GROUNTS FOR POST-TENSIONED PRESTRESSED CONCRETE MEMBERS

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Presented at the FIP-RILEM Symposium on Injection Grout for Prestressed Concrete

Trondheim, Norway, January, 1961

INTRODUCTION

The desirability of grouting the tendons of cables in post-tensioned prestressed concrete members is well recognized. The two main objectives of grouting are to protect the steel from deterioration due to corrosion and to provide bond between the tendons and the concrete member after tensioning. Both of these requirements call not only for a complete filling of the void space within the post-tensioning units but also for a properly designed grout mixture possessing desired fresh and hardened properties. Grouts employed must be of sufficiently low viscosity to permit easy injection; should be of low water content to insure high strength and low shrinkage characteristics; and should be of very low bleeding characteristic to prevent segregation and formation of water pockets under the tendons or in the top of the cable. They should also contain a gas-forming agent which will cause the fresh grout to expand (if unrestrained) during the first few hours and develop pressures when restrained against expansion. When inlets and outlets are closed after grouting, the pressures developed reduce the size of entrapped air bubbles in accordance with Boyle's Law. Grouting equipment and the grouting procedures employed are also of great importance in insuring a complete filling of the void spaces in the cables.

Too little attention is being paid in practice to proper grouting procedures of post-tensioning units. There have been reported some failures of prestressed concrete members resulting from corrosion of tendons due to the use of improper grouts or grouting techniques. Malpractice of the art of grouting can frequently be observed in the field. Current American specifications and recommended practices for grouting post-tensioned prestressed concrete 2,3,4 are of little practical value. They contain only very brief statements on the various phases of grouting and are of no real value to the uninformed engineer or contractor.

This paper, which discusses the various factors concerning grouts for post-tensioned prestressed concrete members, is based on results of many investigations in the field of cement grouting carried out at the University of California over the last 20 years.5,6,7

COMPOSITIONS OF GROUTS:

Cement grouts are composed of cementing material, water, chemical admixture, and sometimes fine sand. Neat cement grouts are those containing cementing material and water. Sand-cement grouts are those containing in addition to the cementing material and water a fine sand. Both of these types of grouts will usually also contain a chemical admixture.

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Whether a neat cement grout or a sand-cement grout should be used will depend on the type and size of cable employed and on the size of the tendons. The use of sand-cement grouts is particularly desirable because of their lower cement content and therefore lower shrinkage characteristics, which is in the interest of sustained high bond. In the Magnel cable for example, the void spaces between wires are large enough to permit the use of a sand-cement grout; whereas the void spaces in some of the Freyssinet or Strescon cables are so small that a neat cement grout has to be used.

It is also desirable to employ in the grouts a chemical admixture or admixtures of proven reliability which will improve plasticity and decrease the tendency towards bleeding of fresh grout, will retard its rate of stiffening, will decrease mixing-water requirement, and will cause the grout to expand (if unrestrained) for a period of several hours after mixing.

Inasmuch as the composition of individual grout materials and their proportions significantly affect the properties of fresh and hardened grouts, laboratory tests should be conducted prior to their use in the field.

GROUT MATERIALS

CEMENTING MATERIAL

The cementing material used in grouts for grouting of post-tensioned concrete members may be an ordinary portland cement, a high-early strength cement, a portland blast-furnace cement, or a portland pozzolan cement.

To increase the water retentivity (reduce bleeding) of the grout and thus reduce the tendency towards separation of its solid constituents, particularly in sand grouts, the use of a material which is more finely divided than the ordinary portland cement is desirable. The objective is to produce a fresh grout for which the solids will remain in suspension with practically no bleeding. This will eliminate the possibility of formation of water voids, which may later become air voids in contact with the steel.

Such materials, used as additions to portland cement include the pozzolans, granulated blast-furnace slag and natural cement. A pozzolan is a finely divided siliceous or siliceous and aluminous material which, when used as an addition in a cement grout chemically reacts with calcium hydroxide (a product of portland cement hydration) to produce cementitious compounds. The pozzolans in themselves possess no cementitious value. Natural cements and granulated blast-furnace slags are cementitious in their own right.

The amounts of any such finely divided material to be added to the portland cement will depend on the nature of the material itself and on the mix proportions of the grout.

In the following tabulations are listed some of the finely divided active mineral materials along with the range of amounts in which they usually would be used as additions to the portland cement in grouts.

<table>
<thead>
<tr>
<th>Type of Material</th>
<th>Addition to Portland Cement, % by weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diatomaceous Earth</td>
<td>3 - 6</td>
</tr>
<tr>
<td>Calcined Opaline Shales</td>
<td>10 - 20</td>
</tr>
<tr>
<td>Natural Cement</td>
<td>25 - 35</td>
</tr>
<tr>
<td>Fly Ashes (of high fineness and low carbon content)</td>
<td>25 - 35</td>
</tr>
<tr>
<td>Water-Quenched Blast-Furnace Slag</td>
<td>30 - 50</td>
</tr>
</tbody>
</table>

Other pozzolans are discussed in a paper by Raymond E. Davis.

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Such materials should be used only if they improve such properties of fresh grout as low bleeding, easy pumpability and penetrability of small voids, and also if the hardened grout is of adequate strength. Their most important contribution to the properties of grouts is their effect on reduction of bleeding and segregation. In neat cement grouts these additions would be used in a smaller percentage than in the sand-cement grouts. Their fineness will also influence the optimum percentage in which they should be added to portland cement. The finer they are the smaller will be the amount needed to achieve the desired effects.

Sand—Except as to grading, the sand used in grouts should meet the same requirements as those sands employed in concrete. Where several sands are available, preference should be given to the one which tests indicate will produce optimum results with regard to such properties as water requirements, bleeding, and strength of hardened grout. All of the sand should pass the No. 30 sieve (0.59 mm). A suggested range of grading limits is shown in the following tabulation.

<table>
<thead>
<tr>
<th>Sieve</th>
<th>Opening, mm</th>
<th>Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>U. S. Std. No.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>0.590</td>
<td>100</td>
</tr>
<tr>
<td>50</td>
<td>0.297</td>
<td>40 - 60</td>
</tr>
<tr>
<td>100</td>
<td>0.149</td>
<td>15 - 25</td>
</tr>
<tr>
<td>200</td>
<td>0.074</td>
<td>0 - 5</td>
</tr>
</tbody>
</table>

The sand grading to be used will depend on the size of the void space to be grouted. Coarser grading should be used for large voids and finer grading for smaller void spaces.

CHEMICAL ADMIXTURES

The two principal types of chemical admixtures widely utilized in grouts are the gas-producing agents and the water-reducing retarders. There is no advantage to be gained through the use of any of the air-entraining agents commonly employed in conventional concrete construction. Examples of the use of chemical admixtures, their advantages and disadvantages, and considerations involved of their use in mortars and concretes are cited in the report of ACI Committee 212 on Admixture for Concrete.9

Gas-Producing Agents—Aluminum is one of the metals which is capable of rapidly reacting in alkaline solutions, such as occur in mixtures containing portland cement, to produce hydrogen gas. There are also some chemical compounds capable of gas generation. For the grouts employed in prestress concrete work, the use of aluminum powder is recommended.

The aluminum powder should be used in quantity sufficient to produce an unrestrained expansion of about 10 percent of the volume of the grout prior to the time of setting. At normal temperatures and with cements of normal alkali content, for an aluminum powder of the proper grade most of the hydrogen gas generation which produces the expansion will take place within the first three to four hours after mixing. The amount of aluminum powder required to produce a 10 percent expansion of grout will range from 0.01 to 0.03 percent of the weight of cementing material. For proper dispersion of such a small quantity of aluminum powder in the grout mixture, the powder should first be blended with cement or other finely divided material in proportions of say one part of aluminum powder to one hundred parts of cement. The material can then be packaged or
batched in appropriate amount for quantities such as one sack of cement.

Since there are many different commercial grades of aluminum powder available, their suitability as a gas-forming agent should be determined by testing them in grouts containing the proposed job materials. In Fig. 1 are shown the results of such an evaluation of six aluminum powders in a grout mixture containing five parts of cement, two parts of fly ash, and six parts of sand by weight at a water-cementing material ratio \(W/(C+F)\) of 0.44 by weight. Aluminum powder samples 1 to 3 were leafing types and samples 4 to 6 non-leafing types. The fineness of these aluminum powders varied in order of their numbers from 31,000 to 11,000 sq. cm. per gram, No. 1 being the finest and No. 6 the coarsest. All powders were employed in the amount of 0.015 percent by weight of cementing material. The grouts also contained a water-reducing retarder in the amount of 0.20 percent by weight of cementing material. The desired 10 percent unrestrained volumetric expansion of the grout was reached within 2 to 4 hours after end of mixing with the three leafing type aluminum powders (samples 1, 2, and 3).

The alkali content and perhaps the compound composition of the cement also has a large effect on the expansion characteristics of grouts.

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**Fig. 1—Effect of type of aluminum powder on expansion characteristics of fresh grouts at 70°F**

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Tests conducted on grouts containing cements of different alkali contents showed as much as 50 percent variation in total expansion. It was also observed that the rate of reaction is less rapid for the unpolished aluminum powder and also the magnitude of grout expansion is less.

Water-Reducing Retarders—The use of a water-reducing retarder which will reduce the water content and retard the rate of stiffening of a grout mixture is highly desirable. Water-reducing retarders which are suitable for this purpose include calcium, sodium, and ammonium salts of some of the ligno-sulphonates, some of the organic acids including those of the hydroxy group and the amine salts of these acids. For use in prestress work any water-reducing retarder should be free from calcium chloride or compounds which might contribute to corrosion of the steel.

Some of the commercially available grouting admixtures contain both a gas-producing agent and a water-reducing retarder. Some even contain a thickening agent which tends to stabilize the grout suspension, reducing the tendency towards bleeding and segregation. Because of the complexities involved in developing such multi-purpose chemical admixtures, it will usually be cheaper and better to employ a commercially available admixture specially designed for the purpose of grouting post-tensioned concrete members.

**MIX PROPORTIONS**

The proportions of grouting materials should be based upon results of laboratory tests made on fresh and hardened grouts prior to their use in the field. The amount of mixing water employed should be such as to produce a grout having the consistency of a thick cream or heavy paint. When permitted to stand until setting takes place, the grout should exhibit practically no bleeding or segregation and should expand not less than 6 nor more than 12 percent of its original volume. For neat cement grouts containing a water-reducing retarder, the water-cementing material ratio will be in the neighborhood of 0.40 to 0.45 by weight. When a sand-cement grout is employed for which the absolute volume of sand is approximately equal to the absolute volume of the other solid constituents of the grout, the water-cementing material ratio by weight will be in the order of 0.45 to 0.55.

Evaluation of mix proportions and of grout materials should be made on grout mixtures of fixed consistencies. Grout consistencies, in terms of a flow factor, can be measured by means of the “flow-cone method,” later described under “Testing Methods”. Test data indicate that a grout consistency suitable for grouting of prestress cables is represented by a flow factor of about 20 to 24 seconds for neat cement grouts, and about 24 to 28 seconds for sand-cement grouts.

Adjustment of mix proportions might also be necessary to produce grouts of desired expansion characteristics, absence of bleeding and satisfactory strength. The variables can include the type of cement, richness of mix, the type and amount of finely divided active mineral admixture (pozzolan, natural cement, or granulated blast-furnace slag), the quantity and grading of sand, and the kind and amount of chemical admixture.

**TESTING METHODS FOR GROUTS**

The important properties of fresh grouts to be evaluated are consist-
ency or viscosity and the expansion and bleeding characteristics. The compressive strength of hardened grout should also be determined.

For laboratory tests of grout properties, it is advisable to adopt a standardized mixing procedure. Such factors as type and speed of grout mixer, manner of charging the mixer, and time of mixing will have an influence on the resulting grout properties.

**Laboratory Mixing of Grout**

The mixer shown in Fig. 2 has been found to be very satisfactory for laboratory tests. The following mixing procedure has long been employed in our laboratory at the University of California.

The estimated quantity of water necessary to produce a grout of desired consistency is placed in the mixing vessel, the motor is started, and the reostat is adjusted so that the speed of stirring is about 500 rpm. The cementing material is then introduced gradually into the mixer over a period of 1 minute. The time of starting this operation is considered as the start of mixing. As the cementing material is fed into the mixing vessel, the speed of stirring is increased gradually until the maximum speed (about 8,000 rpm) is attained. Three minutes of mixing is sufficient to produce a homogenous mixture. If the grout is to contain sand, the sand is introduced after 3 minutes of mixing, gradually pouring it into the mixing vessel over a period of about ½ minute, and continuing the mixing for an additional 2½ minutes. The total elapsed time in this case is 6 minutes from the time of starting.
Fig. 3-Flow Cone apparatus

**Consistency Determination**

The consistency, or essentially the pumpability, of the grout is measured by the resistance of flow through a pipe or an orifice. A convenient method for evaluating consistency is by the measurement of the time of efflux of a fixed quantity of grout, under falling head through a standardized discharge tube. For this purpose a flow-cone apparatus having the shape and dimensions shown in Fig 3 is utilized. The consistency is determined as the time required for a given volume (1725 ml) of grout to flow from the cone through the discharge tube. This time of efflux of the grout, in seconds, is called the "flow factor". The flow cone should be moistened prior to use by flushing it out with water and allowing it to drain for about 1 minute, before the grout for test is to be poured into the flow cone. During filling of the cone with grout, the discharge tube is sealed by placing a finger over the end. Immediately after filling of the cone, the grout is allowed to discharge by quickly removing the finger; and a stop watch is started simultaneously. The watch is stopped at the first break in continuous flow of grout from the tube.

**Measurement of Expansion**

The expansion of a sample of grout is determined as the change in volume of a grout column between the original level and the level at the end of a specified period. For this test approximately 900 ml of freshly mixed grout is poured into a standard 1000-ml graduated cylinder, and the volume is observed and recorded. The expansion of the sample is periodically observed. Depending upon the type of grout tested, the test may be discontinued at either 3 or 4 hours when its evident that expansion has practically ceased. At the end of this period, the bleeding water, if any, is poured from the surface of the grout into a small graduated cylinder, where its volume is observed.

The grout expansion is reported as percent expansion based on original grout volume. As discussed earlier, it is generally considered that a total expansion of $10 \pm 2$ percent is desirable. If there is any bleeding water on the surface of the grout, it should be collected, measured, and reported as percent of bleeding based on original volume of grout. For the type of grouts considered here, it is desirable that they exhibit practically no bleeding. In no case should the use of a grout exhibiting bleeding in excess of 0.4 percent be permitted.

**Compressive Strength**

In evaluating the compressive strength of a grout, it is difficult to simulate the conditions to which the grout is subjected in the post-tension-
ing cables. It was found that a suitable method for manufacture of grout specimens is to use heavy steel molds provided with end plates and rods that will insure complete restraint of the grout after specimens are cast. At the University of California 3 by 6-in. molds, with their bottom plate in position, are filled with grout and immediately sealed by fastening the top plate securely with the rods. To insure a complete seal, the end plates should be provided with suitable gaskets. The tendency for the grout to expand will develop a pressure similar to that expected to be developed in the post-tensioning cable. In Fig. 4 are shown the pressures developed by a grout mixture containing five parts of cement, two parts of fly ash, and six parts of sand by weight at a water-cementing material ratio of 0.44 by weight. The grouting admixture contained 0.015 percent of a water reducer by weight of cementing material. Three hours after casting, the grout developed a pressure of 28 psi.

Restraint of the grout has a significant effect on the compressive strength. To evaluate this effect, a neat cement grout containing ten parts of cement and one part of fly ash at a water-cementing material ratio of 0.40 by weight was used for manufacture of restrained and unrestrained grout specimens tested in compression at various ages. This grout contained 0.015 percent aluminum powder and 0.20 percent of a water-reducer by weight of cementing material. Its free expansion was 11.0 percent by volume. The test results obtained are shown in Fig. 5. The specimens for the restrained condition were kept in sealed 3 by 6-in. steel molds up to the age of test. The unrestrained specimens were cast in 3 by 6-in. cardboard molds with an open top. The grout which rose above the top of the mold was cut off four hours after casting of the specimens. The 28-day compressive strength of the unrestrained specimens (1870 psi) was only about

![Figure 4 - Pressures developed due to volumetric restraint of fresh grout.](image)
28 percent of the compressive strength obtained on the restrained specimens (6750 psi). The low strength of the unrestrained specimens is due for the most part to the free expansion of the grout which in this case was 10.9 percent at three hours.

The data of Fig. 5 clearly indicates that compressive strength tests conducted on unrestrained grout specimens are of no practical value.

**GROUTING METHODS**

Because of possible corrosion damage to post-tensioning steel, grouting should be performed as soon as is practicable after stress is applied to the cable.

Grout holes at both ends of a duct should be provided with a ¼-in. or preferably ⅜-in. pipe connection.

These connections, equipped with a stopcock or plug valve should be tight so that pressures as great as 100 psi may be applied without loss of air or water. For long members of a continuous structure, it is desirable to have vents at high points of the duct for bleeding of air. If the walls of the duct to be grouted are the concrete of the member itself, the duct should be filled with water under pressure for an hour or more before the time of grouting.

Prior to grouting, the duct should be flushed out with water and compressed air, to remove any loose material which might obstruct the free flow of grout.

The grout should be injected by the use of a grout pump of either the piston-displacement type or the

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**Grout Mix:**

Cement : Fly Ash = 10 : 1 by wt.

\[ \frac{w}{(c+F)} = 0.40 \] by wt.

Free expansion =

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**Fig. 5—Effect of Restraint on compressive strength of neat-cement grout.**
screw or impeller type. The grout should be pumped continuously at a slow rate until the cavity is filled. The use of a pressure pot as a device for injecting the grout is not advisable since control of the rate of grouting is difficult, and there is always the possibility of slugs of air being forced into the cavity. After grout appears at the vent openings of the duct, grouting should continue (wasting excess grout) until it is clear that all entrapped air has been removed, and the duct is completely filled with grout of good quality. If there are several vent openings, they should be progressively closed in the direction of grout flow. To insure complete filling of a duct, it is also important that it be free of abrupt changes in cross sections, and that there be no interconnection between one duct and another.

As soon as the duct is completely filled with grout, the valve at the outlet end should be closed. A grout pressure as high as 100 psi should then be applied and held for about one minute after which the valve at the near end should be closed. All valves of the duct should be kept closed and in place until final setting of the grout has taken place.

**SUMMARY**

1. Ducts of post-tensioned concrete members should be grouted after tensioning to protect the steel from corrosion and to provide bond between the tendons and the concrete.

2. Current practice in prestressed concrete pays very little attention to, or is ignorant of, proper grouting procedures and several failures due to poor grouting have been reported.

3. Grouts for post-tensioned concrete members should be composed of cementing material, water a chemical admixture, and sometimes fine sand. The cementing material may be either ordinary portland cement, a high-early strength cement, a portland blast-furnace cement, a portland pozzolan cement, or a portland cement with a finely divided active mineral admixture (pozzolans, natural cement, or granulated blast-furnace slag).

4. Whether a neat cement grout or a sand-cement grout should be used depends on the type and size of cable and size of the tendons. Cables with large void spaces (Magnel cable) will permit the use of sand-cement grouts whereas those having small void spaces (Strescon cable) require the use of neat cement grouts.

5. The chemical admixture, usually in powered form, should be designed to produce an expansion of the grout through generation of tiny gas bubbles, to reduce the mixing water requirement, and to retard the rate of early stiffening and the time of setting. The expansion is produced through the use of aluminum powder. A water-reducing retarder is used to reduce the water requirement and provide retardation of stiffening and setting.

6. Cement composition, mix proportions, and type of admixture will influence properties of grouts. Grout materials and grouts should be evaluated prior to use in the field. The sand for the grouts should all pass No. 30 sieve.

7. Grouts for post-tensioning cables of prestressed concrete members should be of as thick consistency as can be readily injected to completely fill the voids within the duct, should be of low water requirement, should be of very low bleeding characteristics, and should expand while in plastic state. The unrestrained expansion of the grout

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should be about 10 percent of its volume.

8. As measured by the flow-cone apparatus, a neat cement grout should have a flow factor of 20 to 24 seconds and a sand-cement grout 24 to 28 seconds.

9. Compressive strengths of grouts should be determined only for specimens which were restrained from free expansion during both their setting and hardening period. Compressive strengths of unrestrained specimens are not applicable.

10. Grout pumps should be employed for the grouting of post-tensioning units. The ducts should be flushed out prior to grouting, and care should be taken to completely fill the void space. Immediately after grouting the valves of the duct should be closed to maintain the grout under restraint during both setting and hardening.

REFERENCES


3. “Specifications for Post-tensioned Prestressed Concrete,” Committee on Post-tensioned Prestressed Concrete Specifications, Prestressed Concrete Institute, 3 p., February 1958.


6. Raymond E. Davis and Milos Polivka, “Composition and Properties of Prepakt Concrete,” RILEM International Colloquium on Injected Concretes, Madrid, Spain, October 1957.


