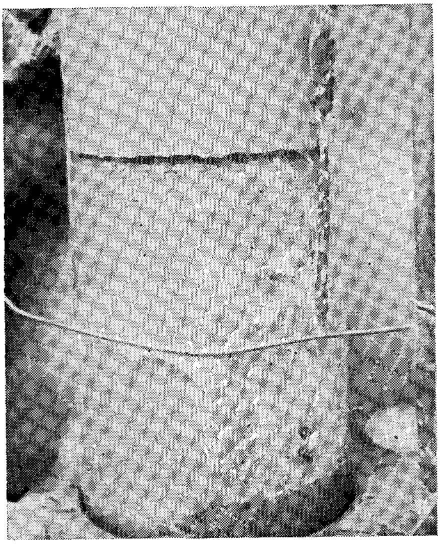


Fig. 3. Close-up of an intermediate water lens in a plastic conduit

To determine the reproducibility of the sedimentation to larger scale, eleven 5-in. (12.7 cm) diameter spiral steel tubes, 20 ft. (6 m) high were tested. Both Type II and Type III cements were used and bundles of 50 ½-in. (12.7 mm) diameter strands were included in eight of the conduits. The results of these tests are shown in Table 2. This test, which was developed by Burns and Roe on behalf of Jersey Central Power and Light Company, uncovered a phenomenon not apparently realized before, namely, that the strands caused increased sedimentation. The phenomenon, labeled "water transport mechanism", is believed to be a filtering process. The seven-wire strands consisted of six wires wrapped spirally and tightly around a slightly larger diameter center wire. The space between the six wires is large enough to permit passage of water, but not of most of the cement particle sizes. The space formed between the six spiral wires and the center wire becomes a path for the filtered water. Since the specific gravity of the grout is about twice that of the water, the water is forced up ahead of the grout. This can cause water pockets on top of the tendon in the range of 20 percent of the total

Table 2. Grout tests on 20-ft. (6m) high ducts

Tube No.	Cement type	Expansion	Initial strand conditions	50 ½-in. (12.7mm) strands	Gross expansion percent	Sedimentation percent	Net void at top percent
1	II	Confined	Wet	None	Confined	*	*
2	II	Confined	Wet	Yes	Confined	12	12
3	II	Confined	Wet	Yes	Confined	12	12
4	II	Free	Wet	None	8	0.4	0
5	II	Free	Wet	Yes	4	20	16
6	II	Free	Wet	Yes	4	20	16
7	III	Free	Wet	None	8	0.5	0
8	III	Free	Wet	Yes	6	20	14
9	III	Free	Wet	Yes	4	10	6
10	II	Free	Dry	Yes	5	17	12
11	II	Free	Dry	Yes	5	14	9

* Top plate broke under pressure and sedimentation water escaped

Ducts: 5 in. (12.7cm) ϕ spiral wound 20 ft. (6m) high

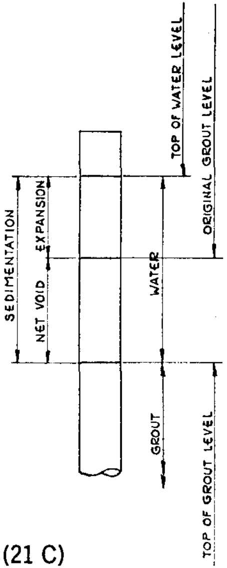
Mixer: Eclipse air powered, 3 blade propellers 5-½ in. (14.0cm) ϕ, 2200 RPM

W/c ratio—for Type II cement: 4.9 gal./sack (0.43)
for Type III cement: 6.3 gal./sack (0.56)

Efflux time: 16 seconds

Admixture: Intraplast RD-4

Initial grout temperature: 69 F (21 C)



free volume in the conduit. Fig. 4 shows the magnitude of the void created by the water transport mechanism.

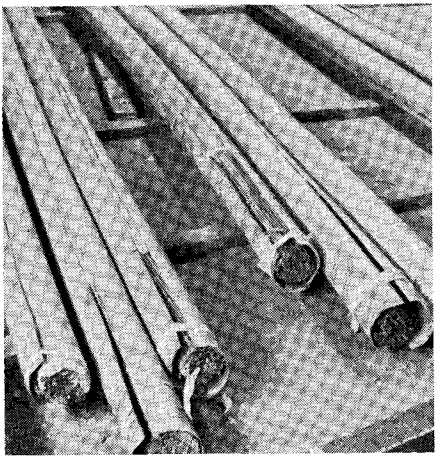


Fig. 4. Sectioned conduit showing void caused by water transport mechanism at top of tendon

Tests were made to determine if this water transport mechanism occurred with all types of strands, and also with grouped parallel bars. It was thought that possibly a Dyform strand, which is pulled through a die after stranding, would be too tightly packed for this phenomenon to occur; however, tests indicated about the same phenomenon with Dyform strand. A loosely twisted strand produced no water transport mechanism; apparently the spaces between the wires were too great to act as a filter. It is not known if this loosely woven strand would remain this way if it were stressed. A tube with three ⅝-in. (16 mm) bars manifested twice the sedimentation of a tube with the same grout but no bars. The sedimentation and expansion vs. time are shown in Fig. 5.

The effects of different admixtures on the water transport mechanism were tested. It was thought that possibly a gelling agent, which would tend to keep the cement in suspension and form a thixotropic mix, might be useful. This produced no improvement with strands when using up to 0.05 percent gelling agent by weight of cement. However, small quantities of gelling agent appeared promising for wire and bar tendons. It was concluded that the water transport mechanism was a particular phenomenon of strand tendons and other procedures would have to be developed to cope with this condition. Actually the phenomenon seemed to be beneficial to the grout

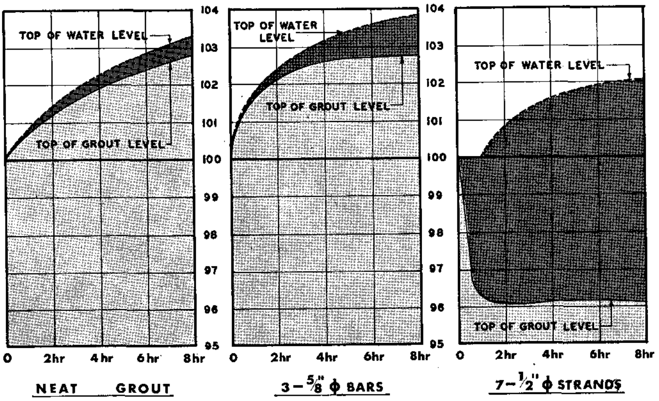


Fig. 5. Comparison of expansion and sedimentation

in that it reduced its water/cement ratio and eliminated intermediate lenses.

Other tests were performed by Burns and Roe actually using the strand to remove the water from the top end of the tendon. Small scale tests showed promise, but larger scale tests did not produce the desired results. Possibly further work will be fruitful in utilizing this phenomenon.

GROUTING 150-FT. VERTICAL TENDONS

For the Robinson Nuclear Power Plant of Carolina Light and Power Company, six 1-⅜ in. (35 mm) high strength bars in 6-in. (15 cm) diameter, 150-ft. (46 m) vertical ducts had to be grouted. Ebasco Services, Inc., the engineer-contractor, desired to grout the tendon in one stage. It was recommended that a gelling agent be incorporated into the admixture and with the cooperation of Sika Chemical Company and Stressteel Corporation, a testing program was initiated.

It was thought that the voids produced by sedimentation, described above, might be a particular problem with grouted long vertical tendons. Although corrosion consultants did not believe water lenses would pose a corrosion problem, because of the enclosure of a gas-tight galvanized duct and the highly alkaline environment, it was deemed desirable to try to eliminate the voids.

From small scale tests, it was concluded that, to insure substantial filling of large vertical conduit containing bar tendons, it would be advisable to eliminate or greatly minimize cement particle sedimentation. Further, since complete elimination of sedimentation was in doubt, a sure system of monitoring the sedimentation process was needed. The simplest way to do this was to leave an open vent hole at the top of the anchorage cap. This fitted in well with the decision not to lock off the conduit under pressure immediately after grouting.

Tests had indicated repeatedly that sedimentation occurred even when the conduits were maintained under pressure, either locked in or due to grout expansion, since both top and intermediate water lenses were observed under these conditions. Furthermore, since initially expansion and sedimentation occur

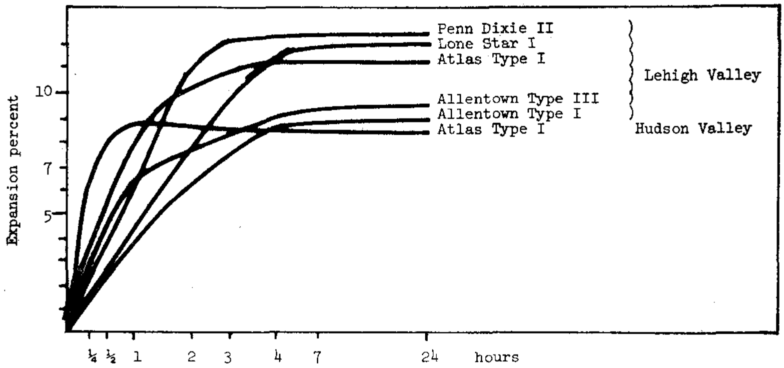


Fig. 6. Nitrogen producing expansion agent performance with different cements

simultaneously, (although sedimentation may continue after expansion stops) it appeared more logical to permit the expanding grout to overflow at the top of the conduit, carrying with it the water separated by sedimentation.

To minimize the sedimentation, particularly the part that would occur after expansion ceased, various types of admixtures and inert fillers were considered. The material which seemed most promising was a gelling agent. Tests were performed with admixtures which included a gelling agent of the soluble cellulose type along with expansion agents. The grouting admixture "Intracrete 2-2," which produces nitrogen gas as an expansion agent, was modified to include the gelling agent. Laboratory tests consistently showed the virtual elimination of sedimentation and also indicated (Fig. 6) that the nitrogen gas production was not significantly dependent on the type of cement as in the case of hydrogen gas developed by the alkali reaction on aluminum powder.

For this particular tendon, Type III cement under a carefully controlled grouting procedure was advantageous because it has faster initial set, thus less time for sedimentation. Also, more finely ground cement has slightly less tendency toward sedimentation. Tests comparing Type II and Type III cements confirmed this.

Based on the successful laboratory tests, no further approach was studied, and field tests were performed on 3-in. (7.6 cm) diameter plastic tubes, 11 ft. (3.35 m) high. These tests indicated no sedimentation and about 5 percent expansion. To confirm the apparent success, two 30-ft. (9 m) high grout tests were made, using 6-in. (15 cm) plexiglas tubes with six 1-3/8 in. (35 mm) bars installed. Fig. 7 shows the thixotropic grout rising in the plastic tube through the anchorage, free of any surface water. Besides the visual inspection of the plexiglas tube and the plexiglas anchorage assembly during the grouting procedure, the test specimens were cut into various sections to determine the completeness of the grout filling. In all cases the grout completely filled all spaces including the interstices in the anchorage and under the anchor plate.

Vertical tendon mock-up. Since the experience in grouting a 150-ft. (46 m) tendon is so limited, a mock-up was made of a 150-ft. (46 m) high conduit to test the grouting procedure, including the equipment setup and the performance of the proposed grout pump. Additional advantage could be gained from a test of this nature by determining the actual sedimentation characteristics of the proposed grout. To perform this test, a 5-in. (13 cm) diameter duct (equal grout cross-sectional area) by 138 ft. (42 m) long was set up vertically along the containment structure. Since it was a cool day, 40 to 50 F (4.5 to 10 C), a trial batch

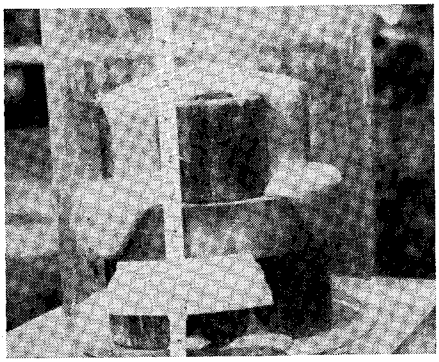


Fig. 7. Thixotropic grout rising in conduit

was prepared with 5-¼ gal. water per sack of cement (0.47). Efflux time was between 25 and 40 seconds. Because of the thixotropic nature of the grout, the efflux time is particularly difficult to evaluate. The grout was readily pumped with the Moyne pump (positive displacement screw type). When the grout reached the 2-in. (5 cm) pipe sleeve at the top of the 5-in. (13 cm) pipe, the grouting was immediately stopped since the consistency of the grout overflow at the top was excellent. An inverted L-pipe was attached to the 2-in. (5 cm) sleeve so that the expansion could be measured. The expansion, crudely measured, amounted to about 0.5 percent. This was to be expected because the grouting operation took about 1 hr., and during that time a good part of the expansion took place. When the expansion was completed, the inverted L-pipe was removed and the surface of the 2-in. (5 cm) sleeve covered to prevent evaporation. Observation until final set did not reveal any surface water or subsidence of the grout. The performance of this grout was excellent.

TENDONS ON SHARP CURVATURE

For tendons with a capacity of over 1000 kips (454 metric tons), 90 ¼-in. (6.35 mm) diameter wires or 28 ½-in. (12.7 mm) diameter strands would be required. If this large number of individual elements is packed tightly into a conduit on sharp curvature, there is a question whether the grout can find its way between all the wires or strands. The limited information on actual performance indicated that grout could pass through a reasonable number of wires or strands effectively, although information was not available on performance on sharp curvatures. The question was, if the wires or strands were packed tightly together, whether the space between these layers of wires would permit the air to be exhausted so that the space could be filled with grout. This was a greater potential problem with wires than with strands because the twisted strands always tend to have transverse space available between bunched strands.

To settle some of these questions for a Metropolitan Edison Company nuclear plant, Gilbert Associates, the architect-engineer, prepared a test to determine the effectiveness of grouting wire tendons. Two 90-wire tendons in the form of an S vertical curve were placed in a beam curved to a 68-ft. (21 m) horizontal radius. The vertical curves were of 20-ft. (6 m) radius. The tendons were stressed and grouted, and with this sharp curvature there was difficulty in getting all the spaces between the wires filled with grout (Fig. 8). The writer then suggested that strand tendons should not have this problem, and a test was performed by VSL Corp. in Bern, Switzerland, with a 28-strand tendon, on a 20-ft. (6 m) radius using the VSL system. The results indicated complete coverage of the strand as shown in Fig. 9.

This test led Burns and Roe, the architect-engineer on another nuclear power plant for Jersey Central Power and Light Company, to establish a test program to determine the feasibility of grouting large post-tensioning tendons effectively. The results of these tests, shown in Table 3, indicated clearly that to grout wire tendons effectively, the wires could not be permitted to bunch together or had to be pre-grouted prior to tensioning. However, strand tendons could be grouted satisfactorily

Table 3. Grouting of stressed tendons in curvature

Duct		Tendon		Grout admixture	Special features	Presence of continuous voids
Diameter in.	Type	Type	System and supplier			
TENDONS IN SHARP CURVATURE: radius—20 ft. (6m); included angle—60°; length—±26 ft. (8m)						
4	Flexible sheath	38-0.5″ø strand	SEEE Stressteel	Intracrete	None	No
4	Flexible sheath	38-0.5″ø strand	SEEE Stressteel	Intracrete	Tendon pre-greased	No
4	Schedule 40 pipe	29-0.5″ø strand	VSL	Intracrete VPN 269	Air separator and grout recirculation	No
3¾	Spiral wound sheath	22-0.5″ø strand	Ryerson WCS	Intracrete	None	No
3¾	Spiral wound sheath	22-0.5″ø strand	Ryerson WCS	Intrusion aid R	None	No
5	Schedule 40 pipe	24-0.6″ø Dyform strand	Freyssinet	Intraplast C	Spacers	No
5	Schedule 40 pipe	24-0.6″ø Dyform strand	Freyssinet	Intraplast C	None	No
2¾	Flexible sheath	40-0.25″ø wire	BBRV Ryerson	Intrusion aid R	Grout recirculation	Yes
3¾	Spiral wound sheath	90-0.25″ø wire	BBRV Ryerson	Intrusion aid R with retarder	Pre-grouted and grout recirculation	No
3¾	Spiral wound sheath	90-0.25″ø wire	BBRV Ryerson	Intrusion aid R	Spacers	Yes
3¾	Spiral wound sheath	90-0.25″ø wire	BBRV Ryerson	Intrusion aid R	Grout recirculation	Yes
LONG CURVED TENDONS: radius—±65 ft. (20m); included angle—60°; length—±75 ft. (23 m)						
4	Flexible sheath	38-0.5″ø strand	SEEE Stressteel	Intracrete	None	No
3¾	Spiral wound sheath	90-0.25″ø wire	BBRV Ryerson	Intracrete	Grout recirculation	Yes

Type II Cement
W/C ratios between 4.2 and 4.7 gal./sack (0.37 and 0.42)
Efflux times between 11 and 21 seconds
0.5 in. = 12.7mm; 0.6 in. = 15.3mm; 0.25 in. = 6.4mm

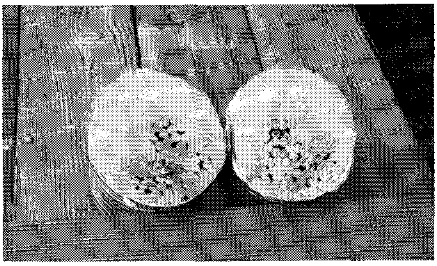


Fig. 8. 90-wire grouted tendon cross-section cut from test beam with tendons on 20-ft. (6 m) radius

under these conditions.

On sharp curvature the wires bunch together against one side of the conduit, leaving at the other side a substantial portion of the cross-section open to the free flow of grout. The bunching of the wires impedes the transverse flow of grout, and the rapid advancement of the grout through the open space does not permit the air trapped between the wires to escape. Slow grouting would help somewhat, but probably would not give fully successful results. A supplier of wire tendons has suggested that three wires be stranded together to achieve the same type of transverse venting existing with seven-wire strands.

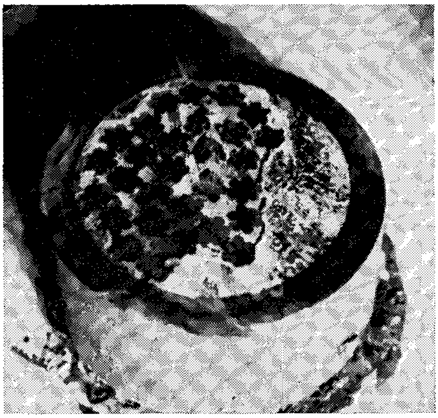


Fig. 9. Cross-section of 28-strand grouted tendon on 20-ft. (6 m) radius

On the basis of the tests described above, it was decided to use only strands in grouted curved tendons. To verify that effective grouting was reproducible in a full-scale tendon, a mock-up of a containment wall section, Fig. 10, was built with provision to accomodate a series of test tendons. Tendons with up to 54 ½-in. (12.7 mm) diameter strands were installed in this test wall, and successfully grouted. Samples of the tendons indicated excellent grouting except that the water transport mechanism described for the vertical tendons was also present in the vertical rise of the tendons above the simulated equipment hatch. At the top of this vertical rise, bleed water was trapped and caused a void. This pointed out the need to permit overflow of the separated water by means of some type of stand-pipe.

GENERAL RECOMMENDATIONS

For grouting tendons with any appreciable vertical rise, if voids are to be eliminated, past practices of grouting will not do the job. For these conditions, it is recommended that:

1. For wire or bar tendons a gelling plus an expansion additive be used in the grout. The additive should be a water reducer but not a retarder. The tendon should not be locked off under pressure, but free expansion should be permitted through a vertical extension that rises above the highest point of the tendon. Grout pumping should be continued until grout of proper consistency overflows at the standpipe. The standpipe should remain open until all expansion has taken place and initial set occurs. For smaller

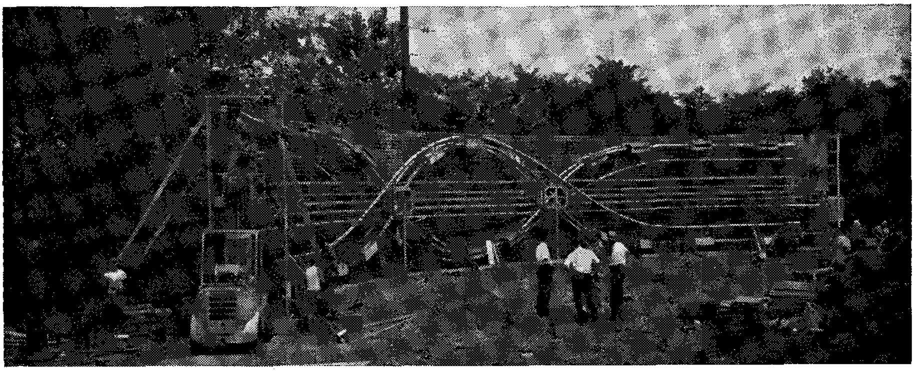


Fig. 10. Full scale grouting test of tendons on sharp curvature

size tendons, the gelling additive may not be necessary if all other steps are taken.

2. For strand-type tendons, it is recommended that neat cement grout with a water reducing, but not a retarding, admixture be used. Use of a standpipe at all high points in the tendon, with sufficient capacity to hold the amount of grout required to displace the water separated by sedimentation is advised. It is preferable to arrange the standpipe so that the grout may be puddled under the anchorage to assure that the water pocket is displaced by the standpipe grout. Other methods are being considered but the above method presently appears best.

ACKNOWLEDGMENTS

Most of the tests for the strand-type tendons were sponsored by General Public Utilities Corporation of New Jersey for its two subsidiaries, Jersey Central Power and Light Company and Metropolitan Edison Company. Gilbert Associates of Reading, Pennsylvania, planned the first wire tendon grouting test and Burns and Roe of Oradell, New Jersey, planned the large tendon tests. The author, as consultant to General Public Utilities Corporation oversaw and guided the above work and performed additional small-scale tests.

The facilities and cooperation of Sika Chemical Company and Stressteel Corporation made these tests possible. Tendons for the large-scale grout test were contributed by Stressteel Corporation, Inland Ryerson Construction Products Co., Freyssinet Company, Inc., and VSL Corporation.

Tests made on high-strength bars were planned and supervised by Ebasco Services, Inc., and the author for Westinghouse Electric Corporation, prime contractors for Robinson Nuclear Power Plant of the Carolina Light and Power Company.

Discussion of this paper is invited. Please forward your discussion to PCI Headquarters by July 1 to permit publication in the July-August 1971 issue of the PCI JOURNAL.