

PARTICULAR SPECIFICATION
APPENDIX BJ
FISSURE ROCK GROUTING SPECIFICATIONS

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1 GENERAL

- 1.1** Fissure Rock Grouting is the injection of grout into rock to reduce the permeability of the rock. This specification is limited to those grades of weathered rock which derive their permeability primarily from fissure, and not pore, flow, i.e. weathering grades I, II, III, as defined in **Chapter 5** of the Civil Design Criteria. The specification is also applicable to grade IV weathered rock only where the permeability of the grade IV rock is derived primarily from fissure flow;
- 1.2** This Specification is for grouting in advance of tunnelling or excavation. It does not apply to grouting carried out to seal exposed rock surfaces.

2 STANDARDS

- 2.1** Fissure rock grouting shall be carried out in accordance with BS EN 12715. Where there is any conflict between the requirements in this Clause and BS EN 12715, this Specification shall govern.

3 SITE INVESTIGATION

- 3.1** Information from the current site investigations conducted by the Authority will be provided upon award of Contract and will form part of the Contract documentation;
- 3.2** Prior to the start of fissure grouting, boreholes shall be completed to identify:
- a) The number and orientation of the joint sets in the rock;
 - b) The general range of aperture size of the joints;
 - c) The nature of the rock joints, including roughness and infilling;
 - d) The range of permeability of the rock, and how this varies with depth, weathering grade etc.;
 - e) The pressure and temperature of the groundwater at the range of depth to be grouted; and
 - f) The chemistry of the groundwater, in relation to any adverse effect that this may have on the setting, strength, permeability or durability of the grout.

- 3.3** Prior to the start of grouting, the Contractor shall carry out sufficient multi-stage Lugeon packer tests (Houlsby, 1976) to identify the appropriate limiting pressures for the range of depths and ground conditions to be grouted. The holes for the multistage Lugeon tests shall be cored, and the cores logged to assess fracture frequency, weathering grade, TCR and RQD.

4 GROUT MATERIAL AND MIXES

- 4.1** Fissure rock grouting shall be carried out by the injection of stable micro-fine cement (MFC) grout, except under the following conditions:
- a) Ordinary Portland Cement (OPC) based grouts may be used for the sealing of disturbed ground (e.g. at the toes of piles), cavities or major conductive features, such as faults, as a pre-treatment in advance of the injection of micro-fine cement grout;
 - b) Ultra-fine cement, colloidal silica or other grout(s) that are finer than micro-fine grout shall be used as a substitute for, or to supplement, the micro-fine grout where the use of these grouts is necessary to achieve the specified post-grouting hydraulic conductivity; and
 - c) When other grout types are accepted by the Engineer.
- 4.2** Additives for the micro-fine grout shall have a value of grain size distribution D_{95} of less than 0.02mm and shall not have a deleterious effect on the effectiveness or durability of the grout;
- 4.3** All grout materials shall be stored in a manner such that they are protected from any adverse effects due to the climate, such as heat, humidity and rainfall;
- 4.4** Grout mixes, and all components of grout mixes, shall be non-toxic;
- 4.5** Mixing water for grouts shall be clean and potable;
- 4.6** The proposed grout mixes shall have sufficient durability to ensure that they remain effective for the intended purpose and duration;
- 4.7** Grouts shall remain fluid, and with limited increase in viscosity, for the duration of injection, except when the grouting is into rock that is subject to ground water flow. Rapid setting grouts may be used to provide an initial seal in rock that is subject to groundwater flow at the time of grouting.

5 DRILLING

- 5.1** All holes drilled for the grouting of rock shall be drilled using water flushing. Compressed air, or a mixture of water and compressed air, shall not be used for flushing during the drilling;
- 5.2** Drill holes for grouting shall be installed within an accuracy of $\pm 1\text{m}$, relative to the design location, at any point along their length. To verify the accuracy of the drilling, the Contractor shall measure the actual location of the drill holes on the following basis:
- a) Every drill hole for the grouting trial;
 - b) The first 20 drill holes for the production grouting; 20 additional holes shall be measured in the event that either the length of drilling increases by more than 3m from the length of hole measured previously, the method of drilling (drill rod size, bit size or type of stabilizer) is changed or more than one hole in twenty that has been measured does not meet the required accuracy;
 - c) Not less than 1 hole in twenty thereafter.
- 5.3** In the event that more than one drill hole in every twenty that are measured does not meet the required accuracy, the Contractor shall propose a change in the length and/or method of drilling and demonstrate that the required accuracy can be achieved.
- 5.4** After drilling, the holes shall be flushed to clear residual drill cuttings, before any water testing and/or grouting.

6 MIXING

- 6.1** MFC grouts shall be mixed using a high speed colloidal mixer with an impeller speed of not less than 1,700rpm.
- 6.2** OPC grouts shall be mixed using a colloidal mixer with an impeller speed of not less than 1,500rpm.
- 6.3** Mixing and holding equipment including grout lines that have been used for OPC grout shall not be used for MFC grout.
- 6.4** Mixers, holding tanks and associated hoses and equipment shall be cleaned regularly, which shall be at least daily during active use or after each grouting shift.

- 6.5** The holding time for mixed grout shall be kept to a minimum. The Contractor shall propose the maximum holding time. The maximum holding time proposed shall be justified by demonstrating, through testing, that the grout has adequate flow properties at the maximum holding time plus the maximum planned grouting time. Any batch of grout that exceeds the maximum holding time shall not be used in the works but shall be disposed of. The grouts shall be constantly agitated during holding.

7 INJECTION

- 7.1** All holes that are drilled for grouting or testing (before, during or after grouting) shall, when all grouting/testing stages are complete, be backfilled with a stable cement grout over the full length of the hole;
- 7.2** Generally, grout holes shall be injected in stages of not more than 5m in length, with the top of the stage being sealed by a packer.
- 7.3** Drill holes in rock shall generally be grouted in upward stages. However, if the holes are found to be unstable, or cavities are encountered, the contractor shall use downward stages or multiple packer sleeved pipe (MPSP), as appropriate. Tubes-a-machetes shall not be used for grouting in fissured rock, except where accepted in writing by the Engineer;
- 7.4** Where drill holes are used for pre-treatment using OPC grout, generally that hole shall not be also used for the subsequent injection of micro-fine (or finer) grouts; a new hole shall be drilled for the injection of the micro-fine grout. However, where OPC grout is to be used for toe grouting at the base of piles or diaphragm walls, the same hole can be used, initially for the toe grouting, and then extended into the rock for MFC grouting;
- 7.5** The Contractor shall propose the limiting pressure and volume, and range of acceptable injection rates, for each stage of grouting. The proposed maximum injection shall be based on the preliminary multi-stage Lugeon testing and the grouting trial and shall be the maximum pressure that can be applied while avoiding excessive opening of the fissures in the rock and excessive loss of grout from the intended grouted zone;
- 7.6** Where holes are collared below the level of the ground water table, the Contractor shall propose method(s) to rapidly seal the hole in the event of loss of ground or fines, or an unacceptable inflow of ground water;

- 7.7** The pressure, volume, rate of injection and duration of every stage of injection of grout, and of water (for water testing), shall be recorded on an automatic data logger. The data shall be exportable to excel and retained on site for the duration of the grouting. The Contractor shall provide the data, in excel and in graphical form, for the injection of any stage that is requested by the Engineer, within 24 hours of the request;
- 7.8** Split spacing injection sequences shall be used wherever practical, unless otherwise accepted by the Engineer;
- 7.9** The Contractor shall provide to the Engineer a daily record that shall include, as a minimum:
- a) The numbers of the holes that have been drilled, with the depth;
 - b) The stages grouted;
 - c) The type of grout, volume, final pressure and hold time for each stage injected;
 - d) Results from tests carried out on the grout(s) used;
 - e) Comments or observations on issues affecting the grouting, such as leakage of grout to the surface, plant breakdowns, etc.

8 PROVING TESTS FOR GROUT MIXES

- 8.1** Prior to any grouting the contractor shall carry out proving tests on each grout mix proposed, to demonstrate that the grout mix is suitable for use. Each grout mix for testing shall be mixed using the proposed mixer for that grout, in similar conditions to what will be applicable at site;
- 8.2** The minimum suites of proving tests to be carried out for MFC and OPC grouts are provided in Table 1. The Contractor may propose alternative test methods, or additional tests, to the acceptance of the Engineer, if it can be justified that the alternative /additional testing provides similar or better information on the quality and effectiveness of the grout;

Table 1 Proving tests for proposed OPC and MFC-based grout mixes

Test for:	Test
Penetrability	Filter pump with range of filter sizes
Bleed	Cylinder test

Setting time	Cup test
Viscosity (at intervals between mixing and setting)	Rheometer or stick tests
Strength of set grout	Cylinder test
Workability (at intervals between mixing and setting)	Fall cone
Cone viscosity	Marsh Cone
Density	Mud Balance
28-day strength	Uniaxial compression or cylinder test
Yield Strength	Rheometer

- 8.3** The temperature of the grout shall be measured at the time of any test;
- 8.4** For grouts other than OPC and MFC based grouts, the Contractor shall propose a suite of proving tests. The tests shall be selected to assess the effectiveness of the grout to achieve the required grouting performance in the conditions applicable at the site;
- 8.5** MFC and OPC grouts shall be stable (<5% bleed over 2 hours). Generally, the grouts shall have a low viscosity (<40 seconds for the marsh cone) throughout the injection period; however, the Contractor may propose to use more viscous or rapid setting grouts in special circumstances, such as when grouting to provide an initial seal in flowing water;
- 8.6** A report on the proving tests for grout shall be submitted to the Engineer for acceptance. The report shall include recommendations on the selection of the grout mixes for the field grouting and the basis on which those mixes were selected;

9 FIELD GROUTING TRIAL(S)

- 9.1** Prior to carrying out production grouting, the Contractor shall carry out field grouting trial(s) to demonstrate that the methods and materials proposed for the production grouting will meet the specified performance requirements for the grouting and the requirements in these specifications;

- 9.2** The number of trials to be carried out will depend on the number of rock formations to be grouted within the Contract boundaries, and the methods of grouting proposed. At least one grouting trial shall be carried out for each rock formation (as defined in the 'Geology of Singapore') to be grouted. The results of any trial shall only be applicable to grouting in the same rock formation and using the same or similar grout mixes and methods;
- 9.3** Each grouting trial shall be carried out at similar depths and in similar ground conditions to the planned production grouting. The location for the trial shall be agreed with the Engineer;
- 9.4** Each trial shall be designed so that the grout mixes, drilling and grouting plant, grouting sequence and volume and pressure criteria shall be as proposed for the production grouting;
- 9.5** The layout of the grout holes for the trial shall be proposed by the Contractor for acceptance by the Engineer, and shall, where possible, be based on the general layout proposed for the production grouting. The trial shall involve the drilling and injection of a minimum of 10 grout holes;
- 9.6** Lugeon testing shall be carried out for every grouting stage on every grout hole in the trial. Each grout hole shall be grouted immediately after the completion of the Lugeon testing on that hole. On completion of the grouting, at least two additional holes shall be drilled within the grouted mass, and Lugeon tests carried out to assess the change in Lugeon value resulting from the grouting. After the Lugeon testing the additional holes shall be sealed by grouting;
- 9.7** 'Water outflow tests' are tests where the rate of flow out of the drill hole is measured at intervals;
- 9.8** Pumping test(s) shall be specified, as part of the design, to justify the effectiveness of the grouting for the trial. The pumping test shall include a pumped well and a minimum of three piezometers to measure the effect of the pumping;
- 9.9** After completion of the grouting trial, the Contractor shall submit a report on the trial to the Engineer for acceptance. The report shall, inter alia, include:
- a) A summary of the grouting done, including the sequence of grouting and testing, and the volumes and pressures used for grouting

- b) A summary of the results of the testing carried out, including the tests on the grout mixes and the Lugeon and pumping tests carried out
- c) Recommendations on any changes proposed for the grouting, based on the results of the trial
- d) Conclusions as to whether the specified performance of the grouting will be met using the proposed method statement for the grouting

9.10 If the Contractor cannot demonstrate that the specified post-treatment hydraulic conductivity can be achieved using the methods and grout mixes used in the trial, the Engineer may reject the trial and require the Contractor to undertake a further trial.

10 QUALITY CONTROL TESTING DURING GROUTING

10.1 The quality control testing for the grouting shall include:

- a) Routine quality control testing on the mixed grout
- b) Additional quality control testing
- c) Lugeon testing, or (for tunnelling) water inflow tests
- d) When specified by the designer, pumping test(s)

10.2 Routine quality control testing for the mixed grout shall be carried out on samples obtained from the holding tank or grout lines. The minimum types of testing for MFC and OPC grouts are provided in [Table 2](#). The Contractor may propose alternative test methods, or additional tests, to the acceptance of the Engineer, if it can be justified that the alternative /additional testing provides similar or better information on the quality and effectiveness of the grout. A full suite of routine quality control tests shall be carried out at least twice per day for each grout mixer that is used for mixing grout on that day;

Table 2 Routine quality control tests for proposed OPC and MFC based grout mixes

Test for:	Test
Penetrability	Filter pump; a single filter size can be proposed for this test

Cone viscosity	Marsh Cone
Density	Mud Balance
Grout shear strength	Yield stick tests

- 10.3** Additional quality control tests shall be carried out when there is a new delivery of cement or micro-fine cement, or when the supplier is changed. The additional quality control tests shall consist of a full suite of the proving tests listed in Table 1;
- 10.4** The temperature of the grout shall be measured at the time of any routine or additional quality control test;
- 10.5** For grouts other than OPC and MFC based grouts, the Contractor shall propose a suite of routine and additional quality control tests. The tests shall be selected to check the effectiveness of the grout to achieve the required grouting performance in the conditions applicable at the site;
- 10.6** Prior to the commencement of production grouting, the Contractor shall propose acceptable ranges of results for each of the types of routine and additional quality control test, using the results of the proving tests on the proposed grouts as a basis for determining the acceptable range. A reasonable margin can be applied to the results of the proving tests to allow for the variation in materials and site conditions, if grout within the acceptable range is suitable to achieve the specified results for the grouting. If a test result falls outside of the acceptable range the related grouting shall be considered unacceptable, and the Contractor shall propose remedial works to the acceptance of the Engineer;
- 10.7** Sufficient Lugeon testing (or, for holes drilled from tunnels, water outflow tests) shall be carried out to verify the pre- and post-grouting permeability of the rock. The number of Lugeon or outflow tests shall be:
- As specified in the Drawings or in the Particular Specification;
 - If not defined in the Drawings or in the Particular Specification, the default requirement shall be not less than one pre-grouting and one post-grouting test hole for every 10 grout holes.
 - Pre-grouting testing can be carried out in one of the holes to be used for grouting, provided that no previous grouting has been carried out nearby;

- 10.8** Pumping test(s) shall be carried out on the completion of the grouting when specified in the Drawings or in the Particular Specification.

11 PUMPING TEST REQUIREMENTS

- 11.1** Minimum 2 numbers of pumping test(s) at the Loyang Station shall be carried out on the completion of the curtain/fissure grouting to verify the permeability requirement of the grouts. Observation wells and piezometers (at least 3 nos. of observation wells and piezometers each for each pumping test) shall be installed both inside and outside of the excavation area for the monitoring of the groundwater levels and pore water pressure in the ground during the pumping tests. Piezometers shall be installed to the formation level. The Contractor is required to submit in advance the method statement for carrying out of the pumping tests to the Engineer and QP(S) for approval.
- 11.2** The pumping tests shall demonstrate that the cut-off is effective and the drawdown outside the retaining walls is limited to less than 1m, when the groundwater has been lowered to a depth of 1m below the base of excavation. If drawdown outside exceeds these limits, the effectiveness of fissure grouting shall be reviewed to seal the leakage/inflow.
- 11.3** The excavation of station and entrances shall commence only after the pumping tests are satisfactorily completed to the acceptance of the Engineer and QP(S).
- 11.4** For the cases of partial installation of retaining wall and fissure grouting, excavation works shall not commence without conducting the pumping tests. For the partially completed retaining wall/fissure grouting systems, fissure grouting cut-off wall shall be installed to form a closed cut-off system for the proposed area with partial fissure grouting system.
- 11.5** The cost for all Works required in order to carry out the pumping tests such as piezometers, observation wells, dewatering, submersible pumps, level switch, monitoring, etc., shall be deemed to have been included in the Contract Price. A method statement and drawings showing the proposed pumping tests shall be included in the Tender Submission.
- 11.6** A detailed report shall be submitted upon completion of the pumping tests. Excavation can only commence when the results from the pumping tests are deemed acceptable by the Engineer and QP(S).

12 SUBMITTALS

- 12.1** Prior to carrying out rock fissure grouting, including the fissure grouting trial, the contractor shall submit method statement(s) that include:
- a) The procedures for the drilling and grouting, including mixes, mixing procedures, grouting sequences, the materials, packers and plant to be used, and the limiting criteria (pressure, volume, hold time) for each hole;
 - b) The results of the required multi-stage Lugeon tests, with an interpretation that provides the basis for the maximum injection pressures proposed;
 - c) The report on the proving tests for the proposed grout mixes;
 - d) The proposed quality control testing for the grout(s), including the frequency of testing, the procedure for testing, and acceptance criteria for each test to be carried out;
 - e) The drilling, grouting and test procedures for the grouting trial(s);
 - f) Procedures for Lugeon and pumping tests;
 - g) Procedure for control and cleaning of grouting equipment.
- 12.2** After the grouting trial, it may be necessary to resubmit the submissions on the procedures for drilling and grouting, quality control testing etc., if changes are to be made as a result of the trial.
- 12.3** The method statement for the grouting shall provide a general framework for the work on site but shall be written so as to provide sufficient flexibility for the number and sequence of holes, materials and methods to be varied in response to observations during the drilling and grouting.
- 12.4** At the completion of an area of grouting, the contractor shall submit record drawings that provide a summary of the volume of each type of grout and final injection pressure for every hole injected, and the results of Lugeon and pumping tests. The record drawings shall be produced so that the results for numerous adjacent holes can be viewed on a single drawing. The detailed format for the record drawings shall be agreed with the Engineer.

- 12.5** The requirements for safety and risk management are specified elsewhere in the documents. A risk that has been associated with grouting is the sudden expulsion of grout pipes/packers from the hole during grouting, due to the force exerted by the grouting pressure exceeding the resistance provided by the packer. If this occurs, there is a high risk of injury, particularly when working in a confined space such as a tunnel. The Contractor shall include this risk in the risk assessment for the grouting and develop appropriate mitigation measures.