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(पहला पुनरीक्षण)

Indian Standard

RECOMMENDATIONS FOR GROUTING OF PERVIOUS SOILS

(First Revision)

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BUREAU OF INDIAN STANDARDS
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Price Group 6

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FOREWORD

This Indian Standard (First Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Foundations and Substructures Sectional Committee had been approved by the River Valley Division Council.

The role that grouting can play in control of seepage depends very much on the type of structure and the nature of foundation strata. Hence the design of river valley structures generally involves a combination of several measures of seepage control. It is neither possible nor desirable to frame a set of specifications applicable, in general, to all types of situations where grouting is contemplated for reduction of permeability.

Choice of the width and depth of the grout curtain and the degree of impermeability to be achieved is essentially a matter of design. Various aspects relevant to such design analysis in relation to earth dams, masonry dams, barrages, etc, will be covered separately.

Evaluation of the efficacy of grout curtains is a matter of as great importance as design or execution; hence it is intended to be covered in a separate recommendation.

This standard was first published in 1968. Over the past two decades, lot of development has taken place in grouting technology, especially in grout materials and in exercising control and monitoring of grouting with sophisticated equipment. It was, therefore, felt necessary to update the specification with more details regarding capability of new grout materials that is chemical and organic grouts. The provisions regarding field control of grouting operations have also been modified.

Sometimes it becomes obligatory to drill and grout the foundation through an existing embankment with the attendant risk of hydrofracturing of the embankment while drilling. A method known as caged hole drilling with air as drilling fluid has been developed for such situations which has been included in the present revision.

As it is neither possible nor desirable to frame specifications applicable to all types of situations, typical specifications given earlier have been deleted to avoid misunderstanding among designers, field engineers and contractors. Since a separate specification for Bentonite for Grouting in Civil Engineering Works has been prepared (*see* IS 12584 : 1989), its reference has been given and the specification has been deleted.

In reporting the results of a test or analysis made in accordance with this standard, if the final value, observed or calculated, is to be rounded off, it shall be done in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'.

Indian Standard

RECOMMENDATIONS FOR GROUTING OF PERVIOUS SOILS

(*First Revision*)

1 SCOPE

1.1 This standard gives recommendations for grouting of pervious soils for control of seepage. These are applicable wherever the primary purpose of grouting is to reduce the permeability of the soil. In such cases, consolidation of the soil would be a subsidiary objective.

1.2 After the width and depth of the curtain is decided as contained in IS 11293 (Part 1) : 1985 or any other relevant Indian Standard, it is necessary to choose the equipment, materials and field techniques so that the desired impermeabilization can be achieved with reasonable assurance. The principal objective of these recommendations is to set out the basic considerations governing choice of grout materials, equipment and field procedures.

2 REFERENCES

The Indian Standards listed below are necessary adjuncts to this standard:

IS No.	*Title*
1892 : 1979	Code of practice for subsurface investigations for foundations (*first revision*)
2132 : 1986	Code of practice for thin walled tube sampling of soils (*second revision*)
4453 : 1980	Code of practice for subsurface exploration by pits, trenches, drifts and shafts (*first revision*)
5529 (Part 1) : 1985	Code of practice for in situ permeability test: Part 1 Tests in overburden (*first revision*)
11293 (Part 1) : 1985	Guidelines for the design of grout curtains: Part 1 Earth and rockfill dams
12584 : 1989	Specification for bentonite for grouting in civil engineering works

3 LIMITATIONS AND CAPABILITY OF GROUTING TECHNIQUE

3.1 Initially it is necessary to ascertain what grouting can achieve and what it cannot. Otherwise there is always a risk that the specifications involve stipulations which cannot be achieved in a reasonable time or at a cost commensurate with the purpose. On the other hand there is the danger of relaxing field control to a point that the efficacy of grouting treatment would be seriously compromised.

3.2 Grout flow generally tends to concentrate in more pervious soil pockets or strata. Hence separate injections are necessary where strata w th a wide range of grain sizes and permeability exist in close proximity. Quite often these characteristics change within a few metres and a soil stratum may contain a sequence of inclined layers only a few centimetres thick.

3.3 The seepage through a pervious stratum is generally governed by the presence of a few pockets or layers of high permeability. Hence it may often be sufficient to treat only such layers to achieve the necessary reduction of permeability.

3.4 Groutability of a soil deposit should therefore be judged not merely in terms of the grain size distribution of each individual layer or lense but in terms of its contribution to the overall permeability. When the curtain is wide enough, lenses of some of the finer ungrouted soil may be completely surrounded by grouted soil.

3.5 Relatively wide curtains can tolerate greater extent, of pervious pockets than narrow curtains, for example, single line grout curtains in rock. The tolerance limit also depends on the relation of the permeability of the ungrouted zones and the overall permeability of the pervious stratum in which the grout curtain is installed.

3.6 Conventional Widths

3.6.1 The thickness of the curtain (that is 1/5 to 1/3 the head) is generally sufficient to achieve an overall reduction of permeability in ratio of 1/100. Pregrouting overall permeability may be assessed by pumping tests to an accuracy sufficient for practical purposes. It is difficult to judge the overall permeability of the curtain without piezometric observations.

3.6.1.1 The thickness of the grout curtain should be such as to dissipate the head to the required extent. The head dissipated through the curtain, may be obtained by converting the curtain resistance into increased length of percolation path, as below:

$$H_c = \frac{HL_g}{L_f + L_g}$$

where

H_c = head loss through the curtain,

H = applied head of water,

L_g = equivalent flow path through grout curtain = $t\, k_f/k_g$,

L_f = length of flow path through foundation material,

t = thickness of grout curtain, and

k_f, k_g = coefficients of permeability of foundation material and grout cut off respectively.

3.6.1.2 A suitable factor of safety may be applied to the value obtained above, on the basis of field tests and experience for site.

3.7 Experience indicates that the reduction in permeability to the extent indicated in **3.6** can be achieved in practice by clay cement injections in soil of permeability greater than 10^{-1} cm/s and generally having 10 percent size, $D_{10} > 0{\cdot}5$ mm. (*see* **4.2.1**, **4.3.1** and **4.4.1**). Progressively greater extent of clay, chemical or silicate grouting is necessary as initial permeability ranges between 10^{-1} to 10^{-3} cm/s. As the permeability further reduces below 10^{-3} cm/s, extensive grouting with silica or lignochrome gel or organic or mineral colloidal or polyurathene may be needed. Below 10^{-3} cm/s grouting with pure solution like acrylomide acrylacride, thenoplast and caminoplast may be necessary; however grouting with these materials is extremely expensive, difficult and time consuming.

3.8 Groutability of a given soil by a particular type of grout is as much dependent on the macrostructure and the presence of fine grained secondary deposits as on the grain size distribution.

3.9 Criteria of the type mentioned in **3.7** and other criteria related to parameters based on grain size distribution should be used with.

Caution: Testing in trial plots is therefore necessary, their utility, however, depends entirely on proper selection of test plot locations.

4 EXPLORATION OF PERVIOUS SOILS

4.1 When grouting is contemplated, the objectives of the investigation are as follows:

a) To judge the overall permeability in order to enable a preliminary assessment to be made of the degree of impermeabilization desired and the feasibility of achieving the same.

b) To explore the local variations in the grain size distribution and permeability in order to ascertain the groutability of various strata and the extent of ungroutable lenses or layers. The presence or otherwise of secondary deposits in the pore space should also be ascertained.

c) To investigate salt content of the soil as well as ground water to identify presence of salts which may inhibit gellation.

4.2 Sampling in Bore Holes

4.2.1 The permeability and groutability of a uniform granular medium depends on the grain size distribution. The D_{10} or D_{16} size is generally a good indication of groutability and permeability; but the nature of the grain size distribution curve should also be considered. When there are pronounced gaps or other discontinuities in grading, indications of the L_{10} to L_{15} size are liable to be misleading.

4.2.2 Natural soil deposits are generally heterogeneous and abrupt changes in the grain size distribution can occur even in a few centimetres especially in glacial or alluvial deposits and sometimes in residual soils also. Representative sampling is therefore difficult as incoherent sands and gravel from adjoining thin layers are liable to get mixed. To collect samples of incoherent materials, flap valve bailers are commonly used which develop pumping actions during operation in the bore holes. In partially indurated soils, sampling is even more difficult as recovering cores may not be possible and the heavy effort required to drive sampling tubes may cause disturbance and mixing. As fines are lost by pumping and mixing increases the percentage of fines in the more pervious layers, it is difficult to determine the true grain size distribution *in situ* by usual methods of sampling. For more details of procedure of sampling, reference may be made to IS 1892 : 1979 and IS 2132 : 1986.

4.2.3 Geological origin generally governs the macrostructure of the soil, that is, deposition and arrangement of materials of various sizes and characteristics in the soil mass. Age of the deposit is another factor which governs secondary deposition of minerals and fines. Presence of lime and iron salts may radically alter the permeability, groutability and resistance to internal erosion without significantly changing the grain size distribution. It may be necessary to do visual observations of underground strata through adits, shafts, etc (*see* IS 4453 : 1980).

4.3 Permeability Tests *in Situ*

4.3.1 The *in situ* permeability is governed by the size, extent and spacing of a few lenses/ layers of high permeability. Hence *in situ* tests are more reliable than statistical analysis of grain size data irrespective of the number of samples, many of which may be non-respresentative. *In situ* permeability test may be conducted by constant head method in accordance with IS 5529 (Part 1) : 1985.

4.3.2 The average permeability of pervious deposits may be determined by pumping out test in accordance with IS 5529 (Part 1): 1985.

4.3.2.1 Use of post grouting pumping tests for evaluation of the efficacy of grout curtains is subject to considerable uncertainty when the curtain is only 5 to 10 metres wide. This is because of the irregularity of the curtain and the abrupt changes in flow conditions in the vicinity of the bore well and the boundary of the curtain.

5 GROUTING METHODS AND THEIR SELECTION

5.1 Pervious soils are generally heterogeneous, and the grain size distribution may change abruptly over a short distance. The grout flow generally concentrates along layers or pockets of coarser and relatively pervious soils. Hence it is necessary to treat short lengths of grout holes at a time and repeat injections to ensure that the least pervious and fine grained soils are treated thoroughly.

The method of grouting selected should, therefore, satisfy the following requirements:

a) Soils of different characteristics should be treated individually;

b) It should be possible to treat short sections of the bore-holes in any desired sequence and repeat the injection, if required; and

c) Leakage along the boreholes shall be prevented.

5.2 Description of Grouting Methods

The following methods are generally followed for grouting soils:

a) *Rising Tube* (*see* Fig. 1)

In this method, grouting is done through the casing which is driven to the bottom of the hole. The tube is withdrawn a short distance and grout is injected through the open end into the cavity left by the tube as it is raised. In this manner the tube is lifted progressively until the entire depth required to be grouted is treated.

b) *Descending Stage* (*see* Fig. 2)

In this method, grouting is done through the lower open end of the grout pipe in short stages of 1 to 2 metres starting with the top of the grouted zone. The process involves repetition of a sequence of operations comprising drilling through the length of each stage and grouting followed by redrilling.

c) *Grouting Through Tubes with Sleeves* (*see* Fig. 3)

In this system of grouting, a pipe, with rubber sleeves fitted at 30 cm intervals, is installed in the borehole by filling the annular space around the tube by a sheath of clay cement grout. Grouting is done by seating a set of double packers opposite the sleeves which open under pressure. The sheath grout is cracked under pressure every time injections are made.

5.3 Choice of the Method of Injection

5.3.1 *Possibilities and Limitations of the Methods*

5.3.1.1 *Rising tube method*

In this method, there is always a possibility of plastering of the sides of the hole by grout. Leakage may occur along the grout pipe as some disturbance around the tube cannot be avoided when the grouting tube is pulled up. Hence it is difficult to treat the soil layers individually.

5.3.1.2 *Descending stage method*

In this method, short passes can be treated individually and there is no risk of leakage

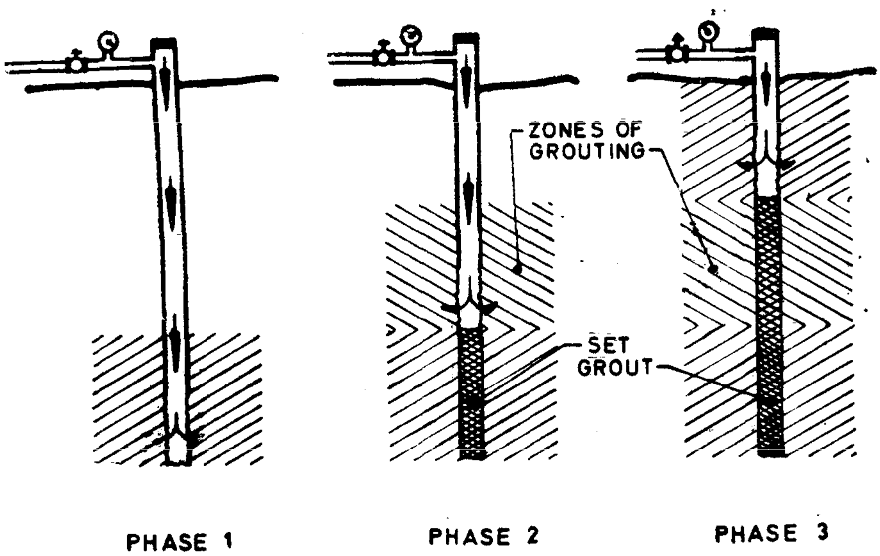


FIG. 1 GROUTING BY ASCENDING STAGES RISING TUBE METHOD

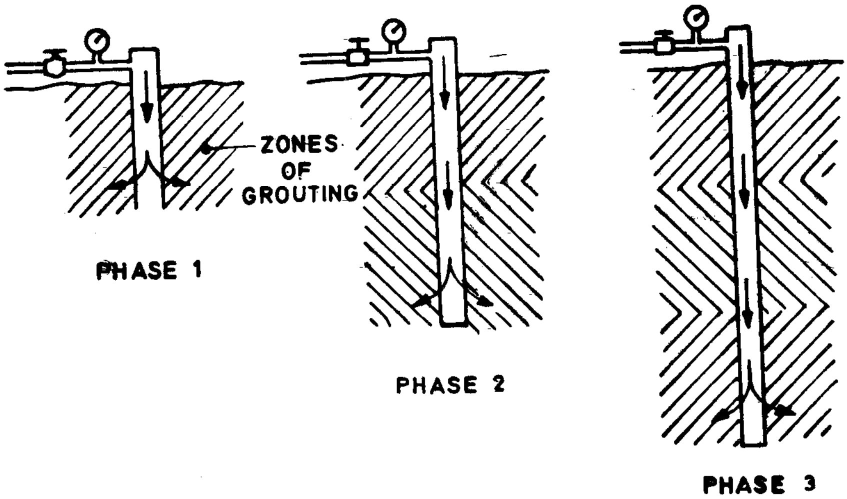
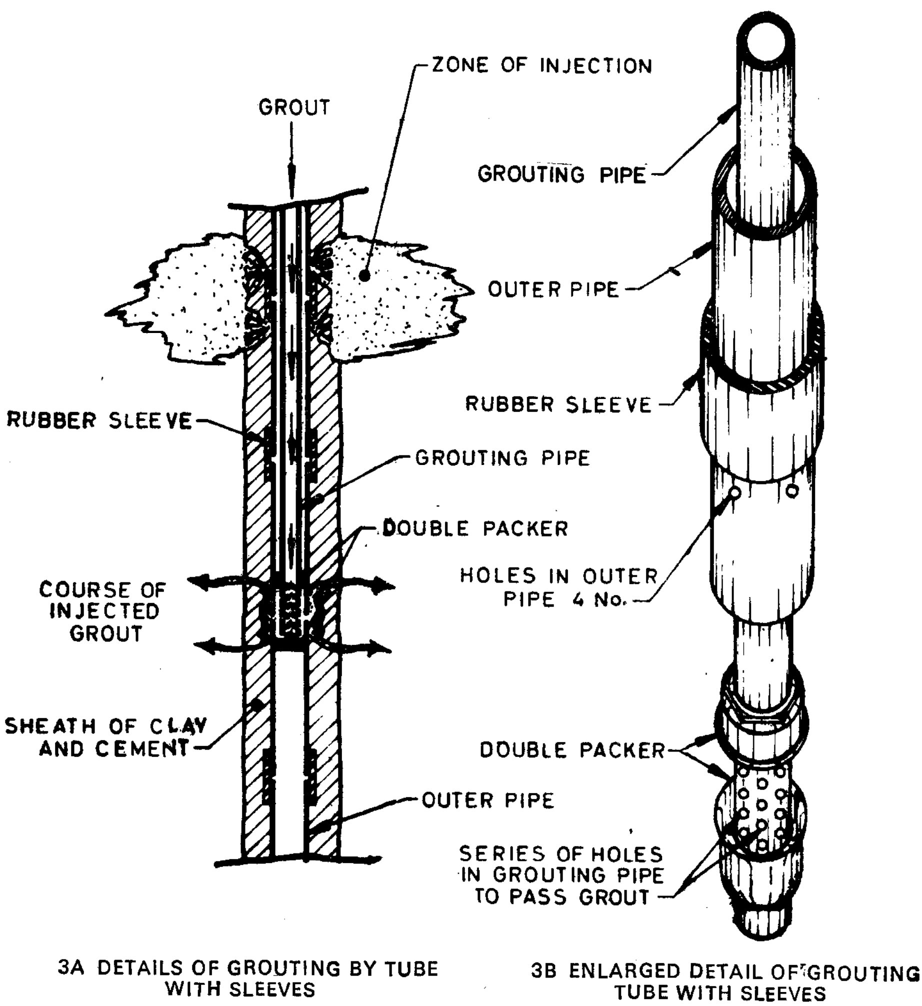


FIG. 2 GROUTING BY DESCENDING STAGES



3A DETAILS OF GROUTING BY TUBE WITH SLEEVES

3B ENLARGED DETAIL OF GROUTING TUBE WITH SLEEVES

FIG. 3 GROUTING THROUGH TUBES WITH SLEEVES along the hole into ungrouted zones. But the time lost in redrilling results in low output of drilling equipment. It is also necessary to redrill if injections have to be repeated.

5.3.1.3 *Grouting through tubes with sleeves*

With this method it is possible to grout in any desired sequence; but high pressures may be required for indurated soils. Because of the pressure required to crack the sheath grout and the uncertainty regarding the resistance to flow in the irregular passage through the sleeves and cracks in the sheath grout, it is difficult to interpret the pressure intake data.

5.3.2 Generally in homogeneous strata, open gravels or boulders, repeated grouting may not be necessary; hence rising tube method of grouting may be useful in such cases. In heterogeneous strata where each stratum or layer has to be treated individually, the descending stage method or the method of grouting tubes with sleeves is generally preferred. Guidance on drilling through gravels, boulder, and heavy silt are given in Annex A.

6 CHOICE OF GROUTING MATERIALS AND MIXTURES

6.1 Grouting material and mixtures selected for treating pervious soils should satisfy the following basic requirements:

a) Particle size (in suspension) should be small enough, so that the grout can penetrate the soil easily. The viscosity of the grout mix should be sufficiently low so that the mix can travel sufficient distance in the soil to achieve an economical and practicable spacing of holes.

b) After penetration into the soil, the grout should form a deposit which will not be eroded by the pressure gradient imposed on the curtain over the entire serviceable life of the structure.

6.2 Economy and practicability of grouting depends on the cost of availability of suitable materials and the cost of drilling and grouting to the required depth. The selection of grouting materials should therefore be considered together with the selection of drilling and grouting methods. Due consideration should also be given to the presence of hard boulders and indurated strata and wastage and overtravel of grout along preferential paths of seepage. Restrictions on pressure due to risk of damage to overlying structures may sometimes render grouting infeasible or a large number of holes may be required which may make it uneconomical.

6.3 It is, therefore difficult to frame general rules governing selection of grout materials and mixtures. Preliminary indications of groutability may, however, be had from an examination of grain size distribution data and by using permeability criteria based on past experience of soils of similar geological origin, age and macrostructure (for example criteria mentioned in **3.7**). These considerations enable only a preliminary selection to be made of the grout material which should be verified by trial grouting *in situ* and sufficient number of pre and post-grouting tests during various stages of execution.

6.4 For continuous flow without blocking the capillaries, the diameter of the solid particles in grout mix must not be more than about 1/10th of D_{10} size of the soil. Criteria such as $\frac{D_{85}}{D_{15}} < \frac{1}{20}$ is also in use. However, these criteria should be used as a guide only, especially when the grain size distribution is irregular or gaps are present in the grading. The sedimentation test often fails to indicate the size of particle in a grout suspension as the degree of dispersion or agglomeration depends on the chemical composition of the grout.

6.5 Limits of the grain size distribution curves of soils which may be penetrated by various types of grouts may be judged from Fig. 4. There is some divergence in the views of various authors because of the differences in the characteristics of grout materials and the macrostructure of the soil treated as well as the efficacy of the field techniques used. When the grading curves are irregular, laboratory tests are essential for verifying the penetrability of the grouts intended to be used.

6.5.1 The criteria given in Table 1 may be used as a guide for grouting of fine grained soils and fissures.

Table 1 Criteria for Grouting Fine Grained Soils and Fissures

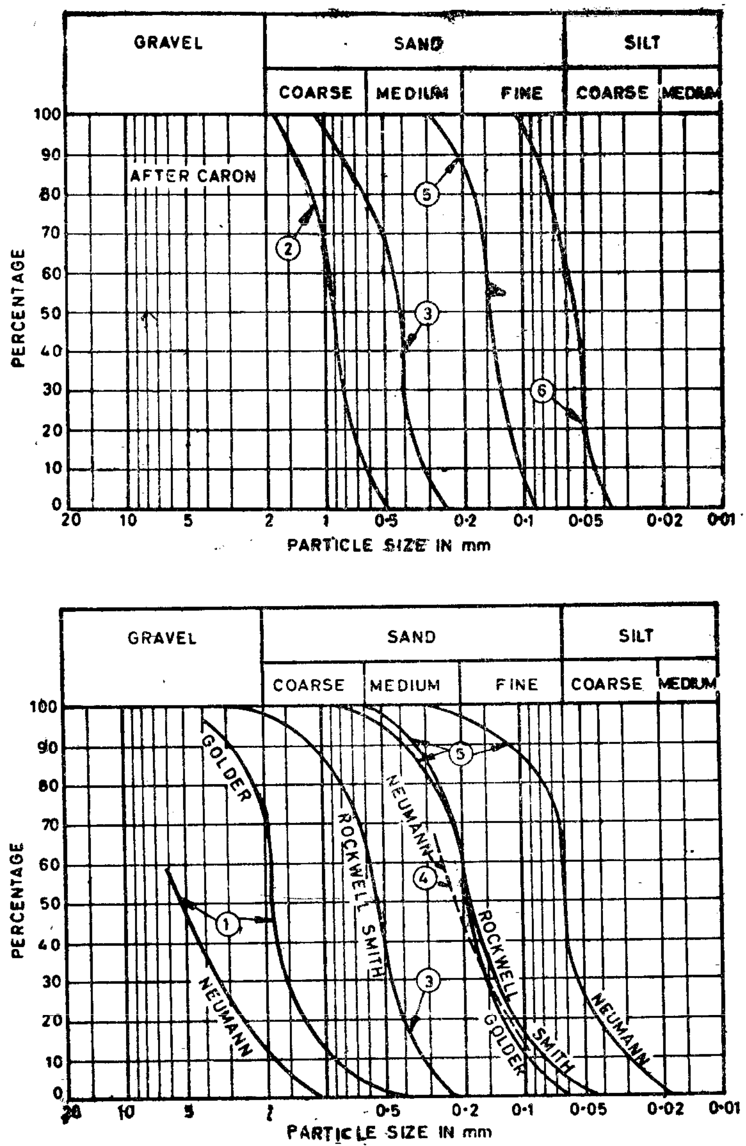
Grout	Material Grouted	Finest Size that Can be Grouted mm	Permeability
Cement	Fissures	0·10	$K > 1$ cm/sec
	Loose sand	$D_{10} = 0·5$	
	Dense sand	$D_{10} = 1·4$	
	Soil	$D_{10} = 0·75$ to 1	
Clay	Soil	$D_{10} = 0·2$	$K > 10^{-1}$ cm/sec
Silicates	Soil	$D_{10} = 0·1$	$10^{-1} > K > 10^{-3}$ cm/sec
		satisfactory results. Difficulty increases with decreasing grain size. Sand-silt or sand clay mixtures cannot be treated at all	
Chemical	Soil	$D_{10} = 0·1$	$K > 10^{-3}$ cm/sec

NOTES

1 Groutability of a uniform granular medium depends on the grain size distribution and the resulting permeability. Hence Table 1 specifies criteria in terms of both these parameters. However, wherever there are difficulties in sampling as narrated under **3.2.2**, more weightage may be given to *in situ* permeability values while selecting the grout material.

2 D_{10}=0·5 mm means 10% particles are finer than 0·5 mm size.

3 Chemical grouts are those grouts which are initially in solution form and which gellify after a predetermined and controllable gellification time.



(1) Cement
(2) Clay Cement
(3) Clay
(4) Silicate (Joosten Process) (Two Shots)
(5) Silicate Gel (One Shot)
(6) Emulsion of Bitumen-Resin

FIG. 4 LIMITS OF GROUTABILITY BASED ON GRAIN SIZE DISTRIBUTION

6.6 Choice of Consistency of the Grout

This depends on the nature of the grout, that is, whether it is a stable suspension or unstable suspension. To be effective, all grouts should eventually form a deposit which would fill the voids in the soil treated. Stable suspensions gellify into volumes which are only slightly smaller than the volume of the grout slurry. Unstable suspensions, on the other hand, lose a large quantity of water in the process of deposition. Hence the following principles govern the choice of consistency of the grout:

a) When excess water can be removed by filtration as in cement grouting of fissures in rock, the water content may be varied at will. Various sequences are used in practice, for example, starting with a fluid mix initially, followed by thickening of grout according to the rate of grout absorption, in the final stages of injection the water content may again be increased.

b) On the other hand, any water in excess of designed water content of the grout mix is undesirable in stable suspensions (cement-bentonite grouts) or in solutions (chemical grouts). Hence care should be taken during grouting to see that no extra water (other than that added as per design) gets mixed with the grout.

6.7 Resistance to Erosion, Solution and Leaching

The resistance of grout to erosion, solution and/ or leaching caused by seepage depends upon its shearing resistance, size of grout particles, the grain size distribution of the soil grouted and the chemical stability of the components of the grout. No general rules have yet been established; however, guidelines based on experience of chemical grouts are detailed in Annex B. Hence it is advisable to verify the stability of the grout by prolonged tests on grouted samples subjected to comparable seepage gradients and by comparison with the strength of grouts successfully used in similar conditions.

7 FIELD CONTROL OF GROUTING OPERATIONS

7.1 Field control of grouting operations involves the following:

a) Choice of the sequence of grouting of holes in the given pattern and the sequence of injection along the depth of each hole;
b) The sequence in which various grout materials have to be injected;
c) Choice of the consistency of the grout; and
d) Control of the pressure, rate of injection (discharge of the grout pump) and the volume of the grout injected.

7.2 While grouting pervious soils, if highly pervious zones or large voids are identified during exploration, such zones should be filled in the first operation preferably with coarser grouts. Otherwise it is difficult to prevent over-travel and wastage of grout. Grouting of zones having relatively finer materials is taken up subsequently by employing more fluid grouts. Under such circumstances it may also be advantageous to grout outer zones first to confine the travel of subsequent grout injection. The inner rows can then be grouted more thoroughly and at a higher pressure. Spacing in the central row may be reduced if possible. If such identification of pervious zones is not possible, then all the holes may have to be grouted with a finer grout first and those holes which indicate higher intake, may have to be grouted gradually with thicker grouts.

7.3 Grout Holes

Subject to the requirements of the width of grout curtain, a minimum of three lines of grout holes is considered desirable. However, in small projects, the outer two rows may be grouted first as contained in **7.2** and then check holes may be drilled along the central row and permeability checked. If these permeability values are within the desired limit, then no further grouting in the central row may be necessary.

7.4 Sequence of Grouting

7.4.1 Grouting of the surface zone of 2 to 3 m below natural ground level is generally unsatisfactory. Hence it should be left ungrouted. After completion of grouting of the zone below, the ungrouted surface zone may be excavated and backfilled with impervious material.

7.4.2 Generally it is advantageous to start with grouting of highly pervious zones, if they are identified during exploration, for example, talus in contact with residual soil or the contact zone of alluvium and rock. The grouting of the strata immediately below or above these zones can be taken up afterwards.

7.4.3 The sequence of grouting along a hole, that is top to bottom or bottom to top, depends on the method of grouting. In the descending stage method, the sequence has to be necessarily top downwards. In the rising tube method, it has to be necessarily from bottom upwards. While when grouting through tubes with sleeves any sequence is possible but it is more convenient to grout from bottom upwards. The initial grouting of more pervious zones should however be completed first as mentioned in **7.4.2**.

7.4.4 When high pressures are used which are liable to crack the soil, the sequence of grouting from bottom upwards is desirable. This will ensure that the cracks, which are always formed above the grouted zone will be filled by subsequent grouting. Such a sequence is not obligatory if it is confirmed by observation and experience that the cracks are too fine to be of any consequence.

7.4.5 While grouting pervious soils, it is customary to begin with coarser and more viscous grouts and follow up in further stages by injections of more fluid and finer grouts. In this way it can be assured that the finer and more fluid grouts, which generally form softer gels, do not fill the larger voids; otherwise there is a risk of internal erosion of such grouts under the action of the hydrostatic pressure operating on the curtain.

7.4.6 During the same stage of grouting, it is desirable to thicken the grout progressively and increase the cement content if the rate of absorption is abnormally high at relatively low pressures.

7.4.7 In the method of grouting through tubes with sleeves, the same hole can be used for the second or subsequent stages of grouting. In the rising tube or descending tube method, fresh holes or redrilling of holes may be necessary for the second and subsequent stages.

7.5 Control of Grout Consistency

In pervious soils as compared to grouting of fissured rocks, the pressures decrease more rapidly with distance. This is because the resistance to flow in the pore spaces in the soils is relatively greater than that in fissures in rock. The divergence of the flow is also more pronounced in soils as compared to the flow through cracks in rocks. Consequently pressures are generally insufficient to remove all the excess water from grouts in soils by filtration. Due to confinement caused by initial injections of coarse and viscous grouts it is also more difficult to remove the excess water. Hence stable suspension or solution grouts should be generally prepared for grouting pervious soils. Close control should be exercised on the consistency so that bleeding is small (preferably less than 5%). Field personnel should not be allowed to increase the water content at will and clear water shall not be injected in the holes during the injection process.

7.6 Control of Pressure

7.6.1 The permissible pressure for grouting is fixed based on experience.

NOTE — The North American practice is to restrict pressures to the overburden pressure. In Europe pressures equal to 5 times the over-burdern pressure, or higher are quite common.

7.6.2 When the pressure is less than the overburden pressure there is no risk of upheaval, cracking or damage to overlying structures. But the spread of grout is liable to be reduced, resulting in closer spacing of holes. It is also necessary to use more fluid and expensive grouts. On the other hand, there is a considerable body of evidence to show that the cracks in the overlying soil are too fine to be of consequence provided that the grout consumption is properly controlled. When grout travels along the cracks, the spread is increased and the range of applicability of low cost grouts is increased. The choice between high pressure and low pressure is therefore a matter of the relative cost of drilling and grouting as well as the cost and availability of more fluid grout materials. The increased consumption of grout in high pressure grouting may often be justified in soil containing a high proportion of material on the margin of groutability of low cost grout.

7.6.3 Cracking and upheaval may not be allowed in rigid structures which may not tolerate differential movement. For treatment of soil underlying such structures, pressures should be kept sufficiently low in order to prevent cracking and upheaval. Limiting the pressure to the overburden stress would be safe. Somewhat higher pressures may be permitted in dense and stiff soils as control can be exercised on the surface upheaval and the rate of consumption as well as the total grout consumption.

7.6.4 In the system of grouting with sleeves, high pressures are required to crack the sheath. High pressures may also be necessary to prevent the cracks in the sheath and surrounding soil from closing. This phenomenon is more common in partially indurated sands or in zones already grouted with clay cement grout. These pressures could be 100 to 150 N/mm² in moderately compact soils, and 300 to 500 N/mm² in dense sands and indurated soils. When high pressures are used the following precautions are desirable:

a) The superficial zone of soil subjected to excessive cracking is removed to a sufficient depth (2 to 3 m) after completion of grouting operations,

b) Close control is to be exercised on the trends of variations of pressure and rate of consumption with time to avoid formation of expanding bulbs of grout,

c) Grouting is stopped when the consumption exceeds a limit which is based on past experience of similar work, and

d) Efficacy of grouting is verified by means of sufficient number of local permeability tests conducted before and after grouting and evaluation of curtain performance is made by piezometric observations or other suitable methods.

7.6.5 The monitoring of grouting operation is very difficult since the strata is generally heterogenous and visual observation is not possible. The time v/s pressure and time v/s intake curves drawn during the operation give adequate knowledge of grout acceptance by underground strata. These curves should be drawn at the site while grouting is in progress and action regarding changes in grouting operation should be taken according to the behaviour of the hole. Some typical curves are given in Fig. 5. Theoretically the rate of grout intake under constant pressure should diminish as grout spreads further and further from the point of injection (curve A_1). Alternatively at constant rate of intake the pressure shoots up (curve A_2). These are ideal curves. The procedure should be continued until refusal.

7.6.6 When grout travels along the crack before it spreads in the soil, rate of grout absorption remains approximately constant over a prolonged period under a constant pressure (curve B_1 and B_2). Under such circumstances, the grouting may be stopped after injecting a predetermined quantity of grout and grouting may be resumed after a lapse of about 48 hours.

7.6.7 Progressive heavy cracking leading to formation of grout bulbs is indicated by a decreasing trend of pressure when the rate of grout intake is approximately constant (curve C_1) or when the rate of absorption increases abruptly while the pressure is held constant (curve C_2). Grouting may be carried out under strict supervision and under lower pressures if required. Spots of leakage may be located and/ or interconnection of the grout holes may also be looked for.

8 CHOICE OF EQUIPMENT

8.1 Choice of Drilling Equipment

Any equipment capable of drilling to the required depth may be used as long as the efficacy of

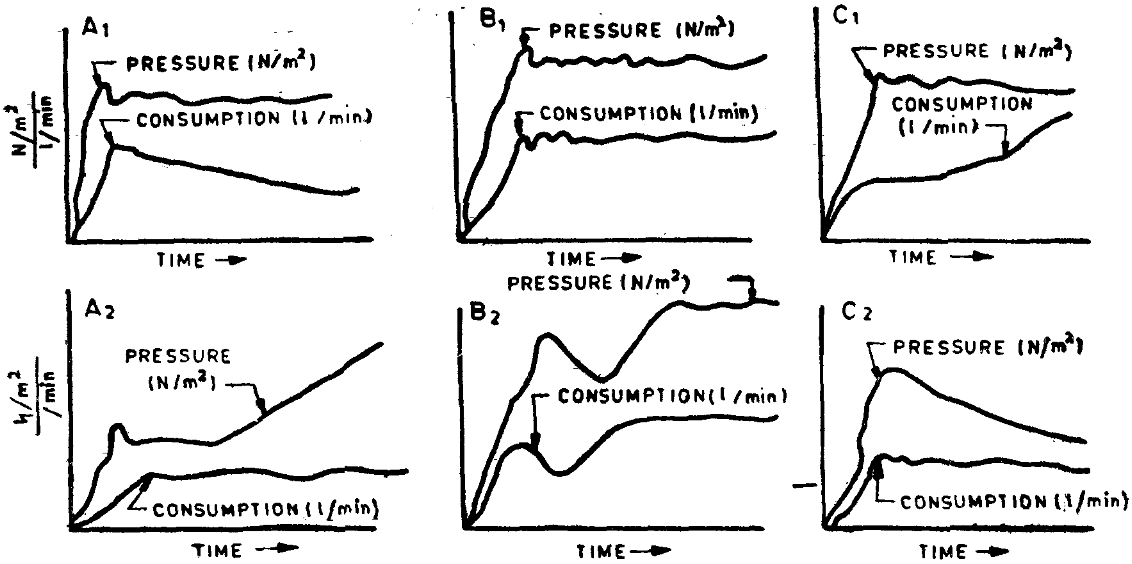


FIG. 5 STANDARD TIME PRESSURE (N/m^2) AND TIME CONSUMPTION (*l*/min) CURVES

grouting treatment is not compromised. From this point of view the factors given in **8.1.1**, **8.1.2** and **8.1.3** should be considered.

8.1.1 When grouting is done at low pressure from an open hole (as in the descending stage or rising tube method), mud drilling is not suitable. The deposit of drilling mud would obstruct the grout flow and it may be difficult to develop pressures high enough to break the 'mud cake' due to leakage along the casing pipe. When sleeved tubes are used the drilling mud is not of any consequences, as the sheath grout is cracked eventually when the 'mud cake' would also be pierced.

NOTE — Sheath grout is a weak grout which could be made using cement and bentonite. Typical mix proportions by weight are : Cement : bentonite of 1 : 2 with appropriate quantity of water. The latter gives 28 days strength of 2 to 4 N/mm^2.

8.1.2 Drilling through embankment of the dam should be performed by caged hole drilling method. In this method, casing of suitable diameter equipped with a suitable bit either percussion driven or rotary driven into the embankment is used. A percussion or rotary drill bit mounted in drill rods is generally used inside this casing. The casing and the percussion bit are advanced together or separately, using separate drives. The casing trails the drill by a few cm. The drill bit is mounted on an accurate coupling so that the drill hole is expanded during rotation of bit to the external casing diameter. Air is used as drilling fluid resulting in very low drilling fluid pressures. This method is likely to reduce the possibility of embankment fracturing during drilling.

8.1.3 Deviations from the alignment are comparatively less when heavy casings are used. In uncased mud drilled holes, deviations may be excessive when large blocks and boulders are present.

8.2 Mixing and Processing Plant

8.2.1 Clay and bentonite (*see* IS 12584 : 1989) generally require processing to remove the coarse fraction. It is desirable to use hydraulic processing equipment (hydro cyclones) and store the processed slurry in large quantities. In this way the clay slurry would be rendered more homogeneous as it is agitated in the storage tanks.

8.2.2 *Mixers and Circulation System*

The apparatus used for mixing and placing grout shall be capable of effectively mixing and agitating the grout and forcing it into the holes in an uninterrupted flow at pressures required for satisfactory penetration of soil. Mixing should be done in high velocity mixers to break down agglomeration of particles and to ensure colloidal suspension. Colloidal mixers are suitable as well as desirable. Mixing plants for chemicals should be designed to achieve the necessary uniformity of mixing. When dosage of any catalyst used is small, dilute aqueous solution should be prepared in advance so that non-uniform mixing and premature gellation are avoided. Arrangements should be made for accurately measuring the quantity of water, cement and other ingredients for grouting. The mixer should have two compartments so that grout may be mixed in one while grout from the other is being pumped. After mixing, the grout should be kept in agitators of suitable design, to maintain the grout in suspension. The grout mixing and conveying system should be laid out to provide sufficient capacity for flow of grout. Upon the completion of any continuous operation all pipes shall be thoroughly cleaned. The agitator shall be provided with a suitable measuring device for controlling and measuring the amount of water used for mixing in the grout. Pressure gauges shall be provided with diaphragm arrangement, or with a short gauge tube filled with semi fluid, water proof grease and oil, or with other devices to prevent the entrance of grout into the gauge. The pressure gauge shall be mounted on a stand pipe so that it will measure the pressure in the hole, preferably, directly on the grout connection itself. The gauge should have a sufficient range.

8.2.2.1 Bentonite slurry of acceptable consistency should be prepared 24 hours in advance and cement should be added just before injection after slurry of acceptable consistency is prepared.

8.3 Grouting Plant

The equipment selected should be capable of maintaining continuous flow of grout and admit of regulation of pressure and rate of injection in the desired range. From this point of view, duplex or single cylinder double acting reciprocating pumps driven by compressed air or by a fluid under pressure are satisfactory provided the pistons and cylinder lining are capable of withstanding abrasion. Valves should also be designed to function without clogging. Electric drives may be used for the pump but return pipes, blow off valves and air chambers are necessary to prevent excessive rise of pressure when resistance to grout flow increases abruptly. Air chambers may be installed to control excessive fluctuations in grout pressure with reciprocating pumps especially when they are single acting.

8.4 Maintenance of Equipment

All equipments shall be maintained in good condition at all times. Pump valves, piston packings, piston rods, cylinder liners and other parts shall be inspected frequently and all parts showing signs of wear shall be replaced. A fine screen capable of being readily removed, cleaned and replaced is desirable between the mixer and agitator pump. Any arrangements of equipment shall be flexible and capable of modification to meet constructional exigencies.

ANNEX A
(*Clause* 5.3.2)

DRILLING THROUGH GRAVELS, BOULDERS AND HEAVY SILT

A-1 Drilling through formations consisting mainly of (i) gravel and boulders or (ii) heavy silt material requires special techniques. Drilling mud may not support sides of holes in such formations and holes cannot remain open for subsequent introduction of grout pipes. Special drilling tools and techniques are available which may be useful in such situations. Typical methods include the following.

A-1.1 Overburden Drilling Method

By a combination of percussion, rotation and water flushing, a drill rod and a casing pipe are simultaneously advanced with the drill hole. Separate cutting bits are attached to the drill rods and the casing.

A-1.2 ODEX Method

This method is similar to overburden drilling method given above, but it involves using of special type of bit on the drill rods. This bit has a folding type cantilever cutter. As the bit drills below the outer casing, the cantilever cutter cuts under the tip of the casing and thus enables downward penetration of the casing simultaneously with the drill rods.

A-1.3 Down-The-Hole Hammer with Special Bits

This equipment is similar to ODEX in principle. It is suitable for large diameter (100-150 mm) holes. The bit has a cantilever cutter, which enables downward travel of the casing pipes over the drill rods. Whenever drilling is stopped, the bit can retract inside the casing pipe and rod assembly with bit can be withdrawn leaving casing in position.

ANNEX B
(*Clause* 6.7)

GUIDELINES REGARDING RESISTANCE OF CHEMICAL GROUTS

B-1 All grouts which contain water that is not chemically bound to the grout particles are liable to mechanical deterioration if subjected to alternately freeze-thaw and/or wet-dry cycles. The rate at which such deterioration occurs varies with the amount of free water available in the grout as well as with the degree of drying or freezing.

B-2 Chemical deterioration of grouts can occur if the grouts react with the soil or ground water to form soluble reaction products or the grout itself is soluble in groundwater or if the reaction products are inherently unstable. There may be locations in which unusual concentrations of strong reactants are present in groundwater and may have deleterious effects on grouts which are otherwise considered permanent. Under such circumstances grout mix design may be done using such groundwater.

B-3 With the exception of sodium silicate grout gelled with a bicarbonate (like sodium bicarbonate), other chemical grouts like sodium silicate formations, acrylamide grouts, lignosolfonate grouts like calcium lignosolfonate, phenoplast grouts like resorcinal formaldehyde grout, ominoplast grouts like urea formaldehyde grouts and water reactive materials such as polyurethane grouts are considered to be more or less permanent grouts.

B-4 Many grouts like sodium silicate grouts exude water and shrink. This phenomenon is called syneresis. In coarse grained soils it may partially negate the initial effectiveness of water shut off. This may result in a residual permeability after several weeks. This may often cause a doubt about permanence.

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