BRITISH STANDARD

BS EN 12715:2000

Execution of special geotechnical work — Grouting

The European Standard EN 12715:2000 has the status of a British Standard

ICS 93.020

National foreword

This British Standard is the official English language version of EN 12715:2000.

The UK participation in its preparation was entrusted by Technical Committee B/526, Geotechnics, to Subcommittee B/526/4, Strengthened reinforced soils and other fills, which has the responsibility to:

— aid enquirers to understand the text;

— present to the responsible European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;

— monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this subcommittee can be obtained on request to its secretary.

Cross-references

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Exécution des travaux géotechniques spéciaux – Injection

Ausführung von besonderen geotechnischen Arbeiten (Spezialtiefbau) – Injektionen

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EUROPEAN COMMITTEE FOR STANDARDIZATION
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Contents

Foreword

This European Standard has been prepared by Technical Committee CEN/TC 188, Execution of special geotechnical works, the Secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by January 2001, and conflicting national standards shall be withdrawn at the latest by January 2001.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

This standard has been prepared by the Working Group (WG 6) of the CEN/TC 288. The general remit of TC/288 is the standardization of the execution procedures for geotechnical works (including testing and control methods) and of the required material properties. WG 6 has been charged with the subject area of grouting, including compaction grouting.

The document has been prepared to stand alongside ENV 1997-1: EUROCODE 7: Geotechnics, Geotechnical Design, General Rules. This standard expands on design only where necessary, but provides full coverage of the construction and supervision requirements.

It has been drafted by a working group comprising delegates from 9 countries and against a background of more than ten pre-existing grouting standards and codes of practice, both national and international. In view of the different construction methods used internationally and the respective experience, it may be necessary to supplement this standard, or parts of it, by National Application Documents to cater for specific or local situations.

The annexes A, B and C are informative.

1 Scope

This standard is applicable to the execution, testing and monitoring of geotechnical grouting work. Specific aspects concerning design are provided since ENV 1997-4 has been abandoned.

Grouting for geotechnical purposes (geotechnical grouting) is a process in which the remote placement of a pumpable material in the ground is indirectly controlled by adjusting its rheological characteristics and by the manipulation of the placement parameters (pressure, volume and the flow rate).

The following principles and methods of geotechnical grouting are covered by this standard:

— displacement grouting (compaction grouting, hydraulic fracturing);

— grouting without displacement of the host material (permeation, fissure grouting, bulk filling).

Specialized grouting activities, generally associated with structural and/or emergency works, are not covered by this standard.

2 Normative references

This European Standard incorporates, by dated or undated reference, provisions from other publications. These normative references are cited in the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.

EN 196-1, *Methods of testing cement – Part 1: Determination of strength.*

EN 196-2, *Methods of testing cement – Part 2: Chemical analysis of cement.*

EN 196-3, *Methods of testing cement – Part 3: Determination of setting time and soundness.*

ENV 196-4, *Methods of testing cement – Part 4: Quantitative determination of constituents.*

EN 196-5, *Methods of testing cement – Part 5: Pozzdanicity test for pozzolanic cement.*

prEN 196-8:1997, *Methods of testing cement – Part 8: Determination of heat of hydration.*

prEN 196-9:1997, *Methods of testing cement – Part 9: Determination of heat of hydration – Semi-adiabatic method.*

prEN 197-1:2000, *Cement – Part 1: Composition, specifications and conformity criteria for common cements.*

prEN 197-2:2000, *Cement – Part 2: Conformity evaluation*.

ENV 451, *Methods of testing fly ash*.

EN 480-1, *Admixtures for concrete, mortar and grout – Test methods – Part 1: Reference concrete and reference mortar for testing*.

EN 480-2, *Admixtures for concrete, mortar and grout – Test methods – Part 2: Determination of setting time*.

prEN 480-3:1991, *Admixtures for concrete, mortar and grout – Test methods – Part 3: Determination of shrinkage and expansion*.

EN 480-4, *Admixtures for concrete, mortar and grout – Test methods – Part 4: Determination of bleeding of concrete*.

EN 480-5, *Admixtures for concrete, mortar and grout – Test methods – Part 5: Determination of capillary absorption*.

EN 480-6, *Admixtures for concrete, mortar and grout – Test methods – Part 6: Infrared analysis*.

prEN 480-7:1991, *Admixtures for concrete, mortar and grout – Test methods – Part 7: Determination of the density of liquid admixtures*.

EN 480-8, *Admixtures for concrete, mortar and grout – Test methods – Part 8: Determination of the conventional dry material content*.

prEN 480-9:1991, *Admixtures for concrete, mortar and grout – Test methods – Part 9: Determination of the pH value*.

EN 480-10, *Admixtures for concrete, mortar and grout – Test methods – Part 10: Determination of water soluble chloride content*.

EN 480-11, *Admixtures for concrete, mortar and grout – Test methods – Part 11: Determination of air void characteristics in hardened concrete*.

EN 480-12, *Admixtures for concrete, mortar and grout – Test methods – Part 12: Determination of the alkali content of admixtures*.

prEN 934-1:1998, *Admixtures for concrete, mortar and grout – General definitions and general requirements for all types of admixtures*.

prEN 934-3:1998, *Admixtures for concrete, mortar and grout – Part 3: Admixtures for masonry mortar – Definitions, requirements and conformity.*

EN 934-4, *Admixtures for concrete, mortar and grout – Part 4: Admixtures for grout for prestressing tendons – Definitions, requirements and conformity.*

EN 934-6, *Admixtures for concrete, mortar and grout – Part 6: Sampling, quality control, evaluation of conformity and marking and labelling*.

ENV 1997-1:1994, *EUROCODE 7: Geotechnical design – Part 1: General rules.*

3 Definitions and symbols

3.1 Definitions

The definitions given in this chapter cover only the most important terms involved in geotechnical grouting. Further definitions are given in the glossary in annex B.

3.1.1 — **fr: injection de comblement**
bulk filling — **de: Hohlraumverfüllung**
bulk filling is the placement of grout with a high particulate content to fill substantial voids

3.1.2 — **fr: injection solide**
compaction grouting — **de: Verdichtungsinjektion (Kompaktionsinjektion)**
displacement grouting method which aims at forcing a mortar of high internal friction into the soil to compact it without fracturing it

3.1.3 — **fr: injection de contact**
contact grouting — **de: Kontaktinjektion**
injection of grout into the interface between man-made structures and the ground

3.1.4 **fr: injection avec déplacement des terrains**
displacement grouting **de: Verdrängungsinjektion**
injection of grout into a host medium in such a manner as to deform, compress, or displace the ground

3.1.5 **fr: pression effective**
effective pressure **de: wirksamer Druck**
actual grout pressure acting in the ground

3.1.6 **fr: injection de fissure**
fissure grouting **de: Kluftinjektion**
injection of grout into fissures, joints, fractures and discontinuities, particularly in rock

3.1.7 **fr: injection gravitaire**
gravity grouting **de: drucklose Verfüllung**
grouting under no applied pressure other than the height of grout fluid. Sometimes referred to as tremie grouting

3.1.8 **fr: coulis**
grout **de: Injektionsgut**
pumpable material (suspension, solution, emulsion or mortar), injected into soil or rock, which stiffens and sets with time

3.1.9 **fr: pression d'injection**
grouting pressure **de: Injektionsdruck**
pressure applied during the grouting process and measured at defined locations (usually at the pump or the borehole collar)

3.1.10 **fr: fracturation hydraulique (injection de claquage)**
hydraulic fracturing (hydraulic fracture, claquage grouting) **de: Hydraulische Rissbildung (Claquage)**
fracturing of a ground initiated by the injection of water or grout under a pressure in excess of the local tensile strength and confining pressure; also called hydrofracturing, hydrosplitting, hydrojacking or claquage

3.1.11 **fr: injection de pénétration**
penetration grouting **de: Eindringinjektion**
grout injection of joints or fractures in rock, or pore spaces in soil, without displacing the ground. The term includes permeation (impregnation), fissure and contact grouting

3.1.12 **fr: injection d'imprégnation**
permeation (impregnation) grouting **de: Poreninjektion (Imprägntion durch Porenverfüllung)**
replacement of interstitial water or gas of a porous medium with a grout at injection pressures low enough to prevent displacement

3.1.13 **fr: injection sans déplacement des terrains**
non-displacement grouting **de: Verdrängungsfreie Injektion (Injektion ohne Baugrundverdrängung)**
substitution of the natural interstitial fluid in the accessible existing voids of the ground by a grout or mortar without any significant displacement of the ground. The term includes penetration grouting and bulk filling

3.1.14 **fr: suspension stable**
stable suspension **de: stabile Suspension**
stable suspensions exhibit in 2 hours less than 5 per cent bleeding of clear water at the top of a 1 000 ml cylinder with an internal diameter of 60 mm at a temperature of 20 °C

3.2 Symbols and units

The following symbols and units are used in this standard.

Symbols	Denomination	Unit
T	Temperature	[°C]
V	Volume injected	[m³]
P	Injection pressure	[Pa]
Q	Injection or flow rate	[m³/s] or [l/s]
k	Intrinsic (absolute) permeability[1)]	[m²]
K	Coefficient of hydraulic conductivity	[m/s]
i	Hydraulic gradient	[dimensionless]
d_{10}, d_{15} D_{85}, D_{90}	Largest particle size of the smallest 10, 15 % of grout Largest grain size of the smallest 85, 90 % of the medium	[mm]
t	Setting time	[s]
σ_c τ_f	Compressive strength Shear strength	[Pa]
σ τ	Normal stress Shear stress	[Pa]
ε	Strain	[dimensionless]
$\dot{\gamma}$	Shear rate	[s^{-1}]
μ_{app} η ν	Viscosity (apparent) (dynamic) (kinematic)	[Pa·s], [kg/m·s] [Pa·s] [m²/s]
c	Cohesion	[Pa]
τ_o	Yield shear stress	[Pa]
ρ	Density	[kg/m³]
γ	Specific or unit weight	[kN/m³]
t_M	Outflow time (Marsh)	[s]
R	Action radius	[m]

1 Pa = 1 N/m² = 10^{-5} bar

1) It is common practice in geotechnical engineering to use *k* for hydraulic conductivity. Nevertheless, this refers to the parameters generally used in rock and fluid mechanics.

4 Information needed

4.1 All information relevant to the execution of the grouting works should be provided with the work specifications.

4.2 The following technical information shall be available on site before the commencement of the works:

- site conditions and limitations, e.g. size, gradients, access;
- working restrictions, including any environmental, legal or statutory restrictions;
- any underground contamination or hazard which could affect the method of execution or the safety of the working environment;
- design and specifications for the works.

4.3 The following technical information should be available on site before the commencement of the works:

— geological and geotechnical conditions (see chapter 5);

— the co-ordinate locations of the site with respect to the national grid;

— existence, location and conditions of any adjacent structures, e.g. buildings, roads, utilities or services, underground structures and their foundations;

— any concurrent or subsequent activities which could affect the works (e.g. groundwater extraction or recharge, tunnelling, other deep excavations);

— any previous experience with grouting or other underground works on or adjacent to the site, or relevant experience in the execution of comparable works under similar conditions;

— any information relevant for the production of drawings and method statements (where required);

— any additional requirements for the supervision, monitoring or testing of the works.

4.4 The following aspects shall be established before the commencement of the works and shall be available in written form on site:

— the requirement, and assignment, for any survey of the condition of adjacent structures, roads, services, etc. to be carried out prior to, during and after the works;

— specific procedures and criteria for the verification, control and acceptance of the grouting works;

— the clear division of tasks with respect to the design, execution, interpretation of results and approval of the works.

5 Site investigation

5.1 General

5.1.1 The general requirements for site investigation are contained in ENV 1997-1:1994, chapters 3 and 7 and the relevant national documents.

5.1.2 For design purposes, the site investigations should:

— provide a comprehensive geotechnical report;

— establish the ground susceptibility to grout;

— furnish a basis for selecting the grout types.

5.1.3 For the execution, the ground investigation report should contain the following specific information:

— the relevant physical and chemical characteristics of the ground;

— the ground level at investigation and testing locations relative to a recognized datum;

— the location, founding level and condition of existing or envisaged structures;

— the presence of any anisotropies or permeable horizons which could influence the grouting works;

— the orientation, frequency, and width of rock joints and the composition and nature of any infill material;

— the location and nature of filled or open cavities;

- the presence of obstructions that require special drilling and grouting methods or equipment;
- the presence and characteristics of ground that is likely to loosen, soften or become unstable, dissolve, collapse or swell as a result of drilling or grouting;
- the groundwater levels and gradients and their variation with time;
- strata with high groundwater velocities and permeabilities;
- the temperature, chemical composition, organic and bacteriological content of the groundwater or ground, if problems are expected.

5.1.4 The geological and geometrical model, and the void structure and its anticipated evolution should be described in the investigation report. The precision and limits of the model should be highlighted.

5.1.5 Where relevant, the following specific drilling information should be recorded:

- location and cause of core losses;
- unstable zones and stabilization measures taken;
- water level at the beginning and end of a run, zones of water loss and gain, measurements of return water, water colour and changes in colour;
- action of the drill rig (jerky, rough, smooth, steady motion);
- recording of drill parameters in the case of destructive boreholes;
- rate of advance.

5.1.6 Special care shall be taken when investigating for injections in high stress regions and in polluted ground:

- for injections in high stress regions, the in situ state of stress shall be investigated before designing a grouting project;
- for the injection of organic gels into polluted soils, a bacteriological investigation of the groundwater and ground shall be carried out.

5.1.7 Site investigation boreholes shall be suitably backfilled when no longer required.

5.2 Permeability testing

5.2.1 The hydraulic conductivity of the ground may be:

- determined from in situ permeability tests or large scale pumping tests;
- estimated from laboratory tests on samples of undisturbed soil or recompacted soil;
- estimated from the particle size distribution of the soil, and/or density of the ground.

5.2.2 Suitable correlations with actual field permeabilities should be established.

5.2.3 Each site investigation hole in rock should be tested to determine the water take and to identify the water bearing or open zones in the hole. The hole should be either tested as it is drilled or tested by the use of packers after drilling is completed.

5.2.4 Special care shall be taken to isolate artesian zones before testing.

5.2.5 Lugeon tests are used in rock to obtain a general impression of the transmissivity of the ground. They do not necessarily provide a reliable correlation with the absorption of a specific grout.

5.3 Field grouting trials and grouting tests

5.3.1 Field grouting trials are executed in order to define or validate a grouting method. Field grouting trials should be considered as part of the initial site investigation. They should be conducted during the final design phase, or the first part of the construction phase if they did not form part of the site investigation. They should be executed where initial investigations and local or comparable experience is insufficient to support or justify the effectiveness of the grouting project. The trials should provide information on borehole spacing, grouting pressure and grout take and type.

5.3.2 Grouting trials shall be planned and executed in close collaboration with the designer of the final grouting program.

5.3.3 The limit criteria for the properties of the proposed grout should be established on the basis of experience gained during the trial grouting.

5.3.4 Detailed records shall be kept of each operation performed during the grouting trials.

5.3.5 An indication of in situ conditions may be obtained by permeating reconstituted soil samples with trial grouts, under laboratory conditions. Permeability measurements made before and after grouting the sample may provide indicative information which will facilitate decisions on the frequency of injection points, the desired properties of the grout mix, and the required grout volume.

6 Materials and products

6.1 General

6.1.1 All grout components and grouts shall comply with the specifications for the works and the relevant EN or national standards.

6.1.2 The compatibility of all grout constituents shall be evaluated. Similarly, an assessment shall be made of the possible interaction between the grout and the ground.

6.1.3 Once established, the sources of grout materials shall not be changed without prior compliance verification or testing.

6.1.4 Materials that do not meet agreed quality standards shall promptly be removed from the site.

6.2 Grout materials

6.2.1 Hydraulic binders and cements

6.2.1.1 Hydraulic binders include all cements and similar products used in water suspension for making grouts.

6.2.1.2 Microfine (ultra-fine) hydraulic binders or cements are characterized by a particle size d_{95} of less than 20 μm.

6.2.1.3 The granulometric curve, especially of the microfine products used, shall be known.

6.2.1.4 When selecting the type of hydraulic binder for grout, its grain size distribution should be considered in relation to the dimensions of the fissures or voids of the ground to be treated.

6.2.1.5 Cements are subject to prEN 197-1:2000 and prEN 197-2:2000. Methods for testing of cements are subject to EN 196. Properties and methods different from those mentioned in those standards and specific to grouting are subject of this standard.

6.2.2 Clay materials

6.2.2.1 Natural clays, activated or modified bentonites can be added to cement based grouts in order to reduce bleeding and filtration under pressure, to vary the viscosity and cohesion (yield) of the grout, or to improve the pumpability of the grout.

6.2.2.2 The mineralogy, particle size, water content, and Atterberg liquid limit of the clay should be known.

6.2.3 Sands, gravels and fillers

6.2.3.1 Sand and fillers are commonly used in cement grouts or clay suspensions as bulking agents or as a means of varying the consistency of the grout, its resistance to wash-out, or its mechanical strength and deformability.

6.2.3.2 Natural sands or gravels may be added to grouts, provided that they do not contain any harmful components.

6.2.3.3 The granulometry of sands and fillers used in grouts shall be known.

6.2.4 Water

6.2.4.1 Water obtained from natural sources on-site should be tested (particularly for chlorides, sulphates and organic matter) and approved.

6.2.4.2 Sea water can be used provided that the properties of the grout mix are not impaired.

6.2.5 Chemical products and admixtures

6.2.5.1 Chemical products such as silicates and their reagents, lignin based materials, acrylic or epoxy resins, polyurethanes or others can be used in grouting work subject to compliance with environmental legislation.

6.2.5.2 The effects of all products and by-products resulting from reaction of the chemical products with other components of the grout or with the surrounding ground shall be considered.

6.2.5.3 Admixtures are organic or inorganic products added in small quantities during the mixing process in order to modify the properties of the grout and to control grout parameters such as viscosity, setting time, stability, and strength, resistance, cohesion and permeability after placement.

6.2.5.4 Admixtures to grout such as superplasticizers, water retaining agents, air entrainers and others are subject of Parts 1, 3, 4 and 6 of prEN 934 and prEN 480-1 to 480-12.

6.2.6 Other materials

6.2.6.1 Calcareous or siliceous fillers, pulverized fuel ash (pfa), pozzolans and fly ash from thermal power plants or any inert or reactive components may be used in grouts, provided that they are chemically compatible with each other and satisfy immediate and long term environmental requirements.

6.2.6.2 Methods for testing of fly-ash are subject to ENV 451. Methods different from those mentioned in that standard and specific to grouting are subject of this standard.

6.3 Grouts

6.3.1 General

6.3.1.1 Grouts are classified as:

— suspensions: either particulate or colloidal suspensions;

— solutions: either true or colloidal solutions;

— mortars.

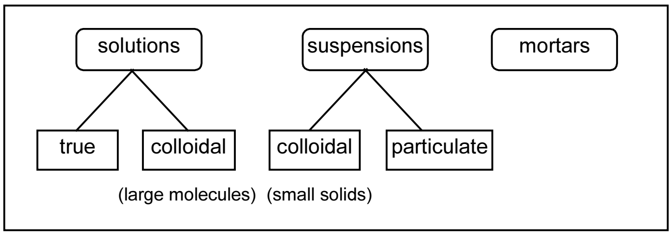


Figure 1 — Grout classification

6.3.1.2 The following intrinsic properties shall be considered when choosing a grout:

— rheology (viscosity, cohesion, etc.), setting time, stability;

— particle size, if applicable;

— strength and durability;

— toxicity.

6.3.1.3 The main parameters that define the properties of grouts before and after setting are listed below.

Table 1 — Parameters characterizing grout properties

	Solutions	Suspensions	Mortars
Before setting	setting time, density, pH, surface tension, pot life, film time, gel time, viscosity, cohesion, thixotropy	setting time, density, pH, grain size distribution, viscosity, cohesion, yield, thixotropy, stability, water retention capacity	setting time, density, pH, grain size distribution, viscosity, workability, water retention capacity
After setting	hardening after setting, final strength, pH, deformability, durability, shrinkage, expansion, shear strength, syneresis (silicate based solutions)	hardening time, final strength, deformability, durability, shrinkage, expansion, density, shear strength	hardening time, final strength, deformability, durability, shrinkage, expansion

6.3.2 Suspensions

6.3.2.1 Suspensions are characterized by:

— the grain size distribution of the solid particles;

— their water/solid ratio;

- the rate of sedimentation and bleeding;
- their water retention capacity under pressure filtration;
- their rheological properties and behaviour with time.

6.3.2.2 The granulometric curve of microfine suspensions should be determined with a laser granulometer or equally precise instrument.

6.3.2.3 The tendency of suspended solids to flocculate (particularly in microfine suspensions) shall be taken into account.

6.3.2.4 The tendency of solids in suspension to settle in water due to gravity forces, and their tendency to bleed under pressure, shall be considered in relation with the nature and properties of the host medium.

6.3.2.5 Colloidal clay suspensions should be prepared so that the clay particles are thoroughly deflocculated and hydrated before injecting.

6.3.3 Solutions

6.3.3.1 Some types of silicate grout are not stable with time and their use should be carefully assessed.

6.3.3.2 Organic silicate gels may lead to the proliferation of bacteria in the ground.

6.3.3.3 The effect of syneresis on the properties of the treated ground and on the environment, particularly their long term effect, shall be evaluated prior to treatment.

6.3.3.4 The effect of temperature differences on the grout behaviour during production and placement shall be taken into account.

6.3.3.5 Special attention shall be paid to:

- the toxicity of individual resin grout components;
- the risk of dilution of the grout mixture in the groundwater leading to prolongation of the setting time or even inhibition of the chemical reaction;
- the toxicity of any substance released into the groundwater if the chemical reaction is not fully achieved or modified by the host medium.

6.3.3.6 Resins are usually applied under the circumstances given in Table 2.

Table 2 — Application of resin grouts

Resin type	Ground type	Use/Application
Acrylic	granular soil finely fissured rock	Reduction of permeability Improvement of strength
Polyurethane	large voids	Foaming to block water inflow (aquareactive resins) Stabilization or local void filling (two component resins)
Phenolic	fine sand and sandy gravel	Tightening and consolidation
Epoxy	fissured rock	Improvement of strength Reduction of permeability

6.3.4 Mortars

6.3.4.1 Mortars showing high internal friction are used for compaction grouting or for the filling of voids. Their rheological behaviour is usually determined by slump tests (workability, see Table A.1).

6.3.4.2 Mortars flowing under their own weight are generally used for filling cavities, large cracks, open fissures and voids in granular soils. They shall be stable and their rheological behaviour (similar to suspensions) is usually characterized with suitably selected flow cones.

6.3.4.3 When used for compaction grouting, the mortar should contain a minimum of 15 % of fines passing 0,1 mm.

6.4 Sampling and testing

6.4.1 The constituent materials of a grout mix as well as the mix itself shall regularly be sampled and tested to verify compliance with the design requirements.

6.4.2 Standardized testing methods (equipment, boundary conditions, analysis) shall be employed to allow comparison of the characteristics of the products provided by different suppliers.

6.4.3 In the laboratory, grout characteristics should be tested at an ambient temperature of 20 °C.

6.4.4 If the conditions on site differ substantially from the laboratory conditions (especially the temperature) tests shall be conducted under the in situ conditions. The temperature development during testing shall be monitored.

6.4.5 Table A.1 presents methods for testing the more important grout parameters.

7 Design considerations

7.1 General

7.1.1 The basic standard for the design of grout injections is:

— ENV 1997-1:1994, EUROCODE 7: Geotechnical design – Part 1: General rules.

7.1.2 This present standard supplements the above document and establishes additional requirements and recommendations for the planning and implementation of geotechnical grouting applications.

7.2 Design basis and objectives

7.2.1 A flexible approach should be adopted to the design and planning of a grouting application in order to adapt the works to unforeseen ground conditions or variations in the behaviour of the host materials as the work progresses.

7.2.2 The principal objectives of geotechnical grouting are:

— the modification of the hydraulic/hydrogeological characteristics the ground;

— the modification of the mechanical properties of the ground;

— the filling of natural cavities, mine workings, voids adjacent to structures;

— inducing displacement to compensate for ground loss or to stabilize and lift footings, slabs and pavements.

7.2.3 In order to formulate a grouting design, the following information shall be made available:

— a definition of the grouting objectives and the control criteria;

- adequate ground information, in particular geological, geotechnical and hydrogeological data (including water chemistry) relevant to grouting (see clause 5);
- limitations imposed by environmental considerations, the influence of or on adjoining structures (buildings and foundations) or any other parameters which could affect the choice of grout mix and placement technique;
- references to other grouting projects executed in the same area or under comparable circumstances.

7.2.4 Based on the site investigation, the grouting trials and the design, the following aspects shall be considered and addressed by the working documents:

- the shape and volume of the ground to be treated;
- the measurable properties to be achieved for the life of the project;
- the drilling method and pattern;
- the grouting techniques and methods to be applied;
- the spacing of injection points;
- the sequencing of the injections with respect to time, grout composition and injection point;
- permissible grouting limits (injection pressure, flowrate and quantity of grout to be injected);
- the grout mix compositions;
- the required tests and field controls to be adopted before, during and after grouting;
- the instrumentation required for monitoring and data logging.

7.2.5 The following aspects should be considered during grouting:

- the reliability and completeness of the ground information available;
- the performance required of the grout;
- the presence of existing structures and their condition;
- changes induced in the in situ state of stress and pore pressures as a result of the grouting work, the existing groundwater conditions as well as expected post construction conditions;
- the toxicity of the grouting products;
- the working environment in which the grouting materials have to be stored, mixed and injected;
- the availability and reliable supply of grouting materials;
- environmental and safety restrictions.

7.3 Grouting principles and methods

7.3.1 General

7.3.1.1 The introduction of grout in a host medium is achieved either with or without displacement of the ground. Figure 2 illustrates the various injection methods associated with these two principles.

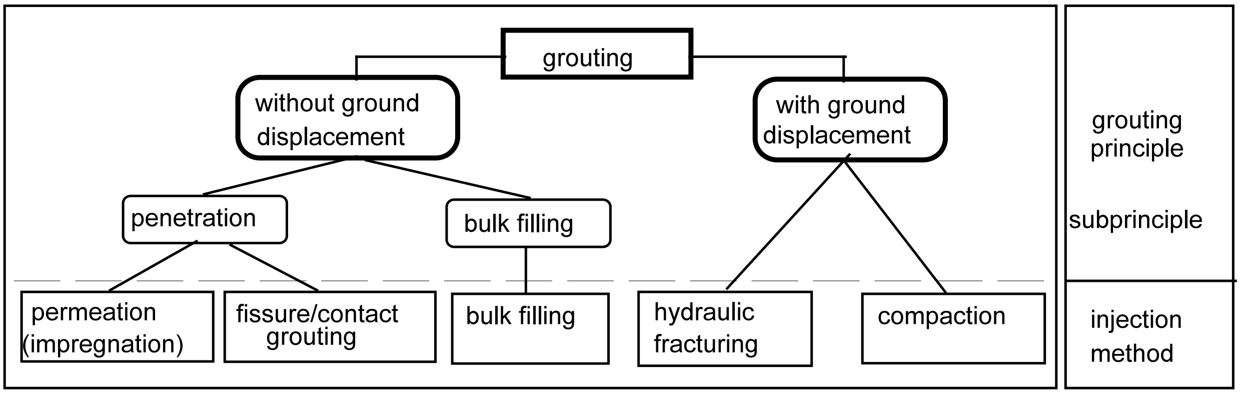


Figure 2 — Grouting principles and methods

7.3.1.2 The term consolidation grouting is sometimes used to emphasize an improvement in the strength or deformation characteristics of a soil imparted by the permeation treatment. The aim of consolidation grouting in soils and rock is to improve the ground so that it does not undergo any inadmissible deformation. As this term does not refer to a grouting principle or injection method, it will be avoided in the following.

7.3.1.3 The term compensation grouting is used when the objective of grouting is to concurrently compensate for ground loss caused by tunnelling or excavation works.

7.3.2 Grouting without ground displacement (non-displacement grouting)

7.3.2.1 Permeation (impregnation) grouting

7.3.2.1.1 Permeation grouting aims at filling the accessible interstices between grains in permeable soils by a grout without destruction of the integrity of the ground. It reduces the permeability of the host material and usually increases the strength and density.

7.3.2.1.2 In order to avoid displacement, permeation grouting shall be carried out at carefully controlled pressures and flow rates.

7.3.2.2 Fissure and contact grouting

7.3.2.2.1 Fissure grouting aims at filling open fissures, fractures or joints in a rock mass with grouts without creating new or opening existing fractures, in order to reduce the permeability and/or increase the strength of the grouted mass.

7.3.2.2.2 The frequency, orientation, extent, width, roughness and infilling of the discontinuities shall be known in order to formulate the design.

7.3.2.3 Bulk filling

7.3.2.3.1 Bulk filling is used for the filling of large natural or man made openings. The term is generally applied to the placement of large volumes of grout under gravity or at low pressures.

7.3.2.3.2 If a large volume of cement is placed in an enclosed space, the effect of high local temperatures and induced stresses shall be taken into account.

7.3.2.3.3 Bulk filling may be followed by a phase of grouting under pressure to fill the remaining voids.

7.3.3 Grouting with ground displacement (Displacement grouting)

7.3.3.1 General considerations

7.3.3.1.1 Displacement grouting refers to the injection of grout under pressure with the deliberate intent of spatially displacing the host medium. The term includes injection methods such as compaction grouting, and hydraulic fracturing (claquage). The method is used to increase the density of a plastically deformable material, and the volume of the treated mass where the plastic deformation limit is reached.

7.3.3.1.2 Controlled displacement grouting can be employed to strengthen the ground under existing structures.

7.3.3.2 Hydraulic fracturing

7.3.3.2.1 Grouting by hydraulic fracturing is used to:

— reinforce or stabilize the ground (soil or rock);

— produce controlled uplift of structures;

— achieve watertightness by creating compartments.

7.3.3.2.2 It is difficult to control the propagation of an hydraulic fracture plane. Hence, the grouting objective should usually be achieved by an incremental series of injections, spread over a period of time.

7.3.3.3 Compaction grouting

7.3.3.3.1 Compaction grouting refers to the intrusion of a comparatively stiff (viscous) particulate grout into the ground to induce displacement and deformation. The grout is usually extruded from open-ended injection tubes. The grout consistency is such that the grout remains as a homogeneous mass and neither permeation nor hydraulic fracturing of the host medium occurs. Compaction grouting is most often used to compact and densify loose ground and to raise and support structures which have settled.

7.3.3.3.2 The final grid of grout holes is generally defined during the grouting process, in accordance with the results of control tests performed in the centre of the primary grid.

7.3.3.3.3 The slow dissipation of pore pressure in low permeable ground shall be taken into account for the control measures.

7.4 Grout

7.4.1 Type and composition

7.4.1.1 The type and composition of the grout shall be selected according to the ground conditions and specifications of the works.

7.4.1.2 The national standards shall be consulted for restrictions in the use of specific types of grouts.

7.4.2 General considerations

7.4.2.1 In order to achieve the performance specifications for grouting works the design shall consider:

— the purpose of the treatment;

— grout placement, timing and sequencing;

— environmental conditions;

— rheological properties of the grout and their change with time, such as the water content of the solid constituents of a grout mix;

— setting and hardening time of the grout;

— the compatibility of the grout with the components of the delivery system and the ground;

- physical properties after setting;
- the effects of syneresis on the mechanical stability of the injected ground (for silicate based grouts).

7.4.2.2 The following environmental conditions shall be considered for the design:

- the size of openings to be filled by the grout and the size of the solid (hydrated) grout constituents, particularly the sizes of the pore necks (smallest access area) rather than the porosity;
- the permeability of the medium to be injected and the penetrability of the grout;
- the chemistry of the groundwater, mix water, and the ground;
- ground and grout temperature;
- the risk and effect of grout drying out upon exposure;
- the environmental impact during mixing, processing and the placement of the grout;
- the pollution potential of the grout.

7.4.2.3 If permeation grouting is to be undertaken, the dimensions of interconnected voids in the soil (effective porosity) or interconnected fissures in rock, should be known before designing the grout. This is particularly relevant for suspensions, where the filter criteria (relating particle size to void opening) and the stability of the mix under in situ gradients should be investigated. The cohesion of the mix should further be related to the desired reach of the treatment, and the viscosity of the grout to the permissible working pressures.

7.4.2.4 The determination of the setting time depends on:

- the volume of grout to be prepared and injected;
- the ground permeability;
- the interconnected porosity of the ground;
- the rate of groundwater flow;
- the time of injection for one pass;
- the anticipated placement time of a prepared batch of grout.

7.4.3 Parameters and criteria

7.4.3.1 The execution design shall state the range and median values of the following grout parameters for given environmental conditions:

- density, viscosity, yield or cohesion;
- shear and compressive strength;
- particle size of cement or binder;
- water retention capacity;
- for silicate gels the relative percentage of the reagent and silicate (neutralization rate);
- sedimentation rate.

7.4.3.2 Table A.1 presents the measuring conditions for the main parameters of each class of grout.

7.4.3.3 The design should further specify criteria for the selection of a specific mix if different mixes have been suggested, and the permitted maximum and minimum grout temperatures during processing and placement.

7.4.3.4 In soils, a groutability ratio, such as the D_{10}/d_{90} or D_{15}/d_{85} criterion, can be used to assess the penetrability of particulate grouts (see glossary, annex B). In rock, the maximum particle size to fissure width is considered (a ratio of three is commonly used).

7.4.3.5 Limit criteria for changing the mix design should be decided upon at the outset of the works for the case that:

— grout takes are significantly in excess of those anticipated in the design;

— no grout acceptance can be achieved with the design mix;

— undesirable ground movement occurs.

7.4.4 Applicability

7.4.4.1 The types of grout applicable for different types of ground are shown in Table 3.

Table 3 — Indicative grouts for different types of ground

Host medium	Range	Non-displacement grouting			Displacement grouting
		Permeation	Fissure or contact grouting	Bulk filling	
	Gravel, coarse sand and sandy gravel K> 5×10^{-3} m/s	Pure cement suspensions, Cement based suspensions			
Granular soil	Sand 5×10^{-5} <K< 5×10^{3} m/s	Microfine suspensions, Solutions			Cement based suspensions, Mortar
	Medium to fine sand 5×10^{-6} <K< 1×10^{-4} m/s	Microfine suspensions, Solutions, Special chemicals			
	Faults, cracks, karst *e* > 100 mm		Cement based mortars, Cement based suspensions (clay filler)	Mortars, Cement based suspensions with short setting time, Expansive polyurethane, Other water reactive products	
Fissured rock	Cracks, fissures 0,1 mm < *e* < 100 mm		Cement based suspensions, Microfine suspensions		
	Microfissures *e* < 0,1 mm		Microfine suspensions Silicate gels Special chemicals		
Cavity	Large voids			Cement based mortars, Cement based, suspensions with short setting time Expansive polyurethane, Other water reactive products	
e = fissure width					

7.4.4.2 Sleeve grouts for sealing the sleeve pipe shall be designed to prevent migration along the annulus, and to facilitate fracturing between the sleeve and the ground.

7.5 Grout placement

7.5.1 General

7.5.1.1 Grout placement methods shall be selected specifically for each job and the choice shall be dictated by the design concept and intent.

7.5.1.2 The injection process is governed by:

— the grout volume *V* per pass;

— the injection pressure *P*;

— the flow or placement rate *Q*;

— the grout rheology.

7.5.1.3 The design should indicate how to adapt *Q, V* and *P* for a given mix design, or the rheology of the mix design, to the anticipated ground response during grout placement.

7.5.1.4 For permeation, the flow (injection) rate *Q* should be controlled to ensure that the effective pressure remains lower than the ground fracturing pressure.

7.5.1.5 The effects of the modification of the pore water pressures induced by the treatment, and related changes in the in situ stresses, should be considered.

7.5.2 Drilling pattern and borehole design

7.5.2.1 The relative positioning of injection points within the mass to be grouted depends on:

— the shape of the mass;

— physical constraints influencing the positioning of boreholes;

— the expected directional tolerances of the boreholes;

— an assessment of the expected distance of grout travel (radius of efficiency) within the host material.

7.5.2.2 The number, position, spacing, depth, diameter, inclination and orientation of boreholes and injection points shall be based on geological conditions, the type of structure to be grouted, the results to be obtained, the grouting method and purpose, the type of grout to be used, injection pressure and rate of grout take. The design shall make adequate provision for any variation in the above parameters.

7.5.2.3 Whenever possible, the design should be refined by conducting site grouting trials.

7.5.2.4 The positions of all foreseen injection boreholes shall be indicated on a plan and they shall be numbered.

7.5.2.5 When impregnating a rock the spatial relationship between bedding planes and joints or fractures shall be taken into account. The boreholes shall be adjusted to the orientation and separation of the principal open features.

7.5.2.6 The grout hole diameter should be based upon the type and condition of the rock to be grouted and the depth and inclination of the hole. It should be chosen to allow any foreseen in-hole tests.

7.5.2.7 Care should be taken to minimize borehole deviations and the design should adjust the spacing between holes to compensate for the deviations expected. In general, the borehole axis should not deviate from the planned orientation by more than 3 % for lengths of less than 20 m. In the case of longer holes the spacing between neighbouring holes should be adjusted to compensate for deviations.

7.5.3 Grouting sequence

7.5.3.1 In its simplest form, a sequence constitutes a single grout type introduced through a single hole.

7.5.3.2 The grout placement sequence may progress to multiple stages, over many holes, with each stage requiring a sequence of injection passes of differing grout types.

7.5.3.3 The design shall therefore specify the following variables:

— the manner in which the treatment will progress through the mass being grouted (inwards or outwards, top-down or bottom-up, etc.);

— the number of grouting phases;

— the number of passes per stage;

— the type of grout introduced for each pass.

7.5.4 Grouting pressure

7.5.4.1 In general practice, the grouting pressure is measured at the grout delivery pump and/or at the hole collar. However, variations in hydraulic head, and friction losses in the delivery system, will result in this 'working pressure' being different from the 'effective pressure' acting in the ground.

7.5.4.2 In rock, the value of the 'effective grouting pressure' can be assessed in relation to the pressure at which:

— the rock breaks under tension;

— predominantly horizontal planes in the rock are parted, and displacement occurs; or

— widening of the treated fissures takes place.

7.5.4.3 During non-displacement grouting of soils, the effective (or limit) grouting pressure is dependent on the confining pressure at the point of injection.

7.5.4.4 For non-displacement grouting, the permissible injection pressure is the maximum pressure at which a grout is allowed to be introduced into the ground in order to avoid any undesirable deformation of the ground.

7.5.4.5 In non-displacement grouting, a value for the permissible injection pressure shall be given in the design.

7.6 Monitoring and control criteria

7.6.1 The design shall specify the monitoring and control criteria before, during and after the grouting works and shall indicate which of the following parameters to monitor and control and how this is to be done:

— the grout properties during processing and placement;

— the tolerances in direction and inclination of boreholes (drilling accuracy);

— the criteria for ending injection after each pass;

— the results achieved after each phase of grouting and/or at the end of the project;

— ground movement or deformations;

— chemistry of water;

— water levels in existing wells or observation boreholes.

7.6.2 The criteria for ending an injection pass should be based on the following:

— in soil:

  — limiting pressure and/or volume;

  — ground movement due to grouting exceeding a limit value;

  — escape of grout to surface, into buildings or neighbouring holes;

  — bypassing of packers;

- in rock:
  - limit pressure (refusal) and/or volume;
  - ground movement;
  - escape of grout;
  - unacceptable loss of grout into adjoining areas.

7.6.3 The design shall specify the control criteria and the tests necessary to verify that the objectives of the grouting works are achieved.

8 Execution

8.1 General

8.1.1 Grouting works shall be staffed with qualified personnel. All key personnel shall have prior grouting experience.

8.1.2 The equipment required to perform a grouting operation includes:

- drilling and driving equipment;
- mixing and proportioning equipment;
- pumping equipment;
- injection piping;
- packers;
- monitoring and testing equipment.

8.1.3 The equipment used for grout processing shall safely withstand the anticipated maximum grouting pressures.

8.1.4 Competent personnel shall maintain the grouting equipment for the duration of the works.

8.2 Drilling

8.2.1 The following drilling methods may be employed:

- rotational drilling;
- percussion drilling using either an external or down-the-hole hammer;
- cased percussion drilling;
- grab-, chisel- and bailer borings;
- driving of lances;
- vibrating of casing or drill pipes.

In unstable ground full borehole penetration may require:

- the use of drilling muds, grouts or foams;

- temporary casing;
- direct insertion of sleeve pipes;
- progressive stabilization as the borehole advances.

If artesian conditions are expected counter-pressure drilling may be required.

8.2.2 Flushing media and drilling techniques shall be chosen so as not to impede the success of any subsequent grouting operation (particularly regarding changes in permeability at the point of injection).

8.2.3 Local adjustments to the angles, orientation, and spacing of grout holes should be made as necessary. New holes should replace holes that are prematurely plugged and holes that show unacceptable borehole deviation.

8.2.4 In open holes, if grouting does not follow immediately after cleaning, the hole collar should be protected to avoid borehole contamination.

8.2.5 After drilling, open boreholes in rock shall be flushed in order to remove detritus and loose material, and to open cracks and fissures. This treatment shall not be applied in the case that the rock might be adversely affected by the flushing medium.

8.3 Grout preparation

8.3.1 Storage

Stored grout components shall be protected from the weather (especially temperature and humidity).

8.3.2 Batching and mixing

8.3.2.1 Contamination of the grout and its constituents shall be avoided during storage, handling and delivery.

8.3.2.2 The storage containers (tanks) for ready-mixed grout shall ensure that the rheological or other properties of the grout are not unduly altered during storage.

8.3.2.3 Containment vessels for chemical grouts shall consist of materials that do not react with the chemicals used.

8.3.2.4 For grouts containing bentonite, the bentonite should be hydrated before introducing the binders.

8.3.2.5 The proportioning of grout components shall be carried out with calibrated measuring devices in accordance with tolerances specified for the works.

8.3.2.6 Mixers shall be selected to ensure the homogeneity of the mix.

8.3.2.7 In order to allow uninterrupted delivery of particulate grouts, an intermediate holding tank should be located between the mixing tanks and the pump(s). The mix in the holding tank should be agitated to prevent separation and/or premature setting.

8.3.2.8 Grouts with a fast setting time should be mixed as close as possible to the point of injection.

8.3.3 Pumping and delivery

8.3.3.1 The grout pumps and injection systems shall be chosen in accordance with the intended injection technique.

8.3.3.2 The following should be considered when selecting injection pumps:

— an adjustable rate of grout delivery;

— outputs which permit sufficient volume of grout to be injected or pressure to be achieved within a given period of time;

— regulation of the injection velocity;

— low-wear pumps (e.g. plunger pumps) for abrasive grouts;

— ease of cleaning and maintenance;

— valve diameters which are able to accommodate the viscosity of the injected material.

8.3.3.3 The injection pressure should be measured as close to the point of placement as is practicable.

8.3.3.4 The injection systems shall dampen pressures surges to minimize the risk of unintended and undetected initiation of hydraulic fractures.

8.3.3.5 If the grout preparation plant is remote from the point of injection, an intermediate relay station should be considered.

8.3.3.6 Grout delivery lines (pipes) shall resist the maximum anticipated pump pressure with an adequate factor of safety. Their diameter shall permit flow rates high enough to avoid separation of the mixed grout components (suspensions).

8.3.3.7 If using sleeve pipes, the interior of the injection tube should be washed at the end of each injection phase.

8.3.3.8 Suspensions shall be agitated until injection of the grout in order to prevent sedimentation. Solutions which tend to separate shall be agitated until injection.

8.3.3.9 At low injection rates, a return flow system should be used to avoid sedimentation.

8.4 Grout placement

8.4.1 The method of grout placement will be determined by the ground condition, the works requirement and the type of grout used. The basic approaches are the following:

a) injection in unsupported boreholes in stable ground;

b) injection via sleeve pipes previously placed in a temporarily cased borehole, in unstable ground;

c) injection through the drill string in unstable ground, generally considered as a pre-grouting phase and to be followed by approaches a) or b);

d) compaction grouting is usually performed through a casing retrieved during upstage grouting.

The general implementation in soil and rock is summarized in Table 4 where a stage is defined as a predetermined length of injection bounded either by a double packer, or by a single packer and the base of the hole.

Table 4 — Grouting strategies

	ROCK				SOIL		
	Stable	Unstable					
	Open hole		Sleeve pipe	Drill rod		Sleeve pipe	Lance or casing
single stage	X			X	X		X
multi-stage			X			X	
ascending stage	X		X	X	X	X	X
descending stage		X	X			X	X

8.4.2 Soil grouting can be achieved with casing, grout sheath, pierced casing, and sleeve pipes.

8.4.3 Sleeve pipes which are permanently sealed into the ground by use of a support mix (sleeve grout) allow a repeated use of the injection points.

8.4.4 When grouting in soils, adjacent sleeve pipes should be flushed as a precaution against grout leakage.

8.4.5 Large openings (voids, cavities, etc.) are generally filled under gravity, either directly, or via a tremie pipe extending to the base of the opening.

8.4.6 Packers are used to isolate a grouting stage. Packers are either passive, mechanical or pneumatic, and have to be long enough to minimize the risk of grout bypass through the medium being grouted.

8.4.7 Packers shall ensure tight sealing between the grout hole wall and the injection pipe at maximum grouting pressure.

8.4.8 In instances where the grout has a tendency to bypass the packers, especially in ascending stage grouting, a flushing system should be installed to wash out bypassing grout.

8.4.9 The maximum stage length in rock should normally not exceed 10 m. In intensely fissured or disturbed rock this length should be adjusted accordingly. Injection stages in soil should not exceed 1 m in length.

8.4.10 When grouting in suspected or known conditions of flowing groundwater, excessive dilution or complete loss of grout should be prevented. Depending on the ground conditions, the purpose to be achieved and the rate of groundwater flow, the following precautions should be taken:

— the use of a grout with a short setting time, even a flash setting time (such as aquareactive resins, cement based grout with sodium silicate);

— the use of a viscous grout or/and grout with a high dry matter content;

— the use of additives to limit grout dilution.

8.4.11 If using suspensions when grouting in absorbent rock, a water retaining grout should be chosen.

8.4.12 Injection parameters (pressure, volume and flow rate) shall be adjusted to avoid unacceptable deformation and displacement of the ground, unless this is specifically intended. Particular caution shall be taken in the vicinity of sensitive structures.

8.4.13 The flow rate for permeation grouting depends on the size of the interstices and the viscosity of the grout.

8.4.14 During the placement and handling of grouts and grout components, precautions shall be taken to avoid spillage and, in particular to prevent the escape of any liquid or grout off-site.

8.5 Grouting sequences

8.5.1 The planning of grouting works is an interactive, on going process requiring on-site management. Decisions concerning changes in treatment or in parameters set out in the design and defined in the method statement, as well as continuation or termination of the grouting operation, shall be taken by all concerned parties.

8.5.2 Descending or downstage grouting is commonly reserved for the treatment of unstable rock. If several holes are grouted using downstage grouting, the uppermost stage in all holes is drilled and grouted before drilling and grouting the next stage in all neighbouring holes.

Upstage grouting is only used in open holes in stable rock or if the aim is compaction grouting.

Multistage grouting, using sleeve pipes is generally used in soils and sometimes in unstable rock.

Combinations of these techniques are possible.

8.5.3 The split-spacing method of first drilling and grouting primary holes, followed by intermediate secondary and finally tertiary or even quaternary holes may be used to provide a minimal uniform coverage and to allow for closer spaced holes to be restricted to those areas where progressive experience shows them to be necessary.

8.5.4 The spacing of the primary injection holes shall be decided upon on the basis of experience or grouting tests.

8.5.5 When using the split-spacing method, selected primary hole should be grouted first as exploratory grout holes except in areas of previous test grouting to:

— allow for better description of the geological and hydrogeological situation;

— permit the final selection of the grout hole depth for the remaining primary holes.

8.5.6 In order to limit the lateral migration of grout beyond the designated treatment area, injections should commence on the perimeter of the zone to be treated and move progressively inward. This procedure should not be used if there is a danger of groundwater entrapment or if the aim is to drive water out of the treatment zone.

9 Execution supervision and control

9.1 General

9.1.1 The supervision of the grouting process shall be based on the design specifications. The supervision procedure shall provide documentation based on detailed observation of each phase of the operation. The documentation shall form the basis for any modifications to the design specifications.

9.1.2 During construction, the design assumptions shall be verified according to the data acquired and, if necessary, modified.

9.2 Supervision

9.2.1 All grouting work should be supervised by suitably experienced representatives from all concerned parties.

9.2.2 Prior grouting experience shall be required of all key personnel.

9.2.3 The execution of the works shall be supervised continuously and all observations made shall be compared with the design parameters and assumptions. If the observations differ significantly from the design, then the reason for deviation shall be investigated and the design or execution parameters adjusted to these new conditions.

9.2.4 The designers shall participate in the decision when specification adjustments are made.

9.2.5 The supervision of grouting sites should be facilitated by automating the mixing and delivery systems and installing mechanical, analogue or, preferably, computerized recording devices for real time monitoring and control of the grout placement parameters.

9.2.6 Records shall be kept during the entire field operation, showing all data pertaining to each phase of the work.

9.2.7 Comprehensive records covering each phase of the work should be incorporated in a final report.

9.3 Monitoring and control

9.3.1 General

9.3.1.1 Prior to commencing work, a location and condition survey should be conducted on any structures and utilities likely to fall within the grout influence zone. Further surveys should be made as grouting proceeds.

9.3.1.2 The type, extent and accuracy of monitoring requirements on and off-site shall be clearly established in project documents and before work commences on site.

9.3.1.3 Computerized systems should be used to:

- monitor the drilling of boreholes;
- measure, control and interpret the drilling parameters;
- measure and control the grouting parameters of the different grouts injected in each grouting stage.

9.3.1.4 The parameters, which should be monitored, recorded and analysed during the grouting process, vary continually with time. Hence, the grouting process should be monitored and preferably controlled by a datalogger or field computer to follow in real-time the grouting parameters.

9.3.1.5 Computerized information control should provide hard copy print-outs or back up copies which should be stored in a safe place.

9.3.1.6 Monitoring and control measurements should be carried out, according to the project requirements (design).

9.3.1.7 When data loggers or field computers are used on site, the data sampling intervals should be chosen according to the project requirements.

9.3.1.8 To determine the success of grouting, appropriate (specified) control tests should be carried out at the earliest practical time in order to react as soon as possible to anomalies.

9.3.1.9 The relative development of the injection pressures, the quantity injected and the flow rate with time should be recorded for each grouting phase and for ongoing comparison as the work progresses.

9.3.2 Environmental impact

9.3.2.1 Any environmental impact assessment and especially the decision regarding admissible limits should be based on two largely independent investigations:

- the status quo should be assessed prior to starting any work, with particular attention paid to groundwater conditions (chemistry, velocity and direction of groundwater flow, existing and planned use of groundwater and distance between withdrawal points);
- the expected polluting effect of the grout and the duration of pollution (in case of transitory effects less stringent levels are applicable) should be determined, distinguishing between gaseous, liquid and solid state.

9.3.3 Control of objective

9.3.3.1 The control methods chosen shall depend on the aim of the treatment.

9.3.3.2 Tests should be conducted both before and after grouting to provide an indication of the grouting success.

9.3.3.3 Test may include permeability tests, mechanical tests in the field and the laboratory, excavation, etc.

9.3.3.4 The choice of permeability test depends on the ground condition, and degree of sophistication required. Rising head or falling head (Lefranc) tests are often conducted in granular soils. Lugeon tests are performed in rock. Large scale pumping or injection tests can determine the regional permeability for a large body of soil or rock.

9.3.3.5 The data recorded during drilling may be used to check whether the objectives are being met.

9.3.4 Monitoring of displacement

9.3.4.1 Appropriate instrumentation should be installed that will be capable of monitoring ground and/or structural movements with sufficient accuracy to ensure that they will remain within the established tolerance limits.

9.3.4.2 (Where required, instrumentation for movement monitoring shall be installed sufficiently in advance of the grouting work to allow the identification of background influences (temperature variations, groundwater fluctuation, etc.), and thereby to compensate for their effect on future readings.

9.3.5 Drilling

9.3.5.1 During drilling, a number of parameters may be recorded automatically:

- rate of penetration;
- fluid pressure;
- flow rate;
- reflected energy;
- rotational speed;
- torque;
- pull down force;
- borehole length.

The interpretation of recorded parameters provides useful information with regard to geological and geotechnical variations.

9.3.6 Grout

9.3.6.1 The quality and consistency of the grout shall be maintained by conducting control tests which monitor the ongoing compliance with the required characteristics.

9.3.6.2 The granulometry of microfine suspensions should be controlled and monitored, taking flocculation into account.

9.3.6.3 On site, the grouts shall be subjected to at least the routine control tests given in Table 5.

Table 5 — Grout control tests

Suspensions	Microfine suspensions	Solutions (chemical grout)	Mortars
Density	Density	Density	Density
Marsh viscosity	Grainsize/sand column tests	Setting time	Workability
Setting time	Viscosity		
Bleeding	Bleeding		

In hardened particulate grouts the compressive strength and/or shear strength shall be tested. For testing, see also Annex A.

9.3.6.4 The batching process shall be continuously monitored and recorded.

9.3.6.5 During grouting the grout components and the quantity prepared shall be monitored.

9.3.6.6 Trace indicators may be used on treated ground in order to assess the presence of grout.

10 Works documentation

10.1 The following documents should be available on site:

- a geotechnical baseline report containing all the investigative data relevant to the establishment of a design for the grouting works;
- an organization chart which clearly defines the decision making responsibilities of the key personnel representing all concerned parties;
- a Method Statement which defines the objectives of the grouting work, details the procedures that will be employed to achieve that objective, and proposes measurable criteria that will be used to establish the attainment of the objective. The Method Statement will be agreed upon by the responsible parties as a basis for commencing the work and contains:
  - a plan detailing all boreholes (plan view and sections), existing structures, geological formations, water levels, planned constructions and boundaries of treatment;
  - a document detailing the types of grout, the envisaged quantities of grout to be injected per grout stage in each borehole, the sequence of injection, maximum pressures and the injection rates expected;
  - documents concerned with monitoring on site, maintenance and further activities after handover of the grouting works.

10.2 The following documents should be produced on site:

- a daily record of observations concerning drilling and grouting;
- a monthly record indicating the daily progress and the grout consumption;
- a final report containing all pertinent technical and quantitative details;
- a handover report on completion of the works in which the concerned parties confirm the attainment of the acceptance criteria defined in the Method Statement.

10.3 The site reports shall mention:

- general:
  - dates of activities;
- drilling:
  - borehole (injection point) number and position, length, diameter, direction and inclination;
  - names of drillers;
  - drilling rig and method;
  - type of drilling fluid;
  - borehole equipment (e.g. casing, sleeve pipes, type of seal grout, etc.);
  - special observations during drilling or installation of equipment (e.g. fluid loss, unexpected loss of seal grout);
- mixing and injection:
  - grout compositions (types and mixing proportions) and characteristics;
  - grout volumes injected into the ground (consumption), pressure and duration for each pass;
  - interaction with other boreholes and observed leakage;
  - any unusual incidents and observations;
- control:
  - sampling of the grout being used;
  - number of samples for laboratory;
  - routine quality controls;
  - names of personnel (and their qualification).

These records shall form the basis of grouting control.

10.4 A record of the ground surface levels shall be kept when necessary.

10.5 The grouting results should be summarized by graphical means and by statistical means where appropriate (e.g. graphs of pressure against time).

10.6 Special events and decisions taken both during drilling and injection shall be recorded in field log books.

10.7 Grouting reports shall be prepared on site and signed by the responsible site engineer or his representative.

11 Special aspects (environment, site safety)

This chapter deals with those aspects of site safety and the protection of the environment which are specific to grouting operations. For general rules concerning site safety and protection of the environment, the relevant European and National Standards shall be consulted/taken into account.

11.1 Personnel safety

11.1.1 The safety of personnel and third parties is of prime importance.

11.1.2 The following potential problems should be considered when using grouts:

— dust from powdered chemicals which are toxic to the skin, eyes or respiratory system;

— fumes released from liquid grout mixtures;

— grout components or grouts which are harmful on contact with the skin;

— contamination of groundwater;

— mixing of chemicals which can cause explosion;

— disposal of refuse or waste water.

11.1.3 For all grouting works, protective clothing and gloves shall be worn at all times since most chemical grouts contain some components which are toxic to the skin. Face masks shall be available for workmen who work in closed areas where fumes from grouts or dust from grout components may be breathed. Protective headgear shall be available for all workmen at the site. Safety goggles shall be available for workmen in areas where grout is being injected.

11.1.4 Large batches of epoxy or polyester resins often generate significant amounts of heat and should therefore be handled with care.

11.2 Environmental protection

11.2.1 Environmental impact, particularly the toxicity of the grout and the grout components and their effect on the ground- and drinking water should be considered before grouting.

11.2.2 When testing the grouting material for environmental impact, the following aspects should be considered:

— whether during processing, transport or grouting, substances can be generated or released which could be hazardous to the environment or the grouting crew;

— whether noxious substances can spread upon mixing with ground water;

— whether reaction products can be produced or released which influence the water quality;

— the type of particles eroded from hardened grout;

— chemical reactions between hardened grout and the ground water.

11.2.3 Environmental impact risks on site include:

— induced ground movement;

— changes of groundwater level;

— spreading of grout;

— pollution of groundwater;

— arial distribution (dust).

11.2.4 Arrangements for disposal of excess grout should be made before the grouting operation begins. Advance consideration should also be given to:

- ventilation in confined spaces;
- catchtrays below grout pumps;
- isolation of flammable materials;
- used water collection.

Annex A
(informative)

Measurement of grout parameters

Table A.1 presents the measuring conditions, measuring devices, test procedures and units for measuring the principal grout parameters.

Table A.1 — Measurement of grout parameters

Parameter		Unit	Measuring apparatus/method	Application	Solution	Suspension	Mortar	Remark
1	Outflow time (Cone viscosity)	[s]	Marsh cone (funnel diameter = 4,75 mm), Other flow cones (diameter = 8, 10, 12 mm)	lab and site	N/A	A	A	*see R1*
2	Viscosity (dynamic or apparent)	[Pa·s]	Coaxial viscometer Rheometers	lab lab and site	A	A	N/A	*see R1 andR2*
3	Density	[kg/m^3]	Pycnometer Beaker Baroïd mud balance	lab and site	A	A	A	
4	Cohesion, Yield, Shear strength	[Pa]	Coaxial viscometer, Rheometer, Plate cohesion meter, Kasumeter, Shearometer	lab lab and site	N/A	A	N/A	*see R4*
5	Water retention capacity	[m^3]	Baroïd filter press (low pressure)	lab and site	N/A	A	A	
6	Bleeding rate, Sedimentation	[%] or [m^3/m^3] for 2 hr	Measuring cylinder	lab and site	N/A	A	A	*see R6*
7	Workability	[mm]	Abrams cone	lab and site	N/A	N/A	A	*see R7*
8	Setting time	[s]	Overturned glass beaker, Vicat needle	lab and site	A	A	A	*see R8*
9	Hardening time	[s]	Vane test Shear box, Unconfined compression test	lab and site	A	A	A	*see R9*
10	Hardening Deformation Final strength		Unconfined compression test with stress-strain record, Triaxial test, Point load tests	lab	A	A	A	*see R10*
11	Durability		Mechanical: flow test Chemical		A	A	A	*see R11*
12	Thixotropy		Rheometer, Viscometer, Hydrometer	lab	N/A	A	N/A	*see R12*
13	Syneresis	[Vol %]	Volume of water expelled from sample with time	lab	A	N/A	N/A	*see R13*
14	Shrinkage/expansion	[%] of vol, length	Shrinkage limit determination	lab and site	A	A	A	*see R14*
15	Granulometry		Particle size measurement	lab and site	N/A	A	A	*see R15*
16	Penetrability		Grouting test Sand column test	site lab	A	A	N/A	*see R16*
N/A = not applicable/not generally used, A = applicable								

(R1) The rheological properties of a grout may be determined with the following equipment:

- flow cone (viscosity);
- rotary viscometer (viscosity and cohesion);
- dipping plate or pipe, ball harp, kasumeter (cohesion).

The air temperature, the temperature of the grout, the dimensions of the flow cone, the fill height and the outflow volume shall be stated. The value obtained is a function of viscosity and cohesion, and it should be noted that different combinations of viscosity and yield point can result in the same outflow time.

Mortars used for compaction grouting are not concerned.

(R2) The air temperature and the temperature of the grout shall be stated. The viscosity may be determined for a given rotational velocity or torque. Torque controlled rotary viscometers should be employed to assess the flow properties at low velocities and hence the penetrability of the grout. Where coaxial viscometers are not available on site, a correlation with cone values previously established in the laboratory may be used.

(R4) The design shall specify the apparatus to be used and the values to be achieved.

Rheometers used for "cohesion" measurements should be torque controlled.

(R5) The design shall specify the pressure and duration of the test.

(R6) The bleeding (sedimentation) rate shall be determined in a cylinder of 1 000 ml volume with an inner diameter of 60 mm.

(R7) The testing method shall follow EN ISO 4109 and prEN 12382:1996.

(R8) The setting time is both temperature and volume dependent. According to the grouting application and the grout type, different tests are used to characterize this property:

- tilting or inverting the test cylinder and noting when the grout no longer behaves as a liquid;
- shaking the test receptacle slightly to see if the grout or gel comes away from the sides;
- carrying out a scaled down penetration test, with for example, the Vicat needle.

The apparatus to be used and the values to be achieved shall be stated in the design.

(R9) The hardening time shall be defined in relation to a design strength value. The design shall specify the dimensions of the samples to be tested and the conditions of testing (rate of stress application, etc.).

(R10) The design shall specify the dimensions of the samples to be tested and the conditions of testing (rate of stress application, etc.).

(R11) The chemical and mechanical durability of a grout and the hardened grout shall be investigated under the in situ conditions of pH.

The mechanical stability can be determined in a flow test whereby water flows through a bore in a sample of hardened grout and the amount of material collected in a container is weighed after the test.

The chemical stability can be determined by a grinding test whereby the specimen is finely ground, kept for a few days in the aggressive ground water, and the volume measured at the end.

(R12) For determining the thixotropy, the rheometer shall allow recording of two continuous curves.

(R13) This test is applicable for sodium silicate gels.

(R14) Refer to national standards for the determination of shrinkage limits and expansion.

(R15) This parameter is of prime importance when using microfine products. The increase in size of grout particles due to hydration shall be taken into account when considering the particle size distribution curves of grouting constituents.

(R16) Penetrability tests may serve to demonstrate the ability of a given grout to penetrate a given ground, or as a means of quality control. An example of penetrability tests is given in the French Standard NF P 18 891.

Annex B
(informative)

Glossary

The following glossary contains definitions of terms which are of importance in the field of grouting and which are often subject to discussion and misunderstanding. It supplements the definitions in clause 3.

Action radius: theoretical distance travelled by the grout from the injection point

Additive (Admixture): any grout ingredient (e.g. liquifiers, stabilizers) other than the basic components of a grout mix (water, aggregates, or cementitious material), which is used to modify the liquid and solid state properties of the grout

Agitator tank: a tank with rotation paddles used to prevent segregation of grout after preparation

Area grouting: see *Blanket grouting*

Ascending grouting: see *Upstage grouting*

Batch: quantity of grout mixed at one time

Bentonite: a clay composed principally of minerals of the montmorillonite group, characterized by high water adsorption and a very large volume change upon saturation or drying. They are clays with a content of swellable smectites of at least 70 % and a water absorption capacity of more than 500 %. A distinction is made between natural, sodic, calcic, modified, and activated bentonites

Bentonite-cement grout: a grout having bentonite, cement and water as its basic ingredients

Binder: a substance which causes cohesion in loosely assembled substances

Bingham fluid: a substance which possesses both viscosity and cohesion

Blanket (or area) grouting: the creation of a grouted mass whose lateral dimensions greatly exceed its depth

Bleeding: the autogenous flow of mixing water within, or its emergence from, newly placed grout

Bleeding rate: the rate at which water is released from grout by bleeding

Bonding (bond) strength: strength developed between the grout and its host material

Casing: a lining tube used to support unstable ground during drilling

Cement grout: a grout in which the primary bonding agent is cement

Chemical grout: any grouting material characterized by being a solution, i.e. having no particles (other than impurities) in suspensions

Circuit grouting: a grouting method where grout is supplied to a hole or group of holes, leaving excess grout travelling back through a return line into a holding tank

Circulation grouting: a grouting method by which grout is circulated through a pipe extending to the bottom of the hole and back up the hole via the annular space outside the pipe. The excess grout is diverted back to the agitator tank. The method is used where holes tend to cave and sloughing material might otherwise clog openings to be grouted

Claquage or Claquage grouting: see *Hydraulic fracturing* in Definitions (French terminology)

Coefficient of permeability (hydraulic conductivity): the rate of discharge of water under conditions of laminar flow through a unit cross-sectional area of a porous medium under a unit hydraulic gradient and standard temperature conditions, usually 20 °C. Intrinsic permeability, *k*, is a property of the material and measured in [m^2]. Hydraulic conductivity is measured as the proportionality constant, *K*, between flow velocity, *v*, and hydraulic gradient, *i* and has units of [m/s]:

$$v = K \times i = k\left(\frac{g \times \rho}{\eta}\right) \times i$$

Cohesion: see Figure B.1

Colloid: a substance consisting of very small particles dispersed in a continuous medium. A colloidal particle is generally accepted as having a size between 5 and 5 000 Ångström

Colloidal grout: a grout with an artificially induced cohesiveness, in which the solid particles or large molecules (colloids) are totally dispersed and remain in suspension, i.e. a grout mixture that does not segregate or bleed

Compaction grouting: see Definitions

Compensation grouting: a term employed for controlled displacement grouting with the aim to counteract ground settlement induced by excavation works. This term refers to a number of grouting methods

Consistency: the relative mobility or ability of freshly mixed mortar or grout to flow. The usual measurements are slump for stiff mixtures and flow for more fluid grouts

Consolidation grouting: this term refers to several injection methods including impregnation, fissure grouting, bulk filling, hydraulic fracturing and compaction grouting, whereby the aim is to strengthen the soil or rock mass

Contact grouting: see Definitions

Continuous mixing: a process in which the ingredients of the mixture are fed without interruption and from which the mixed product is discharged in a continuous stream

Cover: see *Overburden*

D_n, d_n: the largest size of the smallest n % of soil grains and the largest size of the smallest n % of grout particles

Degree of settling: see *Sedimentation rate*

Design strength: the strength required to fulfil the design requirements for the grout or grouted ground

Displacement grouting: see Definitions

Double packer: a device consisting of a pair of seals (packers) fitted to a grouting pipe at a predetermined distance apart, used to limit grout injection to the ground between the two packers, i.e. the packed-off length or stage

Downstage (Descending stage) grouting: a grouting technique where a given distance (stage) is drilled and grouted before the borehole is advanced by further drilling or packers are employed to start grouting at the top of the borehole and advance the grouting process progressively down the hole

Durability: resistance to mechanical and chemical attack. Mechanical durability is usually measured by either slake durability tests or flow durability tests, during which ground water is flown through a bore in a specimen of cemented host material. Chemical durability tests are usually conducted on ground samples of the cemented host material which are kept in the ground water

Effective pressure: see Definitions

Emulsifier: a substance that modifies the surface tension of colloidal droplets, keeping them from coalescing, and keeping them suspended

Emulsion: a system containing dispersed colloidal droplets

Epoxy grout (resin): a multi-component resin grout that usually exhibits very high tensile, compressive and bond (adhesive) strengths

False set: the rapid development of rigidity in a freshly mixed grout without the evolution of much heat. Such rigidity can be dispelled and plasticity can be regained by further mixing without the addition of water. Premature stiffening, hesitation set, early stiffening, and rubber set are other terms that refer to the same phenomenon

Filler: an inert material added to a grout to modify its properties or to replace a component

Film time: see *Setting time*

Filter cake: a concentrated solid or semi-solid material that is separated from a liquid and remains on the filter after pressure filtration

Filter press: an instrument used for measuring the filter-loss characteristics of a grout

Filtration water: quantity of water which comes out of a grout in a given time during a filtration test

Final set: a degree of stiffening of a grout mixture greater than the initial set, generally stated as an empirical value indicating the time in hours and minutes that is required for cement paste to stiffen sufficiently to resist the penetration of a weighted test needle

Fissure grouting: see Definitions

Flash set: the rapid development of rigidity in a freshly mixed grout, usually with the evolution of considerable heat. This rigidity cannot be dispelled nor can the plasticity be regained by further mixing without addition of water; also referred to as quick set or grab set

Flow cone: a device for measurement of grout consistency in which a predetermined volume of grout is permitted to escape through a precisely sized orifice, the time of efflux (flow factor) being used as the indication of consistency

Flow rate: the volume of fluid (grout) passing through a unit area per unit time

Fluidifier: an additive which improves the flow characteristics of a grout

Fly ash: a fine residual product derived from the combustion of ground or powdered coal. Similar to *Pulverized fuel ash*

Foam: foams used in grouting are solid structures encapsulating air, usually in closed pores. They are obtained either by injecting a gas into a grout or by a reaction between the grout and the ground water which liberates a gas

Fracturing: see *Hydraulic fracturing*

Gel: the condition where a liquid grout begins to exhibit measurable shear strength. A colloidal material in which the dispersed substances form a continuous branching cohesive network. It may contain a proportion of liquid but possesses some properties of a solid. Some gels can be returned to the liquid phase by disturbance or mixing and will thereafter reform as a gel again (see *Thixotropy*)

Gel strength: the shear strength of a gel. This may be measured at a fixed time interval after mixing or breaking up of a gel or when the gel has fully developed

Gel time: the measured time interval between the mixing of a grout and the formation of a gel

GIN method: GIN stands for "Grouting Intensity Number". The method, applied in rock grouting, uses this number as a parameter for limiting grouting applications, notably in fissures, to a maximum given GIN value. This value is obtained by multiplying the injected grout volume (in litres) by the effective grouting pressure (in bar) per meter of borehole

Grain size distribution: the distribution by weight of the grain sizes of a medium; usually expressed as a cumulative percentage

Gravity grouting: see Definitions

Grout: see Definitions

Groutability: the ability of a ground to accept grout

Groutability ratio: the groutability ratio, GR, expresses the relationship between the particle size of the grout (suspension type grout) and the grain size of the soil to be grouted. The ratios, GR = D_{15}/d_{85} or GR = D_{10}/d_{90} are used, where: D_x = the size which x % of the soil particles are smaller than, d_y = the size which y % of the grout particles are smaller than

Grout curtain: a grouted mass whose vertical dimensions greatly exceed the width

Grouting Intensity Number (GIN): the product of pressure and injected grout volume. See *GIN Method*

Grouting pressure: see Definitions

Grouting (trial) test: test injection prior to grouting operating to assess the groutability of a ground or the appropriateness of a given grout type

Grout mix: the constituents of a mixture normally expressed by weight or volume, or as a proportion of the quantity of water or other major constituents

Grout take: the measured quantity of grout injected into a unit volume of ground, or a unit length of grout hole, or a complete hole

Hardener: in a two component chemical grout, the component that causes the base component to cure

Hardening: increase in strength of a grout after setting

Hardening time: the time for a grout to reach its design strength

Hydration: the formation of a compound by incorporation of molecular water into a complex molecule with molecules or units of other species

Hydraulic binder: finely ground inorganic material which when mixed with water forms a paste which sets and hardens by means of hydration and which retains, after hardening, its strength and stability even under water

Hydraulic fracturing (fracture): see Definitions

Hydrofracture: see *Hydraulic fracture*. Term not recommended

Hydrostatic head: the fluid pressure expressed as an equivalent height of water above a given level

Impregnation: see *Permeation* in Definitions

Initial set: a degree of stiffening of a grout mixture generally stated as an empirical value indicating the time in hours and minutes that is required for cement paste to stiffen sufficiently to resist the penetration of a weighted test needle

Injection: see Definitions

Injection valve: openings along the injection string of a sleeve pipe, usually covered by a flexible sleeve, the whole of which acts as valves

Jet grouting: a process consisting of the disaggregation of the soil (or weak rock) and its mixing with, and partial replacement by, a cementing agent. The disaggregation is achieved by a high energy jet of a fluid which can be the cementing agent itself

Kasumeter: instrument for measuring the yield point

Layer hardening time: see *Setting time*

Lefranc test: in situ falling head permeability test, where the development of a water level in a standpipe is observed to calculate the permeability

Lugeon value: a relative unit of transmissivity representing the absorption of a water flow of one litre per minute, per metre of a 76 mm diameter borehole, at a pressure of 1 MPa in rock

Marsh funnel: see *Flow cone*

Marsh viscosity: viscosity tests are carried out with the Marsh cone. The duration of flow, of a given volume of liquid, expressed in seconds, is called the 'Marsh viscosity'. See also *Flow cone*

Micro-fine or ultrafine product: very fine product having a uniform, steep particle size distribution curve, where $d_{95} < 20\ \mu m$

Moisture content: the ratio, expressed as a percentage, of the weight of water in a given grouting material to the weight of dry solid particles. Also called *Water content*

Mortar: a highly particulate grout containing sand

Mud cake: see *Filtercake*

Neutralization rate: for sodium silicate gels, the proportion of sodium neutralized by the reactant

Newtonian fluid: a true fluid that exhibits constant viscosity at all rates of shear. A Newtonian fluid has no yield point

Non-displacement grouting: see Definitions

Overburden: the thickness of rock and soil material overlying the stage of the hole being grouted

Packer: a device inserted into a drill hole or sleeve pipe to isolate one part of the hole from another. A packer is usually an expandable device activated mechanically, hydraulically or pneumatically

Particle size distribution: the distribution by weight of particles of grouting material among various sizes; usually expressed in terms of cumulative percentage larger or smaller than each of a series of diameters (sieve openings) or the percentages between certain ranges of diameters (sieve openings)

Particulate grout: a grout containing particles, larger than colloids, suspended in the liquid

Pass: injection of a given length of hole without interruption

Penetrability: the ability of a grout to penetrate a ground

Penetration grouting: see Definitions

Permeability: a measure of the ease with which a fluid passes through a porous medium. See also *Coefficient of permeability*

Permeation grouting: see Definitions

Phase: grouting activity, with defined criteria which is a part of a sequence

Polyurethanes: chemical resins reacting to produce foams. Their viscosity is largely similar to that of epoxy resins and they harden very quickly (0,5 min to 10 h). One component polyurethanes harden upon reaction with water. Two-component polyurethanes usually foam up in contact with water, the foaming process causes a kind of self-injection which ensures a better adhesive strength and a certain deformability

Porosity: the ratio, usually expressed as a percentage, of the volume of voids of a given soil or rock mass, to the total volume of the soil or rock mass

Pot life: see *Setting time*

Pozzolane: a siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties

Pulverized fuel ash (pfa): by-product of burning of coal for electric power generation with high content of mineral matter

Resin: a material that constitutes the base of an organic grout system, such as acryl, epoxy, polyester and urethane

Rheological properties: the properties governing the flow of a fluid or plastic solid

Rheopectic: the viscosity (structuring) of rheopectic fluids increases with increasing shear rate (loading) and returns to its initial value after a certain time of rest

Rotary viscometer: in rotary viscometers the viscosity and yield point are determined on the basis of the relationship between torque and rotation speed, respectively shear stress and shear gradient. The viscosity is derived from the ratio of shear stress to shear rate

Sedimentation: the accumulation of grout particles at the bottom of a container when left unagitated as a result of gravitational forces

Segregation: the non-uniform distribution of particles within a grout or mortar due to sedimentation

Sequence: the order in which different grout types are injected in different holes over time, or programmed succession of grouting phases

Set: the condition reached by a grout when it has lost plasticity to an arbitrary degree, usually measured in terms of resistance to penetration or deformation; initial set refers to first stiffening and final set refers to an attainment of significant rigidity

Set time (Setting time): the time between mixing and the achievement in a significant change in the rheological properties. The setting time is volume and temperature dependent and is measured in a number of ways

Shearometer: an instrument for measuring the shear strength of fluids or weak gels

Shear strength: the stress at which a material can no longer resist the applied shear force

Shear stress: τ is the shear force applied per unit area

Shrinkage: a reduction in volume of grout

Single packer: a single packer comprising one seal. See *Packer and Double packer*

Sleeve grout: a grout which fills the annulus between the sleeve pipe and the borehole wall

Sleeve pipe (tube): a grout pipe perforated at regular intervals. The perforations are covered externally by sleeves acting as non-return valves

Sleeve pipe (TAM) grouting: grouting method using sleeve pipes, which allow repetitive placement of grout

Slump test: test for assessing the consistency of a mortar by use of an Abram's cone. The cone is filled with mortar to a given height, the cone lifted and the distance of initial height of the cone to final height of the mortar mound measured

Solution: a liquid formed by completely dissolving a chemical in water to give a uniform fluid without solid particles. Solutions are Newtonian liquids with neither rigidity nor particles and harden in a predetermined period of time, called the 'setting time'. They can be true or colloidal solutions. In the case of colloidal solutions, large molecules are contained in the liquid

Split spacing: the procedure by which additional grout injection holes are located at half the distance from previously grouted holes

Stable suspension: see Definitions

Stage: a given injection length

Stage grouting: sequential grouting of a hole in separate stages as opposed to grouting the entire length at once

Superplasticizer (Plasticizer): additive, which increases the workability of mortars and reduces the viscosity of suspensions

Suspension: a mixture of liquid and solid materials. Behaves as a Bingham fluid during flow, possessing both viscosity and cohesion (yield strength). Particulate suspensions contain particles larger than clay size, while colloidal suspensions contain particles of clay size

Suspending agent: an additive that decreases the settlement rate of particles in liquid

Syneresis: the expulsion of liquid (generally alkaline water) from a set gel which is not stressed, accompanied by a contraction of the gel. Syneresis occurs over a period of a few months

Take: see *Grout take*

Thixotropy: the property of a material that enables it to stiffen in a relatively short time on standing, but upon agitation or manipulation to change to a very soft consistency or to a fluid of high viscosity, the process being completely reversible, i.e. the viscosity of thixotropic fluids decreases with increasing shear rate (loading) and returns to its initial value after a time of regeneration. Fluids that show an increase in apparent viscosity with time are called thixotropic. Thixotropy is common in non-Newtonian grouts

TPA method: TPA stands for "Transient Pressure Analysis". The method, used in rock grouting, is based on the information obtained from observation of the pressure development after shut-in of the grout after a pass. This is done by stopping the pump deliberately and observing and plotting the ensuing pressure drop against time

Transmissivity: the transmissivity T [m^2/s] is the rate of flow of water through a vertical strip of ground which is 1 meter wide and extends the full saturated thickness of the ground when the hydraulic gradient i = 1. It can be expressed as the product of the hydraulic conductivity K [m/s] and the thickness of the aquifer. A customary unit of transmissivity of the rock mass is the Lugeon. The transmissivity of the rock mass in Lugeon units is defined as the seepage flow in litres/minute per meter length of borehole under a pressure of 1 MPa

Tremie grouting: see *Gravity grouting*

True solution: one in which the components are 100 % dissolved in the base solvent

Tube-à-manchette: see *Sleeve pipe*

Unconfined compressive strength: the load per unit area at which an unconfined prismatic or cylindrical specimen (height = 2 $\times$ width) of material will fail in a simple compression test without lateral support

Upstage grouting: a grouting procedure, usually in rock grouting, where the grout hole is drilled to its full depth and thereafter grouting takes place in stages from the base of the hole upwards

Viscosity: the internal fluid resistance of a substance which makes it resist a tendency to flow. A distinction is made between kinematic viscosity, ν, and dynamic viscosity, η, for which: $\nu = \eta/\Delta$, where: Δ = density. Apparent viscosity is equivalent to dynamic viscosity, but considers point events:

$$\mu_{\text{app}} = \frac{dy}{dv}\tau_{\text{shear}}$$

The apparent viscosity, μ_{app}, measured in [Pa·s] represents the ratio of shear stress, τ, and shear rate, $\dot{\gamma}$. For most solutions, the viscosity is a function of the shear stress and depends on the agitation of the substance. If subjected to rapid agitation, the viscosity of a substance reduces and tends towards a minimum value called plastic viscosity. For some substances, notably Newtonian liquids, the viscosity is independent of the shear stress and the ratio, $\frac{\tau}{\dot{\gamma}}$, becomes a constant, the absolute (dynamic) viscosity, η. Hence, for Newtonian fluids such as the true solutions used during grouting, the concept of plastic viscosity does not apply. The kinematic viscosity, ν, measured in m^2/s is a function of the density of the material $\nu = \mu/\rho$

Void filling: see *Bulk filling*. Term not recommended

Watertable: the phreatic surface at which the pore water pressure equals atmospheric pressure, i.e. the standing water level which establishes in a hole dug in the ground

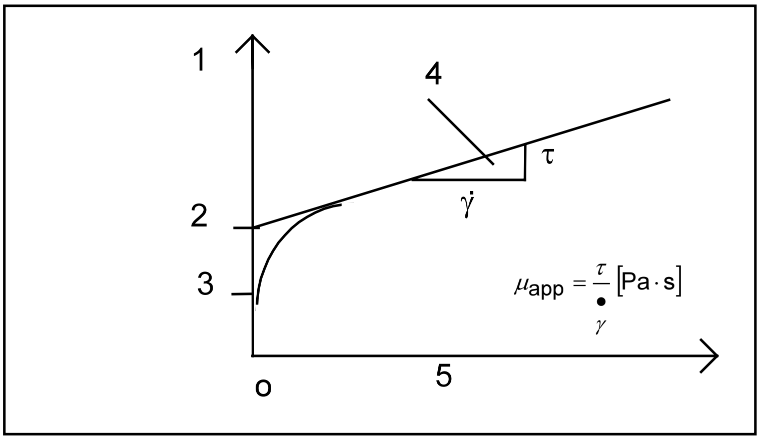
W/C ratio: the water-cement ratio is the ratio by weight of water to the dry cement content of a grout

Water content: see *Moisture content*

Water retention capacity: the ability of a suspension to retain water if not subjected to pressure

Yield point (Yield stress): the lowest shear stress value at which there is a sudden drop in the value of the applied stress and from where continuing extension occurs at more or less the same stress value. The yield point, yield stress or cohesion τ_0 is the shear stress at which plastic deformation occurs and a Bingham fluid begins to flow. The yield stress, τ_0, of a Newtonian fluid is zero

Yield strength: the stress at which a material exhibits a specific deviation from proportionality of stress and strain



Key

1 Shear stress τ [Pa]
2 τ_0 yield point = yield stress
3 c cohesion
4 Apparent viscosity μ_{app}
5 Shear rate $\dot{\gamma} = \frac{dv}{dy}$ [s^{-1}]

Figure B.1 — Definition of rheological parameters for a Bingham fluid (plastic)

Annex C
(informative)

Degree of obligation of the specifications

The provisions are marked corresponding to their degree of obligation:

- RQ: requirement;
- RC: recommendation;
- PE: permission;
- PO: possibility and eventuality;
- ST: statement.

1	Scope
2	Normative references
3	Definitions and symbols
4	Information needed
4.1	RC
4.2	RQ
4.3	RC
4.4	RQ
5	Site investigation
5.1	General
5.1.1	ST
5.1.2	RC
5.1.3	RC
5.1.4	RC
5.1.5	RC
5.1.6	RQ
5.1.7	RQ
5.2	Permeability testing
5.2.1	PO
5.2.2	RC
5.2.3	RC
5.2.4	RQ
5.2.5	ST
5.3	Field grouting trials and grouting test
5.3.1	RC
5.3.2	RQ
5.3.3	RC
5.3.4	RQ
5.3.5	PO
6	Materials and products
6.1	General
6.1.1	RQ
6.1.2	RQ
6.1.3	RQ
6.1.4	RQ
6.2	Grout materials
6.2.1	Hydraulic binders and cements
6.2.1.1	ST
6.2.1.2	ST

6.2.1.3	RQ
6.2.1.4	RC
6.2.1.5	ST
6.2.2	Clay materials
6.2.2.1	PE
6.2.2.2	RC
6.2.3	Sands, gravels and fillers
6.2.3.1	ST
6.2.3.2	PO
6.2.3.3	RQ
6.2.4	Water
6.2.4.1	RC
6.2.4.2	RC
6.2.5	Chemical products and admixtures
6.2.5.1	PE
6.2.5.2	RQ
6.2.5.3	ST
6.2.5.4	ST
6.2.6	Other materials
6.2.6.1	PO
6.2.6.2	ST
6.3	Grouts
6.3.1	General
6.3.1.1	ST
6.3.1.2	RQ
6.3.1.3	ST
6.3.2	Suspensions
6.3.2.1	ST
6.3.2.2	RC
6.3.2.3	RQ
6.3.2.4	RQ
6.3.2.5	RE
6.3.3	Solutions
6.3.3.1	RC
6.3.3.2	PO
6.3.3.3	RQ
6.3.3.4	RQ
6.3.3.5	RQ
6.3.3.6	ST
6.3.4	Mortars
6.3.4.1	ST
6.3.4.2	RQ
6.3.4.3	RC
6.4	Sampling and testing
6.4.1	RQ
6.4.2	RQ
6.4.3	RC
6.4.4	RQ
6.4.5	ST
7	Design considerations
7.1	General
7.1.1	ST
7.1.2	ST
7.2	Design basis and objectives
7.2.1	RC
7.2.2	ST
7.2.3	RQ
7.2.4	RQ
7.2.5	RC
7.3	Grouting principles and methods
7.3.1	General
7.3.1.1	ST
7.3.1.2	ST

7.3.1.3	ST
7.3.2	Grouting without ground displacement (non-displacement grouting)
7.3.2.1	Permeation (impregnation) grouting
7.3.2.1.1	ST
7.3.2.1.2	RQ
7.3.2.2	Fissure and contact grouting
7.3.2.2.1	ST
7.3.2.2.2	RQ
7.3.2.3	Bulk filling
7.3.2.3.1	ST
7.3.2.3.2	RQ
7.3.2.3.3	PO
7.3.3	Grouting with ground displacement (Displacement grouting)
7.3.3.1.1	ST
7.3.3.1.2	PE
7.3.3.2	Hydraulic fracturing
7.3.3.2.1	ST
7.3.3.2.2	RC
7.3.3.3	Compaction grouting
7.3.3.3.1	ST
7.3.3.3.2	ST
7.3.3.3.3	RQ
7.4	Grout
7.4.1	Type and composition
7.4.1.1	RQ
7.4.1.2	RQ
7.4.2	General considerations
7.4.2.1	RQ
7.4.2.2	RQ
7.4.2.3	RC
7.4.2.4	ST
7.4.3	Parameters and criteria
7.4.3.1	RQ
7.4.3.2	ST
7.4.3.3	RC
7.4.3.4	PE
7.4.3.5	RC
7.4.4	Applicability
7.4.4.1	ST
7.4.4.2	RQ
7.5	Grout placement
7.5.1	General
7.5.1.1	RQ
7.5.1.2	ST
7.5.1.3	RC
7.5.1.4	RC
7.5.1.5	RC
7.5.2	Drilling pattern and borehole design
7.5.2.1	ST
7.5.2.2	RQ
7.5.2.3	RE
7.5.2.4	RQ
7.5.2.5	RQ
7.5.2.6	RC
7.5.2.7	RC
7.5.3	Grouting sequence
7.5.3.1	ST
7.5.3.2	PO
7.5.3.3	RQ
7.5.4	Grouting pressure
7.5.4.1	ST
7.5.4.2	PE
7.5.4.3	ST

7.5.4.4	ST
7.5.4.5	RQ
7.6	Monitoring and control criteria
7.6.1	RQ
7.6.2	RC
7.6.3	RQ
8	Execution
8.1	General
8.1.1	RQ
8.1.2	ST
8.1.3	RQ
8.1.4	RQ
8.2	Drilling
8.2.1	PO
8.2.2	RQ
8.2.3	RC
8.2.4	RC
8.2.5	RQ
8.3	Grout preparation
8.3.1	Storage
8.3.1.1	RQ
8.3.2	Batching and mixing
8.3.2.1	RQ
8.3.2.2	RQ
8.3.2.3	RQ
8.3.2.4	RC
8.3.2.5	RQ
8.3.2.6	RQ
8.3.2.7	RC
8.3.2.8	RC
8.3.3	Pumping and delivery
8.3.3.1	RQ
8.3.3.2	RC
8.3.3.3	RC
8.3.3.4	RQ
8.3.3.5	RC
8.3.3.6	RQ
8.3.3.7	RQ
8.3.3.8	RQ
8.3.3.9	RC
8.4	Grout placement
8.4.1	ST
8.4.2	PE
8.4.3	ST
8.4.4	PE
8.4.5	ST
8.4.6	ST
8.4.7	RQ
8.4.8	RC
8.4.9	RC
8.4.10	RC
8.4.11	RC
8.4.12	RQ
8.4.13	ST
8.4.14	RQ
8.5	Grouting sequences
8.5.1	RQ
8.5.2	ST
8.5.3	PO
8.5.4	RQ
8.5.5	RC
8.5.6	RC
9	Execution supervision and control

9.1	General
9.1.1	RQ
9.1.2	RQ
9.2	Supervision
9.2.1	RC
9.2.2	RQ
9.2.3	RQ
9.2.4	RQ
9.2.5	RC
9.2.6	RQ
9.2.7	RC
9.3	Monitoring and control
9.3.1	General
9.3.1.1	RC
9.3.1.2	RQ
9.3.1.3	RC
9.3.1.4	RC
9.3.1.5	RC
9.3.1.6	RC
9.3.1.7	RC
9.3.1.8	RC
9.3.1.9	RC
9.3.2	Environmental impact
9.3.2.1	RC
9.3.3	Control of objective
9.3.3.1	RQ
9.3.3.2	RC
9.3.3.3	PO
9.3.3.4	ST
9.3.3.5	PO
9.3.4	Monitoring of displacement
9.3.4.1	RC
9.3.4.2	RQ
9.3.5	Drilling
9.3.5.1	PO
9.3.6	Grout
9.3.6.1	RQ
9.3.6.2	RC
9.3.6.3	RQ
9.3.6.4	RQ
9.3.6.5	RQ
9.3.6.6	PO
10	Works documentation
10.1	RC
10.2	RC
10.3	RQ
10.4	RQ
10.5	RC
10.6	RQ
11	Special aspects (environment, site safety)
11.1	Personnel safety
11.1.1	ST
11.1.2	RC
11.1.3	RQ
11.1.4	RC
11.2	Environmental protection
11.2.1	RC
11.2.2	RC
11.2.3	ST
11.2.4	RC

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