U.S. NUCLEAR REGULATORY COMMISSION

Revision 1
February 1977

REGULATORY GUIDE

OFFICE OF STANDARDS DEVELOPMENT

REGULATORY GUIDE 1.107

QUALIFICATIONS FOR CEMENT GROUTING FOR PRESTRESSING TENDONS[1] IN CONTAINMENT STRUCTURES

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.

The prestessing tendon system of a prestressed concrete containment structure is a principal strength element of the structure. Since the ability of the containment structure to withstand the events postulated to occur during the life of the structure depends on the functional reliability of the structure's principal strength elements, any significant deterioration of the prestressed elements due to corrosion may present potential risk to the public safety. Hence it is important that any system for inhibiting corrosion of the prestressing elements possess a high degree of reliability in performing its intended function.

This guide describes quality standards acceptable to the NRC staff for the use of portland cement grout as the corrosion inhibitor for prestressing tendons in prestressed concrete containment structures. The Advisory Committee on Reactor Safeguards has been consulted concerning this guide and has concurred in the regulatory position.

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

* Lines indicate substantive change from previous issues.

B. DISCUSSION

The recommendations of this guide are applicable when portland cement grout is used as the corrosion inhibitor for the highly stressed tendons of prestressed concrete containment structures. The recommendations of the guide are not intended for use in relation to the grout for foundation anchors.

To date, the staff has evaluated applications proposing grout as the corrosion protection system for both bar tendons and strand tendons. The recommendations of this regulatory guide therefore apply to a grouted tendon system when the tendon is fabricated from either bars or strands. For grouting of wire tendons, a program based on similar quality standards may be developed and submitted to the staff for evaluation.

Unlike greased tendons, grouted tendons are not available for direct inspection after they are grouted. It is therefore essential that the proposed grout and grouting procedure be thoroughly evaluated before it is used in the construction of the containment structure. An advantage of grouting, in addition to providing corrosion protection, is that a well-designed and well-constructed grouted tendon system provides a degree of bond between the tendons and the surrounding concrete. This bond in turn helps the anchorage system to resist the fluctuating stresses that arise after construction of the structure.

Section III, Division 2, "Code for Concrete Reactor Vessels and Containments," of the ASME Boiler and Pressure Vessel Code (Ref. 1) provides some requirements for grout constituents and for the

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physical and chemical properties of grout. Regulatory Position C.1 of this guide briefly describes minimum quality standards for grout materials, referencing the ASME Code Articles where applicable and acceptable to the NRC staff. The regulatory position also outlines important considerations affecting proper grouting. References 2, 3, and 4, as well as data furnished by applicants who have proposed grout as the corrosion inhibitor for prestressing steel, have been used to arrive at this position.

Appendix A to this guide provides a list of relevant literature that may be used by the applicant to establish procedures and criteria for the specific grouted tendon program. However, the listing of these references does not constitute a blanket endorsement by the staff of their content.

Specific areas of concern that should be given proper attention during the development of a grouted tendon system are discussed in the following paragraphs.

The effectiveness of grout in performing its intended function of inhibiting corrosion depends mainly on two characteristics:

1. The grout (whether freshly mixed or hardened) should not cause chemical attack on the prestressing elements through its interaction with the material of the tendon steel, the material of the anchor hardware, or the material of the duct.[2]

2. The grout should completely fill the tendon duct on hardening.

Various deleterious substances have been reported as potential sources of corrosion of prestressing steel. Most of the reported failures of prestressing elements have been attributed (a) to the presence of chlorides in the atmosphere or in the constituents of grout or (b) to the presence of hydrogen sulfide in the atmosphere (Refs. 5, 6, and 7). Nitrates and sulfates generally found in mixing water have been theorized to be potential sources of stress corrosion of prestressing steel. However, it has been reported (Ref. 8) that, in a concrete environment, oxygenated anions such as sulfates and nitrates do not exhibit intense corrosion properties. It has also been reported (Ref. 3) that most of the chlorides are neutralized during the hydration of portland cement. The threshold values below which these substances will not participate in initiating corrosion have not been established. Hence a safe and prudent approach would be to make sure that these substances are limited to the lowest practical levels in grout constituents. The use of water contaminated with hydrogen sulfide should be prohibited.

[2] For the purposes of this guide, a "duct" is a hole or void provided in the concrete for the post-tensioning tendon. A duct may be provided by embedding metal sheathing in cast-in-place concrete.

The limits recommended for chlorides, nitrates, sulfates, and sulfides in Regulatory Position C.1.e should not be exceeded in the overall composition of the grout. The quantities of these substances in the grout constituents should be determined individually for each of the constituents by the applicable ASTM (American Society of Testing and Materials)[3] methods and expressed in parts per million parts of water in the grout composition.

In general, portland cement conforming to ASTM C150, Type I or Type II, is suitable for the grout. However, grouting under certain climatic or environmental conditions may dictate the use of other types of cements. Chlorides are normally present in cement, but the amount is usually not reported. The determination of chlorides in cement should be a requirement when specifying the cement for grout.

Admixtures should be free of any substance likely to damage the prestressing steel. Use of aluminum powder to produce expansion has been viewed by many engineers as having possible deleterious effects. Under an alkaline environment (pH >9), the aluminum powder generates minute bubbles of hydrogen gas (H_2) that would not endanger the tensioned steel at the prevailing range of pressures and temperatures. However, the potential danger of hydrogen attack on steel does exist if the tensioned steel elements or stressed anchorage components contain surface flaws. The parameters affecting the use of aluminum powder are described in Reference 9.

The protective mechanism of grout is primarily dependent on its ability to provide a continuous alkaline environment around the tensioned steel elements. The natural alkalinity of the primary product of cement hydration (i.e., calcium hydroxide) tends to be at a pH value of 12.5. The effectiveness of the alkaline environment may be reduced by the leaching of alkaline substances with water, by reaction in an acidic or sulfide-containing environment, or by the presence of oxygen and chloride ions. It is reported in Reference 10 that the ability of chloride ions to develop corrosion increases with decreasing alkalinity of the calcium hydroxide solutions. Thus it is advisable to monitor the pH value of the in-place grout under actual field conditions and ensure that it remains above a value where the passivating effect of the grout is not reduced by the available chloride ions in the composition of the grout.

Section CC-2243.2 of the ASME Code (Ref. 1) requires the use of flow cones with the limits on efflux times at the specific quiescent times to ensure adequate fluidity of the grout. However, for certain types of grouts (in particular, one with a thixotropic additive), these requirements may not be appropriate to define their pumpability. Applicants in such cases

[3] A list of relevant ASTM standards is provided in Appendix B of this guide.

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should propose alternative means of quality control to accomplish the same objective. Also, a general practice is to limit the pumping pressure during grouting to 300 psi (see Refs. 2 and 3). However, grout with a thixotropic additive may need higher pumping pressures for long vertical tendons. In such cases, it should be demonstrated through tests that high pressures will not deteriorate the quality of grout; damage the duct, duct splices, or surrounding concrete; or deform the containment liner.

In addition to the control on grout materials and on mixing and injecting the grout to ensure the intended protection of the prestressing steel, it is important to take other precautions directly related to the corrosion protection of the prestressing steel:

1. It is necessary that the tendon remain clean, dry, free from deleterious corrosion, and undamaged up to the time it is grouted. Specific protection measures should be provided at coastal sites, at sites having a high moisture level, and at sites near industrial areas.

2. When a preassembled tendon-sheathing assembly is to be placed before concreting, the tendon should be protected against corrosive environment during assembly, handling, storing, transporting, placing, and tensioning.

3. Before placing the tendon in the duct, it is important to ascertain that the duct is free of obstructions, moisture, and other deleterious substances.

4. Ferrous metal sheathing is galvanized to protect it against corrosion before grouting of the tendon. However, the contact surfaces of the tendons and the sheathing are potential areas for the formation of corrosion cells and hydrogen evolution. From the tendon corrosion point of view, this is critical if the time between the tensioning and grouting is long and the duct contains moisture with or without deleterious substances.

5. In general, the period between tensioning and grouting is critical from the standpoint of stress corrosion or hydrogen stress cracking. Steps should be taken to minimize this time period.

Effective corrosion protection of prestressing tendons can be provided by portland cement grout if appropriate precautions are taken to eliminate the potential sources of corrosion. To this end, close quality control is necessary for each constituent of the grout, the tendon material, and the tendon duct material and for the method of mixing and pumping the grout and ensuring that the tendon is surrounded from end to end with qualified grout.

C. REGULATORY POSITION

The following minimum quality standards should be maintained when portland cement grout is to be used for the corrosion protection of prestressing steel.

1. Materials

a. *Portland Cement.* Cement should conform to the requirements of ASTM C150. The type to be selected should be suitable for the intended use.

b. *Fine Aggregate.* Fine aggregate-filler may be used when permitted by the requirements of Article CC-2243.1 of the ASME Boiler and Pressure Vessel Code, Section III, Division 2 (Ref. 1).

c. *Water.* The water should not contain ingredients harmful to the prestressing steel or the grout. Water contaminated (1 ppm) with hydrogen sulfide (sulfide ion) should be prohibited. The water to be used for grouting should be qualified for use by making comparative tests in accordance with the test methods and tolerance levels described in Article CC-2223.2 of the ASME Code.

d. *Admixtures.* Acceptable admixtures may be used if tests have demonstrated that their use improves the properties of grout, e.g., increases workability, reduces bleeding, prevents water separation when pumped at high pressure, entrains air, expands the grout, or reduces shrinkage. The quantities of harmful substances in the admixture should be kept to a minimum. Use of calcium chloride should be prohibited.

e. *Limits on Deleterious Substances and pH.*

(1) The quantity of the following substances (added individually for each constituent and expressed as parts per million parts of water) in the overall grout composition should not exceed the following limits:

Chloride	100 ppm (200 ppm if pH is maintained above 12)
Nitrates	100 ppm
Sulfates[4]	250 ppm
Sulfides	2 ppm (test method of Ref. 15)

(2) The pH value of the grout at inlet and outlet of the duct should be maintained above 11.6 (12 if the allowable chloride content is 200 ppm).

(3) During the grouting period, the amount of deleterious substances in the grout constituents should be checked weekly and whenever the composition of the constituents is changed or is suspected of having changed.

[4] Sulfates in the form of sulfur trioxide as a cement component need not be considered.

2. Physical Properties of the Grout

The physical properties of the cement grout should satisfy the requirements of Article CC-2243.2 of the ASME Code. Adequate tests should be carried out in accordance with the test methods described in that article to demonstrate that the grout satisfies these requirements.

3. Duct

a. The duct size should be adequate to allow the insertion and tensioning of tendons without undue difficulty. The area of the grout that penetrates and surrounds the tendon at any section should be at least equal to the cross-sectional area of the tendon. The duct sheathing and its splices should be of ferrous metal and should be protected to prevent corrosive deterioration prior to the grouting of tendons. The duct sheathing and its splices should be sufficiently tight that a thin cement slurry cannot pass through while the surrounding concrete is being placed. The duct sheathing and its splices, when surrounded by hardened concrete, should be capable of withstanding the maximum grouting pressure without leakage.

b. Vents should be provided at any major changes in section of the duct, as well as at the high points. Drains should be provided at the low points. Vents and drains should be checked for possible obstructions prior to grouting.

4. Equipment for Grouting

a. The grouting equipment should include a mixer that is capable of continuous mechanical mixing and that can produce a grout free of lumps and undispersed cement. To this end, tests should be performed to demonstrate the optimum range of mixing time and the sequence of placing the constituent materials in the mixer under extreme anticipated environmental conditions.

b. The pump should be of the positive displacement type and should be capable of exerting the required maximum pressure. A safety device should be provided to guard against exerting a pressure that could damage the duct, duct splices, or surrounding concrete or deform the containment liner. The pumps should not suck air in with the grout.

c. A screen having clear openings not more than 1/8 inch (1/4 inch for grout with a thixotropic additive) should be provided between the mixed grout and the pump to ensure that the grout does not contain lumps. If an excessive amount of lumps remain on the screen, the batch should be rejected.

5. Grouting

a. Grouting should be carried out immediately after tensioning. The period between tensioning and grouting should be kept below 72 hours. The tendon should be protected from inclement weather and other adverse environmental conditions during this period. If an additional delay is expected, the tendons should be protected by methods or products that would not jeopardize the effectiveness of the grout as a corrosion inhibitor. In any case, the tendon anchorages should be visually examined just prior to grouting to detect any breakage or degradation of prestressing elements as evidenced by the movement or dislocation of anchoring hardware.

b. Flushing before grouting is not recommended. When flushing has to precede the grouting, appropriate measures should be taken to ensure that:

(1) The level of harmful substances in the in-place grout does not increase above that in the designed grout, and

(2) The properties of the injected grout satisfy the recommendations in Regulatory Position C.2.

c. Tests should establish the length of time that the grout can be used after mixing. The tests should verify that:

(1) The intended reaction of such admixtures as expansive agents continues when such a grout is injected in the duct, and

(2) This time is less than that required for the initial set of the grout as determined by the method of ASTM C191.

d. The temperature along the entire length of the tendon duct during grouting should be above 35°F. This temperature should be maintained until the minimum (2-inch cube) strength of the job-cured grout exceeds 800 psi. The grout temperature should not exceed 90°F during mixing and pumping unless it can be established by test that a higher temperature will not adversely affect the grouting operation.

e. The development of the grouting procedure should consider the extremes of anticipated environmental conditions. The procedure should ensure that the ducts will be filled and that the tendon steel will be completely surrounded by grout.

f. All openings, air vents, and drains should be hermetically sealed after grouting to prevent the ingress of water and other corrosive agents.

g. If an applicant chooses to provide permanent protection of the anchor hardware by means of qualified grout or concrete, the protection should be provided on the following bases:

(1) All exposed anchor hardware should be thoroughly examined before being provided with the permanent protection.

(2) The permanent protection should be designed and constructed in a manner that would prevent the intrusion of water and deleterious substances to the anchorage components.

6. Tendon

The tendon should be clean, dry, free from deleterious corrosion, and undamaged up to the time when it is grouted. The preassembled tendon sheathing assembly should be protected against corrosive influences from the time of assembly to the time of grouting.

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 proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the guide will be used by the NRC staff on the following bases:

1. Submittals in connection with construction permit applications docketed after February 14, 1977, will be evaluated on the basis of this guide.

2. Submittals in connection with operating license applications for plants whose construction permit applications were docketed prior to February 14, 1977, will be evaluated in accordance with the commitment made by the applicant in the construction permit.

APPENDIX A

REFERENCES

1. "Code for Concrete Reactor Vessels and Containments," American Concrete Institute Committee 359 and American Society of Mechanical Engineers Subcommittee on Nuclear Power, 1975. Copies may be obtained from the American Society of Mechanical Engineers, 345 E. 47th St., New York, N.Y. 10017 or from the American Concrete Institute, P.O. Box 19150, Redford Station, Detroit, Mich. 48219.

2. "Recommended Practice for Grouting of Post-Tensioned Concrete," Prestressed Concrete Institute Committee on Post-Tensioning, published in PCI Journal. Nov./Dec. 1972. Copies may be obtained from the Prestressed Concrete Institute, 20 North Wacker Drive, Chicago, Ill. 60606.

3. "Report on Grout and Grouting of Prestressed Concrete," Proceedings of the Seventh Congress of the Federation Internationale de la Precontrainte, 1974. Copies may be obtained from the Federation Internationale de la Precontrainte, Terminal House, Grosvenor Gardens, London SW1W OAU.

4. "Specifications for Structural Concrete for Buildings," American Concrete Institute Committee 301, 1972. Copies may be obtained from the American Concrete Institute, P.O. Box 19150, Redford Station, Detroit, Mich. 48219.

5. Leonhardt, F., *Prestressed Concrete Design and Construction*. Wilhelm Ernst & Sohn, Berlin, Second Edition, 1964.

6. Szilard, R., "Corrosion and Corrosion Protection of Tendons in Prestressed Concrete Bridges," ACI Journal, Jan. 1969. Copies may be obtained from the American Concrete Institute, P.O. Box 19150, Redford Station, Detroit, Mich. 48219.

7. Monfore, G. E., and Verbeck, G. J., "Corrosion of Prestressed Wire in Concrete," ACI Journal, July 1960. Copies may be obtained from the address shown in Reference 6.

8. Scott, G. N., "Corrosion Protection Properties of Portland Cement Concrete," Journal of the American Water Works Association, Vol. 57, No. 8, Aug. 1965. Copies may be obtained from the American Water Works Association, 2 Park Avenue, New York, N.Y. 10016.

9. "Admixtures for Concrete," American Concrete Institute Committee 212. Copies may be obtained from the American Concrete Institute, P.O. Box 19150, Redford Station, Detroit, Mich. 48219.

10. Hausman, D. A., "Steel Corrosion in Concrete," *Materials Protection*, November 1967. Copies may be obtained from the National Association of Corrosion Engineers, 2400 West Loop S., Houston, Texas 77027.

11. Harstead, G. A., et al, "Testing for Large Curved Prestressing Tendons," Proceedings of the American Society of Civil Engineers, Power Division, March 1971. Copies may be obtained from the American Society of Civil Engineers, 345 E. 47th Street, New York, N.Y. 10017.

12. Lange, H., "The Vacuum Process, A New Method for Injecting Prestressing Tendons," paper submitted for the Seventh Congress of the Federation Internationale de la Precontrainte, New York, N.Y. 1974. Copies may be obtained from the Federation Internationale de la Precontrainte, Terminal House, Grosvenor Gardens, London SW1W OAU.

13. Schupack, M., "Development of a Water Retentive Grouting Aid to Control the Bleed in Cement Grout Used for Post-Tensioning," presented at the Seventh Congress of the Federation Internationale de la Precontrainte, New York, N.Y., 1974. Copies may be obtained from the address shown in Reference 12.

14. Kajfasz, S., et al, "Phenomena Associated with Grouting of Large Tendon Ducts and Morphology of Defects," technical contribution to the Seventh Congress of the Federation Internationale de la Precontrainte, New York, N.Y. 1974. Copies may be obtained from the address shown in Reference 12.

15. "Standard Method for the Examination of Water and Waste Water"—1971. Copies may be obtained from American Public Health Association, 1015 18th Street NW., Washington, D.C. 20036.

APPENDIX B

LIST OF RELEVANT ASTM STANDARDS

C109-73, "Standard Method of Test for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. Cube Specimens)"
C150-74, "Standard Specification for Portland Cement Concrete"
C191-74, "Standard Method of Test for Time of Setting Hydraulic Cement by Vicat Needle"
C260-74, "Standard Specifications for Air-Entraining Admixtures for Concrete"
C494-71, "Standard Specification for Chemical Admixtures for Concrete"
D512-67, "Test for Chloride Ion in Industrial Water and Industrial Waste Water"
D992-71, "Test for Nitrate Ion in Water"
D516-74, "Tests for Sulfate Ion in Water"
D596-74, "Reporting Results of Analysis of Water"
D1129-74, "Terms Relating to Water"
D1293-65, "pH of Water and Waste Water"

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