Chapter 16

WATER TESTING FOR GROUTING

Introduction

Water testing is necessary for evaluating seepage potential and for determining whether grouting is necessary or practical. Water testing for designing a grout program is often secondary to the main purpose of the water testing program, which is to determine permeabilities for seepage evaluation or control. Design of an exploration program for water testing for grouting can be significantly different from permeability testing for the design of a dam or tunnel because of the desired results, the restricted area of a damsite, or the often high-cover linear tunnel site. Regardless of the main reason for the investigations, design of a program for water testing for grouting should consider:

(1) The type of structure to be built. Water testing for evaluating and grouting a dam foundation is significantly different than water testing for a tunnel. More drill holes are generally available for testing in dam foundations where seepage potential is the primary concern and grouting is secondary. Relatively few drill holes are available for evaluating tunnel alignments because of the great depths often necessary and the linear nature of a tunnel. A great deal of judgment is necessary in evaluating the data for tunnels because of the small sample size. Ground conditions are of primary interest, and permeability and groutability are secondary, especially if the tunnel will be lined.

(2) The geologic conditions at the site and the variations between areas or reaches. Generalizations based on other sites are usually inaccurate because geologic conditions depend on the

interrelationship of the local depositional, tectonic, and erosional history that uniquely determine geologic conditions important to the permeability and groutability of a site. Damsite foundation permeabilities can vary over short distances because of lithology and fracture changes, faults, or stress relief in the abutments. Tunnel studies compound the difficulties because of the linear nature of the structure, the often high cover, and access problems. Proper evaluation of water test results requires that the values be correlated with geologic conditions. The permeability values should be noted and plotted on the drill logs along with the water takes and test pressures. The test interval should be drawn on the log so that the water test data can be related to fracture data.

(3) The level of seepage control desired. Seepage quantities beneath a dam in the arid West may be insignificant compared to those in an area with abundant rainfall. Infiltration into a tunnel may be insignificant in one area but, because of overlying cultural and environmental features, may be the controlling factor in a dewatering, excavation, or lining design. The economic value of the water may also be a significant factor.

(4) Groutability and permeability are not necessarily related. A highly fractured rock or a gravel may be very permeable but essentially ungroutable using standard cement grout. Water test data must be correlated with geologic data to properly assess groutability.

(5) Groutability depends on fracture openness and number. Connectivity is not necessarily important because of the relatively limited travel of grout.

(6) Permeability depends on fracture openness, number, and connectivity. Highly fractured rock with low connectivity will have low permeability, and a slightly fractured rock with high connectivity can have high permeability.

(7) Exploratory drill hole orientations introduce a significant bias into water test results. The orientation of the drill hole relative to the fractures has a direct effect on the number of fractures intercepted by the hole. Vertical boreholes intercept very few vertical fractures and can provide very misleading water test information on rock mass permeability and groutability. A vertical hole drilled in a material that has predominantly vertical fractures like flat-bedded sediments will not intercept the fractures that control the rock mass permeability. Drill holes should be oriented to cross as many fractures as possible not only for more meaningful permeability tests but also to get more meaningful rock mass design parameters. If a preferred hole orientation is not practical, the results may be adjusted for the orientation bias.

(8) Water test calculation results can be very misleading. Water test calculations based on a 10-foot (3-meter [m]) interval with one 1/4-inch (6-millimeter [mm]) fracture taking water can have a significantly different seepage and grout potential than a 10-foot (3 m) interval with dozens of relatively tight fractures taking the same amount of water. Each water test must be evaluated individually to determine what the data really mean.

(9) Different rock types, geologic structures, or in situ stresses have different jacking and

hydrofracture potential and, therefore, different maximum acceptable water testing and grouting pressures. Dam foundations are more sensitive to jacking and hydro-fracturing than tunnels. Dam foundations can be seriously damaged by jacking and hydrofracturing. A dam foundation in interbedded sedimentary rock with high horizontal in situ stresses is very sensitive to jacking. A dam foundation in hard, massive granite is almost unjackable and may have to be hydrofractured before any movement can take place. Tunnels are less susceptible to jacking because of overburden depth and may benefit from jacking open fractures to provide grout travel and closure of ungrouted fractures.

(10) Rock mass permeability or groutability cannot be determined by drill holes alone. Mapping and analysis of the fractures are necessary factors in determining seepage potential and groutability. Drill holes usually do not provide a realistic characterization of fracture orientations and connectivity. All these data should be integrated to determine rock mass permeability or groutability.

(11) Rules of thumb are not good substitutes for using data and judgment in making decisions in grouting unless specifically developed for the site conditions.

(12) Hydraulic models are a tool that can be used to evaluate seepage potential and groutability but depend on realistic design and data input parameters. Water test-derived permeability and groutability are important parameters for hydraulic models. Water tests must be carefully evaluated to ensure that bad test data are not used in models.

Models large enough to approach characterizing a site are usually very large and expensive. The tendency is to build models that are small and economical and, therefore, have a limited connection with reality. Realistic parameters are difficult to obtain in quality or quantity. Few exploration programs provide a statistically significant sample size to fully characterize a site, especially tunnels. Model input parameters and design should be part of any modeling report so the output can be properly evaluated.

Procedure

Calculations

Permeabilities can be calculated in lugeons, feet per year (ft/yr), centimeters per second (cm/sec), or other units from the same basic field data. Lugeons are used in the following discussion because these units are commonly used in the grouting industry. Chapter 17 has a thorough discussion of testing and calculating in other permeability units. One Lugeon equals:

(1) 1 liter per minute per meter (l/min/m) at a pressure of 10 bars

(2) 0.0107 cubic feet per minute (ft^3/min) at 142 pounds per inch (psi)

(3) 1 x 10^{-5} cm/sec

(4) 10 ft/yr

The formula for calculating Lugeons (lu) is:

$$\frac{\textbf{\textit{take}}}{\textbf{\textit{test}}} \times \frac{10 \ \textbf{\textit{bar}}}{\textbf{\textit{pressure}}\ (\textbf{\textit{bars}})} \qquad \frac{\textbf{\textit{take}}}{\textbf{\textit{test}}} \times \frac{155}{\textbf{\textit{pressure}}\ (\textbf{\textit{psi}})}$$

Take is in liters per meter per minute or cubic feet per foot per minute. One bar equals 14.5 psi. Takes should be measured after flows have stabilized and should be run for 5-10 minutes at each pressure step.

Geologic Data

The geologic data should be examined to determine the optimum drill hole orientations and locations. Geologic structure, such as bedding and rock type, can be used to set the initial maximum water test pressures. Easily jacked or hydrofractured rock should initially be water tested at a pressure of 0.5 psi per foot (2.2 kilogram per square centimeter per meter [$kg/cm^2/m$]) of overburden and increased pressures based on stepped pressure tests or jacking tests.

Stepped Pressure Tests

Stepped pressure tests are the best method of conducting water tests. Pressures are stepped up to the maximum pressure and then stepped down through the original pressures. Comparison of the calculated permeability values and the pressure versus flow curves for the steps can provide clues as to whether the flow is laminar, if jacking or hydrofracturing is occurring, and if fractures are being washed out or plugged. Single pressure tests can be misleading because of all the unknown pressure and flow variables affecting the test. The Lugeon value for the test interval should be determined by analysis of the individual test values and not necessarily by an average. The individual tests are used to determine what is happening in the rock, and one value of the five tests is usually the appropriate value to use.

Figures 16-1 through 16-5 are bar chart plots showing the relationship of pressure to Lugeon values for the

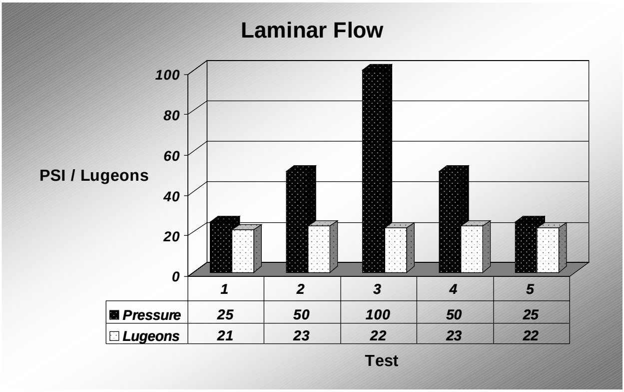

Figure 16-1.—Bar chart showing relationship of test pressure and Lugeons in laminar flow.

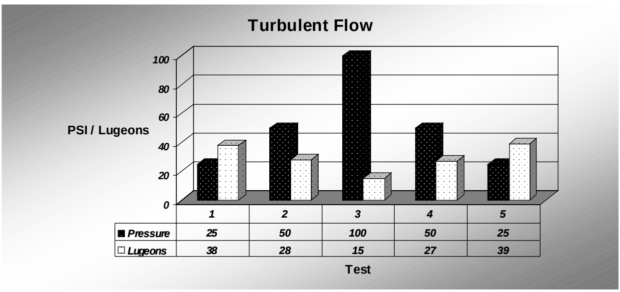

Figure 16-2.—Bar chart showing relationship of test pressure and Lugeons in turbulent flow.

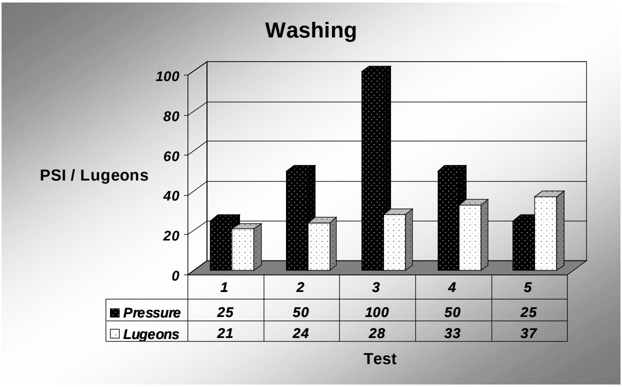

Figure 16-3.—Bar chart showing relationship of test pressure and Lugeons when fractures are washing out.

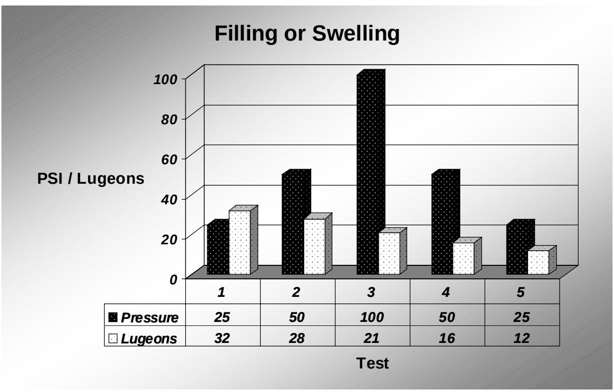

Figure 16-4.—Bar chart showing relationship of test pressure and Lugeons when fractures are filling or swelling.

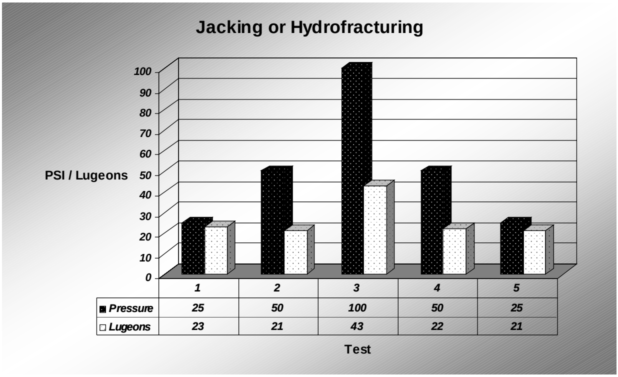

Figure 16-5.—Bar chart showing relationship of test pressure and Lugeons when rock is hydrofractured or joints are jacked open.

more common types of water test results. Figure 16-1 is a plot of laminar flow in the fractures. The permeability is essentially the same no matter what the pressure and resultant water take. Figure 16-2 is a plot of turbulent flow in the fractures. Permeability decreases as the pressure and resultant flow increases because of the turbulent flow in the fractures. Figure 16-3 is a plot of flow in fractures that increase in size as the water washes material out of the openings. Permeability increases because fractures are enlarged by the test. Figure 16-4 is a plot of flow in fractures that are being filled and partially blocked as water flows or the fractures are in swelling rock that closes fractures over time because of the introduction of water by the test. Figure 16-5 is a plot of testing in rock that is being jacked along existing fractures or rock that is being fractured by the highest water test pressure. Flow is laminar at the lower pressures.

Combinations of these types of flow can occur and require careful analysis. If the pressures are increased to where jacking or hydrofracturing is occurring, the design grout pressures can be set as high as possible to get effective grout injection yet preclude fracturing or, if appropriate, induce fracturing. Hydrofracture tests are easier to analyze if a continuous pressure and flow recording is obtained. The resolution of a step test may not be adequate to separate hydrofracturing from jacking. Figure 6 is a plot of a continuously recorded hydrofracture/jacking test.

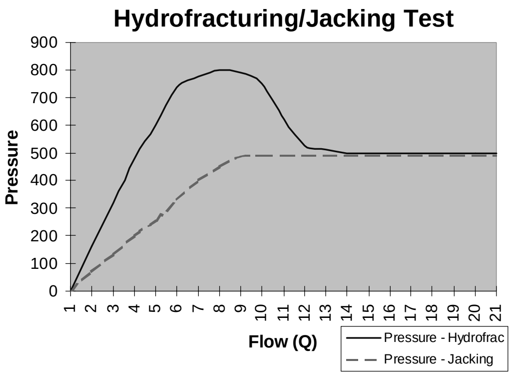

Figure 16-6.—Continuously recorded plot of pressure and flow.

Back Pressures

Back pressures should be measured after every test to determine if the hole holds pressure and if fracturing or jacking has occurred. If the hole holds pressure and backflow occurs while releasing the pressure, hydrofracturing or jacking may have occurred at the test pressure.

Test Equipment

Test equipment can affect the test results. At moderate to high flows, the friction loss caused by the piping and the packer should be considered. Significant loss of pressure occurs between the gauge and the packer. At high flows, the plumbing system "permeability" can be the controlling factor and not the permeability of the test interval. If meters and gauges are located in optimum relation to each other and close to the hole, the arrangement of pipe, hose, etc., will not seriously influence shallow tests although sharp bends in hose, 90-degree fittings on pipes, and unnecessary changes in pipe and hose diameters should be avoided. Laying the system out on the ground and pumping water through the plumbing to determine the capacity of the system is a good idea, especially if using small-diameter piping or wireline packers.

Water Takes Relative to Grout Takes

Water takes alone may be an indication of whether grouting is necessary, and Lugeon calculations may not be necessary after enough water tests with subsequent grouting provide sufficient data to determine a correlation. This shortcut is usually used during the actual grouting because not enough data are available from exploration unless a test grout section is constructed. The correlation can change if the geologic domain in a foundation changes, so any correlation must be continuously checked.

Depth of Grouting

Grouting depth for dam foundations is commonly determined by a rule of thumb related to dam height. A better method is to base the depth on water test data and geologic data. Weathered rock and fracture surfaces are an indication of permeable rock. Grouting to tight, unweathered rock, where practical, makes more sense than trying to grout tight, impermeable rock or not grouting pervious rock because of a rule-of-thumb approach.

Grouting in tunnels should be based on the thickness of the disturbed zone around the periphery of the tunnel and the depth necessary to get the desired results when grouting natural fractures. A machine-bored tunnel will have a much shallower disturbed zone than a conventionally excavated (drill-blast) tunnel and may require less or no grouting.

Bibliography

Ewart, Friedrich-Karl, *Rock Permeability and Groutability Related to Dams and Reservoirs*, lecture notes, University of Paderborn, Germany, September 1994.

Water Resources Commission N.S.W., *Grouting Manual*, 3rd edition, Australia, 1980.