NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP Report 378

Recommended Guidelines for Sealing Geotechnical Exploratory Holes

Transportation Research Board
National Research Council

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Recommended Guidelines for Sealing Geotechnical Exploratory Holes

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Subject Areas

Soils, Geology, and Foundations

Research Sponsored by the American Association of State Highway and Transportation Officials in Cooperation with the Federal Highway Administration

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY PRESS
Washington, D.C. 1995

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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NCHRP REPORT 378

Project 21-4 FY'91

ISSN 0077-5614

ISBN 0-309-05707-8

L. C. Catalog Card No. 95-62216

Price $20.00

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The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation officials, or the Federal Highway Administration, U.S. Department of Transportation.

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Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Printed in the United States of America

FOREWORD

By Staff
Transportation Research
Board

This report will be useful to geotechnical engineers and others who conduct subsurface explorations. It contains the results of a thorough evaluation of the materials and techniques that can be used to effectively seal exploratory holes. Through the research, a set of recommended guidelines has been developed that provides information on properly sealing small-diameter geotechnical exploratory holes; background information is available to validate these guidelines.

Most transportation projects require some type of on-site intrusive geotechnical investigation. Left improperly sealed, geotechnical exploratory holes can provide a pathway for movement of surface or subsurface contaminants within the subsurface environment. Proper sealing of geotechnical exploratory holes can prevent subsurface contamination, loss of ground water, or mixing of ground water.

Under NCHRP Project 21-4, "Sealing Geotechnical Exploratory Holes to Protect the Subsurface Environment," the research team performed a detailed state-of-the-practice review and established sealing criteria on the basis of extensive laboratory testing and field verification. A thorough evaluation of some of the common sealing materials and techniques that can be used to seal geotechnical exploratory holes was performed, and a comprehensive set of sealing guidelines was developed.

The recommended Guidelines are published herein in an easy-to-use format. Readers will note that the research report, "Sealing Geotechnical Exploratory Holes to Protect the Subsurface Environment," is not published. A short video titled "Seals that Work" has also been produced as part of this project as an introduction to future training workshops. For a limited time, copies of both the research report and video will be available on a loan basis or for purchase ($15.00 each) on request to NCHRP, Transportation Research Board, Box 289, Washington, D.C. 20055.

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CHAPTER 1

INTRODUCTION

Most transportation projects require some type of on-site intrusive geotechnical investigation to identify subsurface conditions. Such investigations typically involve drilling and sampling of small-diameter (< 200 mm [8 in.]), geotechnical, exploratory holes to depths of up to 60 m (200 ft) or in situ testing with even smaller-diameter cone penetrometers or other in situ tests. Geotechnical exploratory holes that penetrate the water table and are not properly abandoned by sealing can become vertical pipes for the movement of contaminants from the surface or from subsurface zones, as shown in Figure 1. Proper sealing of these holes can prevent potential subsurface contamination, loss of ground water, or mixing of ground water.

This Guide presents recommendations for sealing geotechnical exploratory holes. Information in this Guide addresses open holes and instrumented holes. Throughout this Guide, ''hole'' is used to refer to exploratory boreholes and probe holes performed in conjunction with transportation-related geotechnical investigations.

The information provided herein is based on the results of NCHRP Project 21-4 sponsored by the American Association of State Highway and Transportation Officials

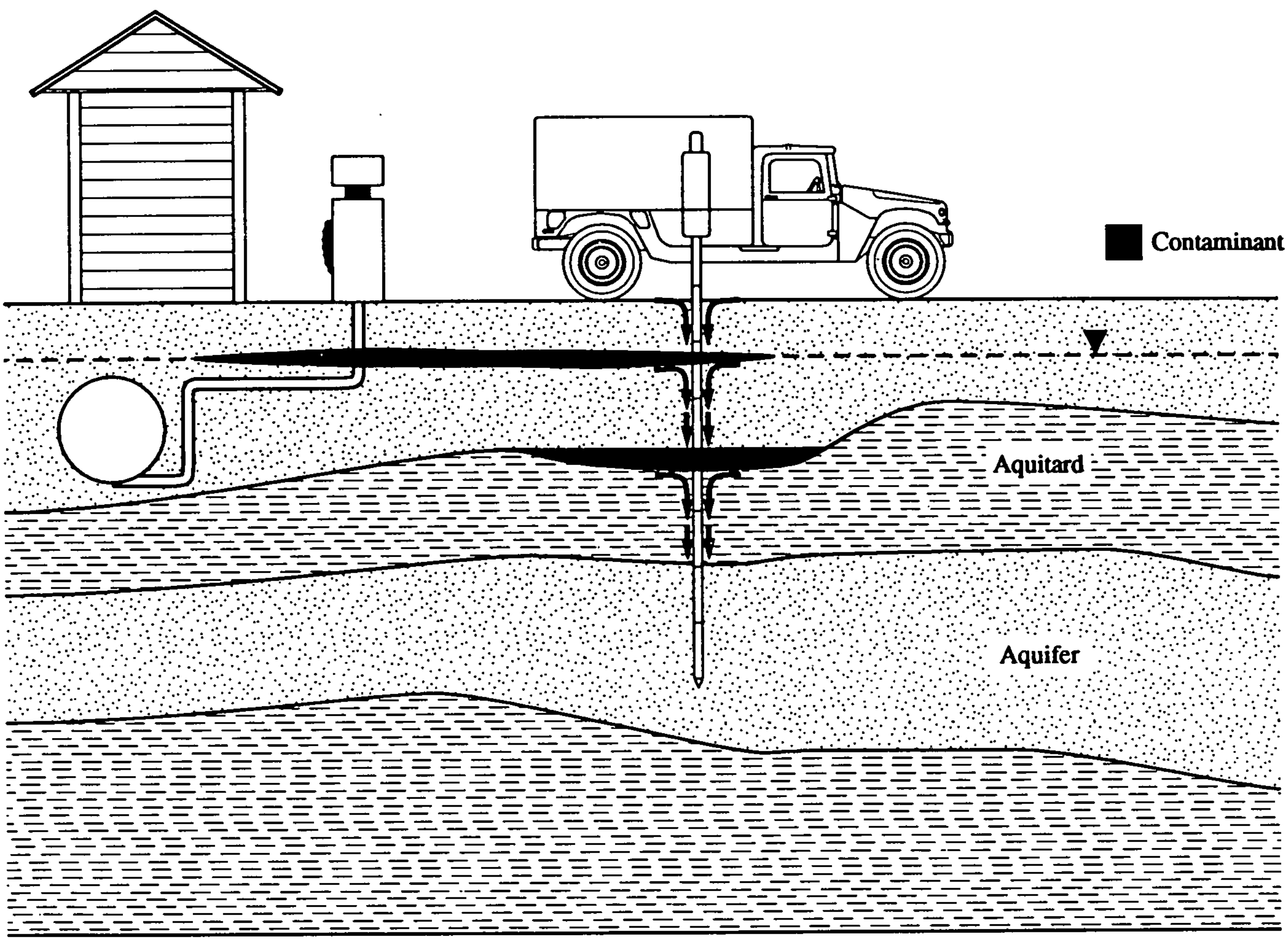


Figure 1. Potential ground water contamination created by exploratory holes.

(AASHTO), in cooperation with the Federal Highway Administration (FHA), and conducted in the NCHRP, which is administered by the Transportation Research Board (TRB) of the National Research Council (NRC). The detailed results of the research, which serve as the basis for the recommendations presented in this Guide, are available from the NCHRP.

CHAPTER 2

BACKGROUND

The recommendations in this document are intended to *help serve as the basis for professional judgement*; the purpose of this Guide is *not to establish regulations*. Additionally, the guidelines presented herein were developed only to address routine, small-diameter (< 200 mm [8 in.]), relatively shallow (<60 m [200 ft]) holes dug as part of a normal site investigation at uncontaminated sites. The guidelines are not intended for use at sites where known contamination exists or where test drilling may discover contamination as a part of the investigation. In these situations, other procedures may be required to control contaminant movement resulting from the site investigation.

2.1 OBJECTIVES OF SEALING

A site investigation performed using drilled or driven holes will penetrate the stratigraphic column and may affect the integrity of the hydrogeologic regime. Generally, this integrity must be restored in order to protect the subsurface environment. *The objective of creating a seal in a hole is to restore the hydrogeological conditions to a quality as good as or better than before the hole was made.* This can be achieved by sealing the hole through selection and placement of appropriate seal material under strict quality control conditions and by verifying the seal installation.

2.2 HOLE ABANDONMENT REGULATIONS AND PRACTICES

Each state has several agencies that deal with or perform the drilling of exploratory and other types of boreholes and wells. These agencies may include the following:

- State highway and transportation departments
- Departments of natural resources
- State geological surveys
- Environmental protection agencies
- Mineral and mining divisions
- Health and environment agencies
- Offices of land and water resources
- State departments of ecology
- State oil and gas boards
- Water management bureaus.

In 1991, a survey was conducted of small-diameter hole abandonment practices in order to identify state and federal regulations. Participants in the survey included:

- State departments of transportation and highways
- Federal and state agencies involved with environmental protection
- Consulting engineering firms
- Societies and organizations involved in drilling activities
- Geotechnical exploration drilling and water well industry personnel
- Manufacturers of various sealing materials and products.

From the responses received, the preferred choices of seal materials in all ground conditions are shown in Table 1. The 1991 survey was not conclusive on who had jurisdiction over the abandonment of holes. Because all agencies are not represented in each state, jurisdiction over hole abandonment varies from state to state.

The survey found that the most common abandonment materials recommended or required by regulations (in order of decreasing preference) were bentonite (in pellets, chips, or grout), cement grout, cement/bentonite grout, cement/sand grout, and cement concrete. Other allowed abandonment materials were native soil cuttings, cement/flyash grout, cement/flyash/bentonite grout, cement concrete/flyash, bentonite/sand grout, and cement/sand/bentonite grout.

There are, as yet, no national or international standards for the proper abandonment of holes. The American Society for Testing and Materials (ASTM) recently developed the *Standard Guide for Decommissioning of Ground Water Well, Vadose Zone Monitoring Devices, Borehole, and Other Devices for Environmental Activities (D5299-92)*, which relied heavily on abandonment practices used in the water well and oil and gas well industry; this standard was intended for large-diameter holes and may not be practical for geotechnical holes. The technology of sealing small-diameter holes is evolving rapidly, however, largely because of heightened environmental considerations.

TABLE 1. Abandonment materials used in current practice

In Exploratory Holes	In Instrumented Holes
Portland cement/bentonite grout	Portland cement/bentonite grout
Native soil cuttings	Bentonite chips, pellets, grout
Bentonite chips, pellets, grout	Portland cement grout
Portland cement grout	Native soil cuttings
Native soil cuttings mixed with powdered bentonite	Chemical grouts
Chemical grouts	Native soil cuttings mixed with powdered bentonite
Other materials	

CHAPTER 3

BACKFILLING VERSUS SEALING

A common practice in geotechnical site investigations is to backfill holes with native soil cuttings, mostly in an uncontrolled fashion. With increased awareness of how these holes can act as conduits for the entry of surface contaminants, the upper 0.3 m (1 ft) is often covered with a bentonite product or cementitious grout. This type of backfilling and surface covering does not prevent the movement of contaminants through the hole, unless the remainder of the hole has been properly sealed. Proper sealing prevents or minimizes the loss and/or mixing of ground water from various aquifers intersected by the hole. Backfilling and sealing are defined as follows:

- Backfilling—Backfilling is the placing of native soil cuttings or other materials in the hole as part of the cleanup or surface restoration procedure. This is largely an uncontrolled process and may only inadvertently produce a seal.
- Sealing—Sealing is the knowledgeable, conscientious construction of a permanent hydraulic barrier in the hole. This is a carefully controlled practice of hole abandonment.

A properly selected and installed seal slows or stops loss or commingling of ground water and the contamination of one stratum by another through the hole. *Proper sealing involves recognizing the importance of hole sealing, knowledgeable seal selection, and conscientious seal placement.*

Even though the use of bentonite and cement powder mixed with soil cuttings as well as compacting soil cuttings in the hole has been shown to enhance their use as a seal, *the practice of creating a seal by backfilling with native soil cuttings is not advocated in this Guide.*

CHAPTER 4

SEAL CRITERIA

To ensure restoration of the stratigraphic integrity, a hole seal should satisfy the following criteria:

1. The seal should have a low permeability (hydraulic conductivity) to prevent water loss, commingling, contamination, or combinations thereof.
2. The seal should possess internal stability and not deteriorate with age.
3. In an instrumented hole, the seal should be compatible with the instrumentation material used.
4. The seal should provide the intended protection of the subsurface environment for a long period of time (i.e., be more or less permanent).
5. The seal should be practical.

All of the materials recommended in this Guide for use as seals demonstrate these characteristics when properly placed.

4.1 SEAL HYDRAULIC CONDUCTIVITY

Hydraulic conductivity is a technical term for permeability (i.e., the ease with which water flows through a soil or rock formation). Hydraulic conductivity, which can be defined as the rate (length/time) at which water flows through soils, is actually a proportional constant that describes the relationship between the flow velocity and hydraulic gradient. Sandy soils have high hydraulic conductivity — water flows through easily. Clayey soils generally have low hydraulic conductivity — water does not flow through them easily. The purpose of a hole seal is to provide a hydraulic barrier; therefore, appropriate seals are materials that provide low hydraulic conductivity when properly placed. Generally, a hole seal should have a value of hydraulic conductivity as low as or lower than the least permeable soil stratum encountered in the exploration with a practical lower bound value of 1×10^{-7} cm per sec.

4.2 INTERNAL SEAL STABILITY

A seal without internal stability may deform, squeeze into the sidewalls of the hole, and be unable to support the weight of additional sealing or other backfill materials. To maintain internal stability, the seal material should meet the following criteria:

1. The seal should not enter the surrounding soil or rock formations because of hydraulic pressures or gradients or other ground water and formation conditions.
2. The seal should prevent internal erosion (also known as piping) by flow of water.
3. The seal should achieve a proper plug-type seal within the hole and not easily penetrate into porous formations (resulting in loss of material).

4.3 SOIL-SEAL COMPATIBILITY

The seal material should provide a satisfactory, watertight bond at the hole wall/seal interface and should, therefore, be compatible with the natural soils around the hole. Sidewall leakage between the seal material and the inside of the hole can occur if the seal material shrinks or loses volume over time. Water flowing between the seal and the surrounding soil may erode the seal or the native soil or both, enlarging the gap further and making the seal ineffective.

4.4 MATERIAL-SEAL COMPATIBILITY

For instrumented holes, the seal material should be compatible with instrumentation materials and hardware in order to provide a satisfactory, watertight bond at the instrument/seal interface.

4.5 SEAL LONGEVITY

The seal should be considered a permanent repair so that the original hydrogeological conditions are maintained or improved upon completion of the geotechnical exploration activity. In most transportation practice, an effective life span of 15 to 20 years is considered adequate because of potential construction at the exploration site and the subsequent destruction of the exploratory holes.

CHAPTER 5

PRACTICAL CONSIDERATIONS FOR CREATING A SEAL

Seals may be characterized on the basis of their potential for success as either material dependent or placement dependent. Material-dependent seals are those that are generally insensitive to placement and perform successfully, regardless of placement technique, i.e., provided they are delivered to the right location, they generally perform well. Placement-dependent seals are those that require proper placement for success and generally only perform satisfactorily if great care and specific procedures are used in the seal construction. Material-dependent seals, which will perform successfully even under the poorest of construction practices or conditions, are preferred.

Practical considerations in the creation of a seal are as follows:

- Ease of construction
- Seal location
- Seal length
- Availability of materials and equipment
- Cost.

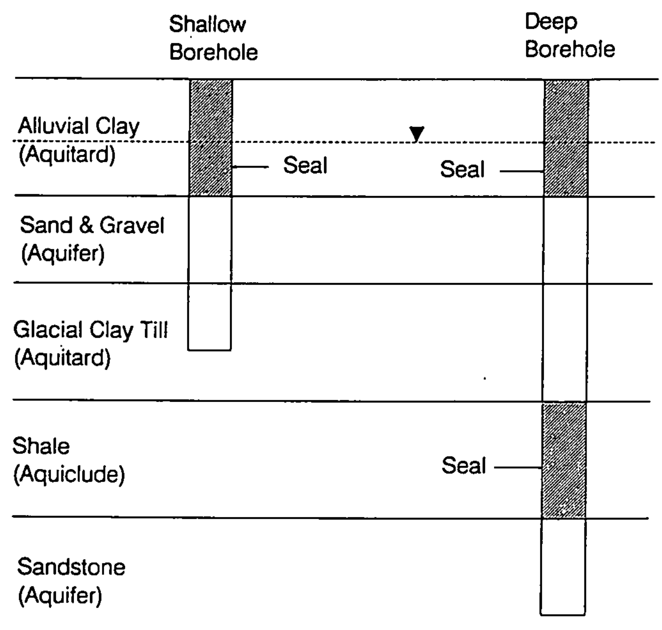


Figure 2. Location of seals to protect aquifers.

5.1 EASE OF CONSTRUCTION

The seal should be easy to construct. Materials should be readily available, non-toxic, and easily handled. Seal "recipes" need to be somewhat flexible without compromising final integrity so that deviation from the recipe in the field will not jeopardize the successful performance of the seal. Field personnel should be knowledgeable about alternative seal materials and placement methods in order to accommodate unexpected field conditions. The integrity of the seal should not depend solely on the quality of construction.

5.2 SEAL LOCATION

The most logical location for a seal within a hole is in stratigraphic units, which act as ground water protection layers, as illustrated in Figure 2. Seals should normally be placed within stratigraphic units that act as aquitards or aquicludes. These are formations that slow down or prevent the flow of ground water, respectively. Aquifers (water-bearing formations) generally are confined between aquicludes and aquitards. Seals placed the entire length of the hole are easier to construct than seals within isolated zones of the hole, i.e., partial seals. A full-length seal may cost more in material charges, but the time and labor costs are likely to be less than for a partial seal.

5.3 SEAL LENGTH

Contaminant movement in the subsurface environment occurs by two basic methods—advection, where the water "carries" the molecules of contamination, and diffusion, when contaminant molecules move from areas of higher concentration to areas of lower concentration. Proper sealing should reduce contaminant movement by both these mechanisms. A full-length seal minimizes advective transport by physically lengthening the travel path of contaminant flow. Diffusion is minimized by choosing a seal material that matches the properties of the soil before the hole was made. There are additional reasons for placing seals full length in the hole. Seal length should provide a sufficient margin of safety if part of the seal does not perform satisfactorily. If an isolated section of the seal fails, the remaining length of seal should provide the required protection.

Partial seals may be appropriate in situations where an aquifer is beneath an aquiclude or aquitard layer extending to the ground surface and drilling progresses into the subjacent aquifer. For example, a partial seal may be appropriate in the upper layer of a permeable sand and gravel aquifer or porous or fractured rock underlying a surficial clay layer. For this to be successful, a plug may be necessary at the interface between the two strata or backfill may be required up to the boundary to support the overlying seal.

5.4 AVAILABILITY OF SEAL MATERIALS AND EQUIPMENT

The most technically acceptable seal material is of limited practical use if not readily available or if the equipment needed to place it is not available. All of the materials described in this Guide for use as seals are easily obtained through local suppliers in most parts of the United States. Equipment for placing dry seals can be easily fabricated from materials obtained through local hardware suppliers. Mixing equipment for liquid seals can be obtained from drill rig manufacturers. Most drilling rigs are equipped with a grout pump, which can be used to place liquid seals.

5.5 COST

The seal should be economical to construct. Cost is, therefore, an important factor in seal selection and placement and includes the cost of the seal material and material wastage; the cost of placing and mixing equipment; the cost for the time taken to mix, place, and cure the seal; and the cost of shipping, storage, security, transportation, and handling. Other added costs in placing seals may include drill rig standby time, additional labor to reroute traffic for longer periods, and added personnel The time taken to install a seal is important, because equipment, crew, and traffic safety charges accrue hourly and could exceed, by several times, the cost of the sealant material itself. Comparisons between various sealing options should consider these cost factors as well.

CHAPTER 6

DESCRIPTION OF SEAL MATERIALS

Although various seal materials are being used or advertised for use in hole abandonment and other ground improvement techniques, some of these products were developed for applications such as slurry trench wall excavation, grouting of fractured rock, and soil stabilization; such seals may work effectively in one application but not in another. Traditional sealing materials in common use for borehole abandonment include bentonite, Portland cement, chemical grouts, compacted native clayey soils, and various combinations thereof.

6.1 BENTONITE

Bentonite is a naturally occurring mineral whose main constituent is a hydrous aluminum silicate clay mineral, montmorillonite. In pure form, bentonite can absorb 8 to 10 times its weight in water, which causes expansion, or swelling, of 10 to 15 times the dry volume. This swelling characteristic makes bentonite an excellent seal material that expands against the walls of the hole or instrumentation hardware. The degree of swelling of bentonite depends on the nature of the cations or positively charged ions in the clay. A sodium-rich bentonite swells more than a calcium-rich bentonite because of physico-chemical effects. If a sodium bentonite is used as a seal material, its effectiveness could be decreased if the seal comes into contact with ground water or fluids rich in calcium; such contact results in cation exchange. When moist, bentonite is soft, flexible, and pliable. This flexibility ensures a watertight seal of irregularly shaped openings. Bentonite is not affected by most common ground water environments, but the presence of either high amounts of dissolved solids or chloride materials in the water or high concentration of organic solvents or separate phase hydrocarbons can reduce swelling properties. To be an effective sealant, the swelling properties of dry bentonite must not be affected by the water from the ground or by water added to the hole.

Commercial bentonite is available in several manufactured forms, including pellets, chips, granules, and powder. These are discussed in detail in the following sections.

6.1.1 Bentonite Pellets

Bentonite pellets are formed by high-pressure compression of moistened bentonite powder into small-diameter spheres, cylinders, or tablets. Pellets typically have a low moisture content, high density, and uniform size, ranging between 6.5 mm (¼ in.) and 13 mm (½ in.) in diameter. Pellets are normally made from sodium montmorillonite, which has a high affinity for water and will hydrate or absorb water upon wetting. Hydration of the surface of these pellets causes the hydraulic conductivity to decrease, thereby slowing the water absorption inside the pellet. Pellets need time for full hydration. When fully hydrated, the pellets expand four to seven times their original size. The actual amount of swelling in a hole depends on confinement—the greater the confinement, the more controlled the swelling but the higher the swelling pressure.

Premature swelling, which can occur when the pellets are dropped into a hole with standing water, may cause pellets to stick to the sides of the hole or casings or augers and prevent or slow the fall of newly added pellets. This type of blockage, called "bridging," occurs when material unites to plug the hole, thereby preventing penetration of new material. Bridging occurs more easily in smaller-diameter (<75 to 100 mm or 3 to 4 in.) holes. To reduce the potential for bridging, the rate of pellet addition to holes should be carefully controlled.

Some manufacturers, to reduce the potential for bridging, coat bentonite pellets with a water-soluble organic resin or other coating to protect against rapid hydration when poured through a column of water. The coating provides the pellets with more time to fall, under their own weight, through a column of water without swelling excessively on the way down. This can be particularly important when pellets must fall long distances. The coating eventually dissolves in water, allowing the pellets to hydrate completely.

6.1.2 Bentonite Chips

Bentonite chips are irregularly shaped chunks of raw-mined montmorillonite, which have been air dried at the plant, broken up, and sieved into different sizes (normally 9.5 mm [3/8 in.] [medium] and 19 mm [3/4 in.] [coarse]). Chips look like crushed limestone and are angular to subangular in shape. Bentonite chips generally hydrate and swell more slowly than pellets. Because of their lower density, bentonite chips also tend to expand less than pellets. When chips are added to a hole too fast, they can also form bridges;

when placed too slowly, they hydrate on their way down, making the water column denser, slowing down the rate of fall of other chips.

6.1.3 Granular Bentonite

Granular bentonite is raw-mined montmorillonite that has been crushed and sieved to a 2.9 mm to 0.85 mm size (No. 8 to No. 20 mesh, U.S. sieve designation) and looks like coarse lawn fertilizer. Granular bentonite can be poured in its dry form into a hole but must be kept from the side of the hole to prevent bridging. Usually, this requires the use of a tremie pipe with a funnel placed at the top. In water-filled holes deeper than about 5 m (≈15 ft) granular bentonite may not reach the bottom because of hydration within the water column and, therefore, may not be a good seal choice. Hydration increases fluid density within the hole and slows the fall of new material. Granular bentonite is best used when premixed with water to produce a slurry and then placed using appropriate methods as described in Chapter 9.

Dry granular bentonite can also be delivered, through small-diameter (12 mm or ½ in.), flexible tubing, to depths exceeding 100 m (≈300 ft) by using sufficient air pressure to keep the water out of the tubing while the bentonite is being injected into the hole. This method of dry injection is described later.

6.1.4 Powdered Bentonite

Powdered bentonite is raw-mined montmorillonite that has been pulverized in the processing plant to produce a fine powder, with the appearance of flour, generally finer than 0.075 mm (No. 200 mesh, U.S. sieve designation). Although bentonite pellets, chips, and granules can be used in their commercially available dry form in certain cases, powdered bentonite is most commonly mixed with water before use. A well-known use of bentonite powder is drilling mud. Powdered bentonite absorbs water almost immediately because of the fine size of the particles. Drilling muds are designed to have a low solids content (5 to 10 percent by volume) to aid in the removal of soil and rock cuttings and sufficient fluidity to remain pumpable. For the very reasons that powdered bentonite is chosen for drilling muds, it makes a poor slurry material for hole sealing. A good seal requires a high solids content mix per unit length of hole; therefore, special proprietary formulations of bentonite have been developed that ensure a solids content of 30 percent or more while maintaining the fluidity of the mix. Solids content is defined as the ratio of weight of solids to total weight of solids plus mixing water.

6.1.5 Applications of Solid Bentonite Seals

In exploratory holes that are initially dry on completion, bentonite pellets, chips, and granules still may be acceptable as sealant materials. In holes with standing water, pellets and chips are preferred over granular bentonite, and chips are preferred over pellets. The recommended use of bentonite pellets and chips as sealant materials is shown in Table 2. In some instrumented holes, centralizing devices may be used to keep the instrument casing in the center of that hole. In these cases, the use of solid bentonite seal materials may be difficult because seal placement may not be easy to accomplish. A grout mixture may be a more appropriate seal.

Prior to use, the pellets and chips should be immersed in ground water from the hole or potable-quality water in a container to see if they swell at least four to five times their original size in 24 hours. They should not be used if swelling is limited or does not occur.

Hydrated bentonite materials, such as chips, pellets, and grouts tend to dry out or dehydrate and shrink when left exposed to the atmosphere. Most natural soil deposits contain sufficient water so that if these materials are allowed to hydrate properly upon initial placement (either by placing as a slurry or by adding water) they will generally remain in their expanded form. Because of their high affinity for water, even if there is a tendency for drying, they pull water from the surrounding soil. Because of direct contact with the sun and wind, the surface 0.3 to 0.6 m (1 to 2 ft) may show signs of drying and shrinkage cracking; however this is considered to have a negligible effect on the integrity of the remainder of the seal. In fact, usually after a rainfall, the bentonite will rehydrate and expand.

Charts provided in Appendix A present an estimate of the amount of bentonite pellets/chips needed to fill various sizes of holes.

6.2 PORTLAND CEMENT

Portland cement is produced by blending limestone, sand, shale, blast furnace slag, and other aluminum- and iron-bearing materials in various proportions and then baking this mixture in a high temperature kiln to form a clinker. The clinker is cooled and ground to a fine powder. Approximately 5 percent of gypsum (calcium sulfate) is added during grinding to control the setting time. Setting time is also controlled by the fineness of the grind. High early strength cements are normally ground much finer than normal Portland cement.

Portland cement is formulated into different types and classes. Each formulation has slightly different properties, controlled by changing the amounts of the major components and by the fineness of the grind. Unlike most bentonite, Portland cement hardens after hydration, even under water. Therefore, it is applied as a slurry or grout and seldom used in its raw form. Hardened cement retains the shape of the cavity into which it has been placed.

The heat of hydration produced by a cement slurry occurs when water reacts with the cement. The heat of hydration

TABLE 2. Recommended use of bentonite pellets and chips

Hole Dia. (mm)	Depth of Hole (m)	Pellets 6.5mm (1/4")	9.5mm (3/8")	12mm (1/2")	Chips Medium	Coarse
<60	<3	●	●	-	●	-
	>3	-	-	-	-	-
>60≤100	<3	●	●	●	●	●
	3-10	●	●	●	●	●
	10-20	●	●	●	●	●
	20-60	-	●	●	●	-
100≤200	<3	●	●	●	●	●
	3-10	●	●	●	●	●
	10-20	●	●	●	●	●
	20-60	-	●	●	●	●
>200	<3	●	●	●	●	●
	3-10	●	●	●	●	●
	10-20	●	●	●	●	●
	20-60	-	●	●	●	●

- not recommended

or the amount of heat produced depends on the chemical composition of the cement and its fineness of grind. The heat of hydration can become so high as to soften thermoplastic well casings and screens. PVC and similar casings have failed in deep holes when they were set in place with cement grouts. The heat of hydration combined with the lateral pressure of the soil at depth can be greater than the strength of some piping materials. Portland-cement-based grouts, including Portland cement concrete (PCC) produce excessive wear on pumps and other mixing equipment, present some cleanup problems, and are difficult to use in freezing temperatures.

6.2.1 Portland Cement Slurry (Neat Cement)

A neat cement slurry is a mixture of Portland cement and water with or without additives and with or without sand. As a general guide, mix water of drinking quality should always be used to produce Portland-cement-based seals.

A cement slurry can be mixed and worked for up to 4 hours, allowing it to be easily placed from the surface. When cured, cement slurry seals are generally stable and strong and exhibit low hydraulic conductivity; however, the use of Portland cement slurries for sealing holes has the following drawbacks:

- Long set time, generally 24 hours
- Shrinkage of 5 to 20 percent after curing for most common mixes in the presence of limited water
- High heat of hydration, which could collapse plastic casing and screens
- Possible production of excessive hydroxyl ions (OH^-), which could affect ground water quality (i.e., increase pH).

6.2.2 Portland Cement/Bentonite Grout

Additives alter the properties of a cement mixture and generally are used to control shrinkage or to improve the pumpability of the mixture. A common additive is bentonite, which is classified as an extender. Extenders increase yield but decrease density. Yield can be defined as the volume of grout produced by the mix. Extenders also increase the amount of water in the mix. The use of extenders prevents separation of water from the slurry. Extenders are particularly useful in avoiding lost circulation in pores, fractures, and weak zones of geological formations.

Bentonite is added to the cement slurry either by dry blending with the cement or by prehydrating with the mix water. The normal practice is to add between 1 and 5 percent by weight of bentonite to the mix water before adding the cement, keeping the mixture continuously agitated. The use of bentonite in a cement slurry has the following effects:

- The hydraulic conductivity of the set cement seal is reduced.
- The viscosity of the slurry is increased.
- The sealing properties of the slurry are improved; fluid losses are reduced.
- Pumpability time is extended but strength development is delayed.
- Compressive strength is reduced.
- Resistance to chemical attack from formation waters is reduced.

6.2.3 PCC

Some state agencies allow PCC as a hole seal material. In general, PCC has the same hydraulic conductivity as neat cement but higher strength. Because the mix contains sand, and occasionally both fine and coarse gravel, its applicability for sealing holes less than about 75 mm (3 in.) in diameter is limited; however, PCC is and can be used for wellhead protection, grouting-in of protective casings, and other work near the ground surface. PCC tends to segregate when placed in deep holes by gravity methods. The use of PCC as a seal material in deep, small-diameter holes requires placement by tremie pipe methods.

6.2.4 Microfine Cement

Microfine cement is a cementitious grouting material composed of ultra-fine particles of cement. Its major advantage over normal Portland cement is its ability to penetrate fine sands and thin fissures. The hydraulic conductivity of microfine cement can be as low as 10^{-9} cm per sec, even when made with water from hazardous waste sites. Microfine cement is available as MC-100 to MC-900. The higher the number, the finer the grind. MC-100 is mixed with a dispersant and water in order to penetrate fine sand and thin fissures in rock. MC-500 is finely ground Portland cement and slag mixed with sodium silicate. It is used in underground works for ground water control.

Microfine cement grouts consist of one-component or two-component mixes. One-component microfine cement is used to reinforce building foundations or to rehabilitate dam grout curtains. The one-component mix consists of water, a suitable dispersant, and MC-100. The two-component microfine cement (generally used for underground water control) is made from water, a suitable dispersant, and MC-500 mixed in one tank, while sodium silicate and water are mixed in another tank. The two components are pumped through a single pipe for shallow grouting. For deeper grouting, each component is pumped through a separate pipe.

6.3 OTHER MATERIALS

Several other materials have shown potential as borehole sealants. These are discussed further in the following sections.

6.3.1 Chemical Grouts

A chemical grout is defined as a pure solution with no particles in suspension. The earliest use of chemical grouts was in 1925 when the Joosten process was patented. In this process, a strong solution of sodium silicate is injected into one hole and a strong solution of calcium chloride is injected into an adjacent hole. The resulting chemical action "solidifies" the soil between the points of injection. In the 1950s, chemical grouts, which were composed of a mixture of organic chemicals, were introduced into the United States. Because of potential neurotoxicity, some of those grouts were removed from the market. In the late 1970s polyurethane was introduced as a grouting material but was used primarily for waterproofing. Acrylate grouts designed specifically to control infiltration at sewer joints have also been introduced. They contain no acrylamide monomer, the toxic component of earlier grouts. Chemical grouts can be classified into various groups as follows:

- Silicates
- Lignosulfates
- Phenoplasts
- Aminoplasts
- Acrylamides
- Polyacrylamides
- Acrylates
- Polyurethanes.

Of these, lignosulfates, acrylamides, and polyurethanes can be highly corrosive. Consequently, their use with metallic casings should be considered carefully, particularly in a moist environment. For sealing holes, chemical grouts need to be non-toxic, should not leach into the ground water, should remain insensitive to common ground water chemicals, and should not shrink upon wetting and drying.

Lignosulfates, phenoplasts, and acrylamides are not acceptable for either wet or dry conditions because they contain toxic components. Aminoplasts (urea formaldehydes) also contain components considered to be health hazards and, in general, require an acidic environment (pH < 7.0) for proper gelation. Most soils and sites where cement is used have a pH of 7.5 or higher, which reduces the effectiveness of chemical grouts. Sodium silicates are acceptable from an environmental point of view, but their hydraulic conductivity is no better than that of compacted soil cuttings.

Of the chemical grouts available, polyurethanes appear to be the best choice for sealing holes. This class of grout has EPA approval for contact with potable water and consists of a urethane liquid containing toluene diisocyanate and acetone. Polyurethane grout should not be allowed to stand in pumps, lines, and in other mechanical equipment for more than 2 to 3 days. All lines and hoses should be moisture proof because the chemical is sensitive to moisture and reaction occurs on first contact. The shelf life of the supplied product is reported to be a year given proper storage conditions; however, the useful life of the grout decreases once the container is opened.

The water-to-chemical grout ratio ranges from 1:1 to 15:1 (by volume). In ratios of 1:1 to 4:1, a foam results. In higher ratios from 5:1 to 15:1, a gel results. With a water-to-chemical grout ratio by volume of 8:1, the product will start gelation in about 30 sec, gaining strength within a minute. The mix water should have a pH between 5 and 9 and preferably around 7. The manufacturer's recommendations should be followed when using this product, as well as any additives such as accelerators, cleaners, gel control agents, and gel-reinforcing agents.

Because of high cost and mixing requirements, chemical grouts may have limited applications as a seal material for exploratory holes, especially if less expensive and equally effective alternative sealant materials are available.

6.3.2 Bentonite/Soil Slurry

The use of a thick slurry of bentonite with entrained soil (either native soil cuttings or sand) has been used extensively as a hydraulic barrier in slurry wall applications to reduce contaminant movement through soils of high hydraulic conductivity. Typically, the added soil provides a skeletal framework that helps gel the slurry. The mix must be preengineered for each specific application; therefore, it generally is not possible to give a general composition of the slurry; however, a typical slurry seal of this type would be at least 10 percent bentonite and have a total solids content of at least 30 percent.

6.3.3 Bentonite/Cement Grout

Bentonite slurry with added Portland cement has been used successfully to create grout curtains that serve as impermeable barriers. The amount of cement added to the mix will depend on the quality and quantity of bentonite used and can range from 10 to 50 percent by weight of the bentonite.

CHAPTER 7

SEAL SELECTION

Correct seal selection will help ensure that a hydraulic barrier has been created along the hole using economical, readily available seal materials and installed in the least possible amount of time under verifiable conditions of quality control. *Proper seal selection requires an understanding of the properties and an appreciation of the limitations of each seal material* and depends on several variables such as ground water conditions, hole characteristics, and the time available to install the seal.

7.1 SEAL SELECTION FACTORS

Seal selection requires a knowledge of the ground water conditions and whether or not the exploratory hole has penetrated the water table, because the use of bentonite products as seal materials depends on this knowledge. At some sites, ground water conditions will not be immediately known or apparent upon completion of the hole. In the absence of this information, the position of the ground water table cannot be assumed.

The diameter and depth of the hole are important considerations in seal selection. Bentonite pellets and chips may be unsuitable for placement in deep, smaller-diameter holes but quite suitable for shallow, large-diameter holes.

Instrumented holes often have very small annular spaces. A seal material that works well in an open hole the same size as the instrumented hole may not be effective in an instrumented hole, primarily because of the inability of the seal material to penetrate narrow or confined annular spaces. In some types of instrumentation, such as slope inclinometer installations, the manufacturer's recommendations for setting the inclinometer casing should be followed. Special mixes may be recommended to ensure that movement of the inclinometer casing and the ground do not break the seal.

Time is of the essence when working along freeways and other crowded or urban areas. Holes should be drilled and completed in a few hours. The material selected for sealing holes under such constraints should be capable of being placed in a relatively short time (30 to 60 min).

7.2 SEAL SELECTION PROCESS

A single sealing methodology is not appropriate for all situations because hole characteristics, ground water conditions, experience of field personnel, and other factors all vary. To assist in the selection of appropriate seal materials for use in different situations, seal selection charts are presented here (see Figures 3, 4, and 5) and in Appendix B.

Before selecting a sealing methodology, personnel should review available site information to determine whether ground water is present and reliable at the site. This information may come from prior experience in the area, expert knowledge of the piezometers, or initial test drilling.

Situations may exist where there is no information about the presence of ground water in the investigation area. This may occur when drilling in a new area where there is no previous experience with the hydrogeologic conditions. If the presence of ground water cannot be determined or ensured, the only recommended seal choices are Portland-cement-based grout mixtures (see Figure 3). Bentonite-based seals are not recommended because of the potential shrinkage associated with dehydration of bentonite.

Where the ground water table is within the upper 3 m (10 ft) of the ground surface, personnel should follow the instructions in Figure 4. For ground water depths greater than 3 m (10 ft), personnel should follow the instructions in Figure 5.

This separation is intended to allow the use of solid bentonite materials directly to the ground surface in appropriately sized holes. Even with the ground water table located at a depth of about 3 m (10 ft), there will be sufficient soil moisture available in most situations to keep the bentonite hydrated and prevent shrinkage. Additionally, the strong capillary attraction provided by the bentonite will tend to pull sufficient ground water from depths ≤ 3 m (10 ft) to keep the bentonite moist. Where the ground water table is located well below 3 m (10 ft) deep, there is no guarantee of the soil conditions having sufficient water for this condition to occur. At intermediate depths, for example just greater than 3 m (10 ft), it could be argued that sufficient water is available; however, the recommendations of branching at 3 m (10 ft) is recommended for consistency. Using this same logic, it could be argued that solid bentonite materials could be used as high as 3 m (10 ft) above the water table when using Chart B. For example, if the water table is at 6 m (20 ft), and the hole is 10 m (30 ft) deep, solid bentonite could be placed in the lower 7 m (24 ft) of the hole and then some other seal material placed above

1. Nominal diameter (d) of borehole (mm) = ____________

2. Nominal depth (D) of borehole below ground surface (m) = ____________

3. If known, depth of ground water table (GWT) below ground surface (m) = ____________

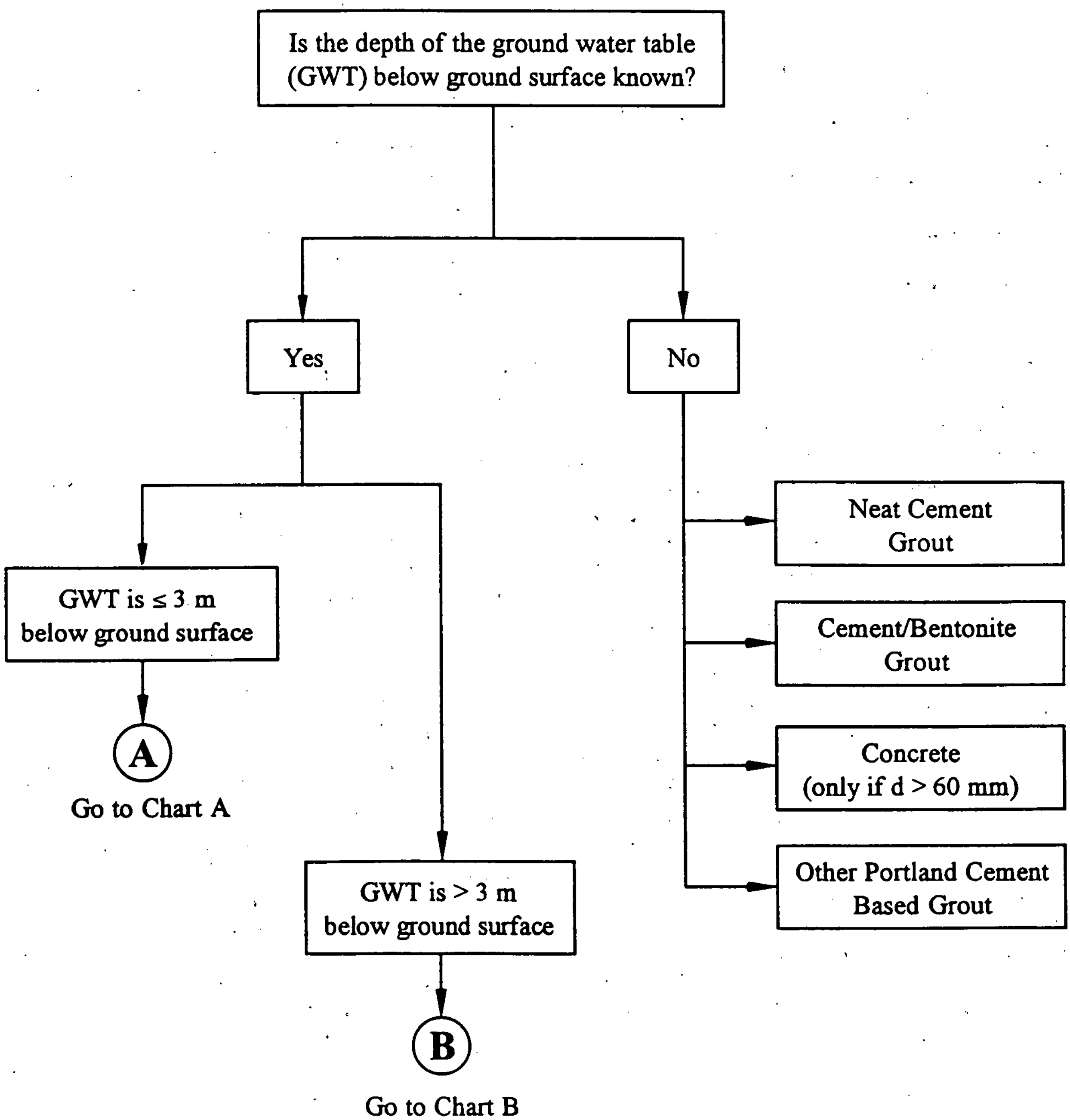


Figure 3. Borehole sealant selection main chart.

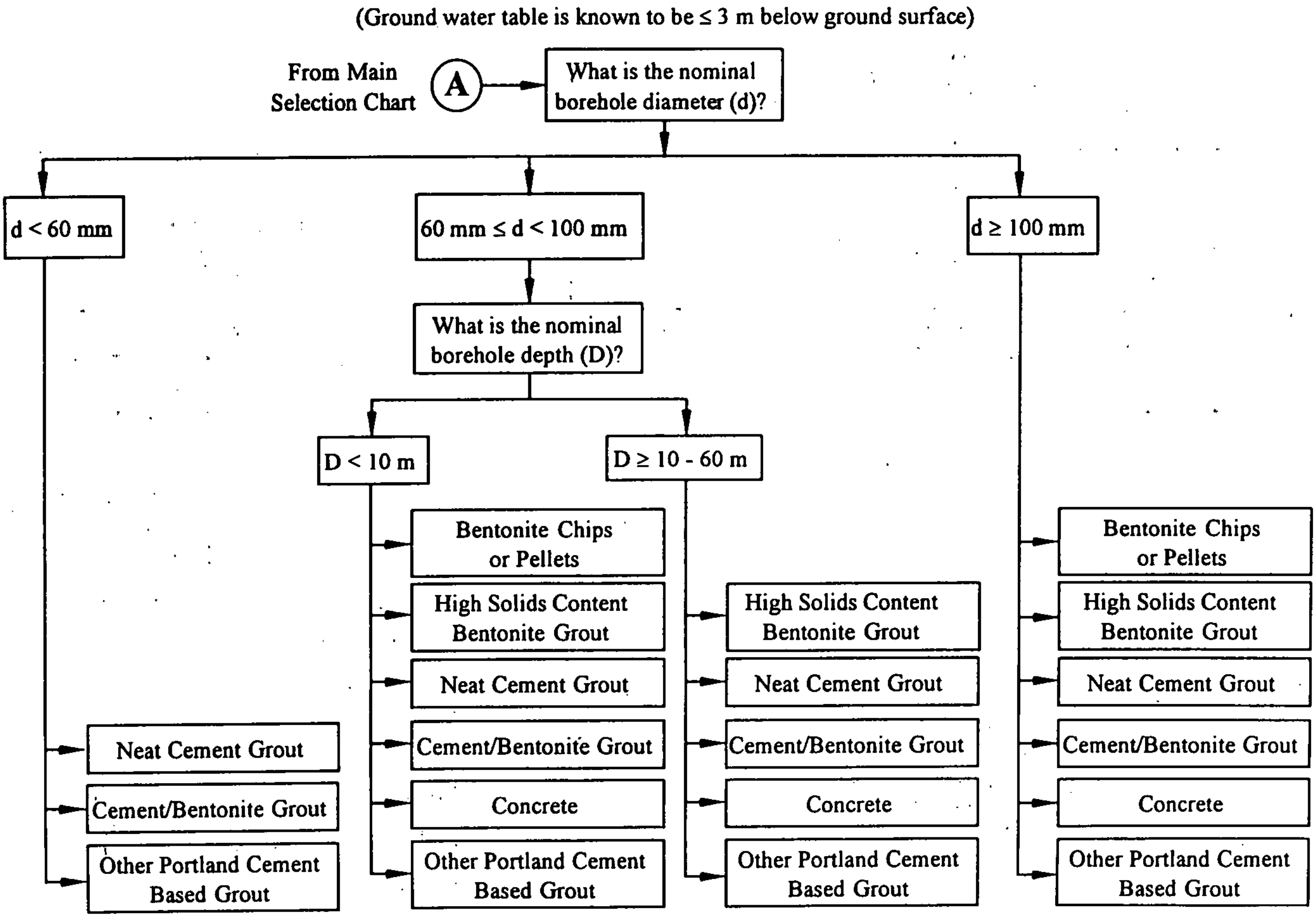


Figure 4. Borehole sealant selection chart A.

3 m (10 ft). Mixing of seal materials in the same hole, however, may not be practical or efficient.

The size of the hole or the annular space between the edge of a hole and instrumentation hardware (such as a standpipe piezometer or an inclinometer casing) may prohibit the use of some seal materials because of the difficulty of placement. *The more difficult a seal material is to place, the less likely will be the success of the seal.* For purposes of seal placement, the diameter of the hole is defined as the size of the opening into which the seal is being placed. For example, if a seal is being placed in a 100-mm (4-in.) borehole produced by solid stem augers, the size of the hole is 100 mm (4 in.). If, on the other hand, a seal is being placed through the center of 108-mm ($4^1/_4$-in.) inside diameter, hollow-stem augers, which actually create a hole close to 194 mm ($7^5/_8$ in.) (i.e., the outside diameter of the flights), the hole size is 108 mm ($4^1/_4$ in.). In calculating the volume balance, the full size of the hole would be used, i.e., 194 mm ($7^5/_8$ in.). In instrumented holes, the appropriate size to use in the chart is the minimum spacing between the wall of the hole and the instrumentation.

The depth of the hole may also restrict the use of certain seal materials because of difficulties associated with placement of some materials beyond a certain depth. This is especially important if seal materials are being placed by surface pouring and are expected to reach the full depth of the hole. Length restrictions are different for different sizes of holes because of the various problems and unknowns that can be encountered. Typically, it is easier to create a seal in a large-diameter, shallow hole than in a small-diameter, deep hole.

Different sealing options are provided for each combination of ground water conditions, hole diameter, and hole length. The final selection of the seal depends on such factors as cost, familiarity, availability of mixing and placement equipment, and scheduling. Soil conditions do not significantly affect the seal selection process when using this chart because all of the recommended seal materials have the required characteristics described in Chapter 4.

Examples of the process described in the preceding paragraphs are provided in Appendix C.

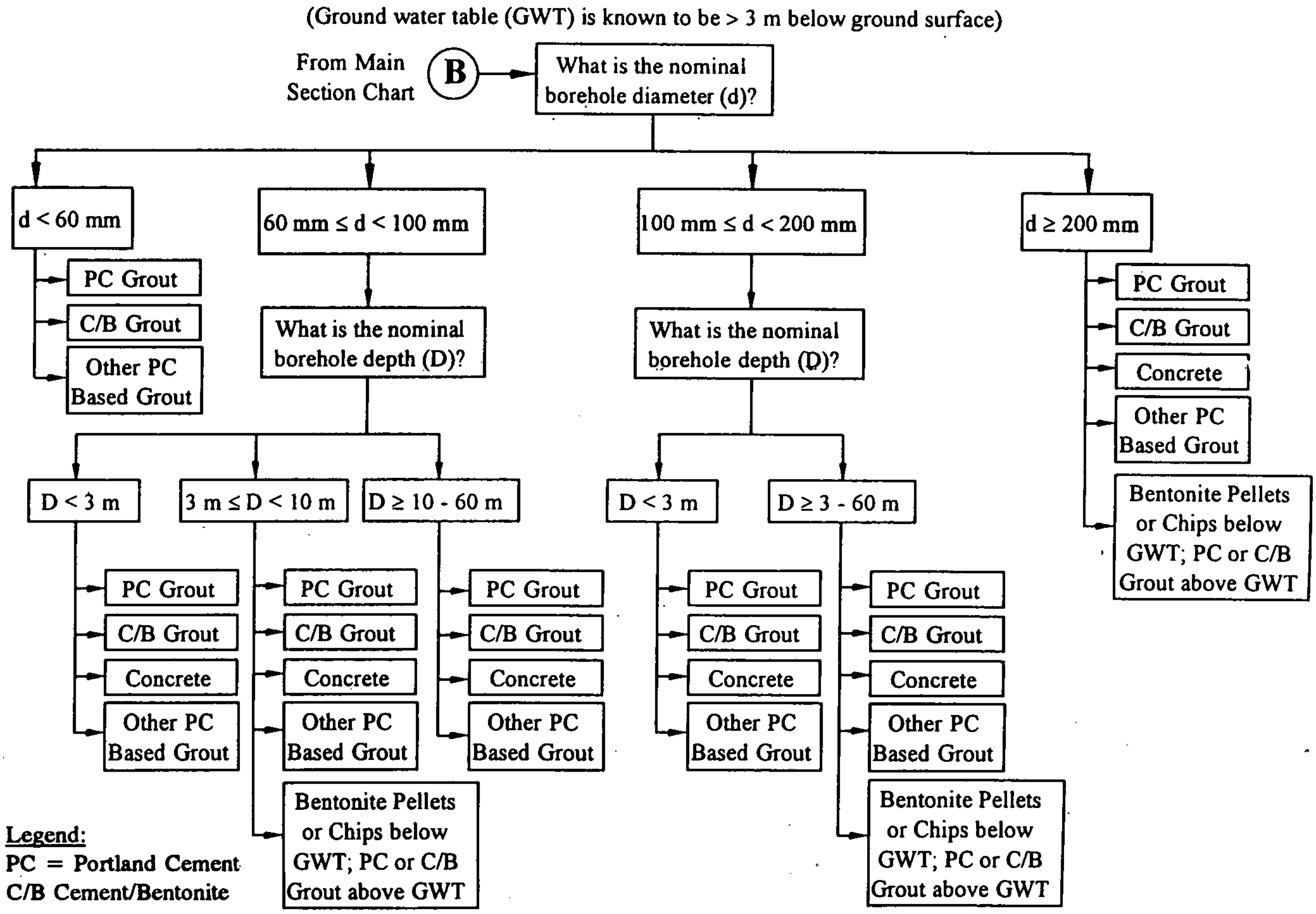


Figure 5. Borehole sealant selection chart B.

CHAPTER 8

SEAL RECIPES

Typical grout mixtures for sealing holes consist of either bentonite- or Portland-cement-based slurries or a combination thereof but may also include various other materials. Appropriate grout materials and mixtures must be pumpable, thick enough to prevent significant bleeding, provide self weight consolidation, and have a low hydraulic conductivity. The selection typically involves finding a balance between making a grout easy to pump (i.e., low viscosity) while producing as high a solids content as possible. For most grouts, the higher the solids content, the lower the bleeding, self weight consolidation, and hydraulic conductivity, but the higher the viscosity. Some manufacturers of bentonite products have developed special proprietary "high solids content" bentonite grouts to overcome this problem.

The properties, placement, and performance of grout seals are greatly influenced by mix proportions, mixing equipment and procedures, and time of mixing and placement. These factors are discussed further in the following sections.

8.1 GROUT MIX PROPORTIONS

This section describes recommended procedures for preparing the following types of grouts:

- Neat cement grout
- Neat cement/bentonite grout
- High solids content bentonite grout
- PCC
- Other Portland-cement-based grouts.

Other types of grouts (e.g., chemical grouts) can seal holes and have previously been described. In addition, many admixtures are available for use with the aforementioned grouts (e.g., fly ash and polymer-based viscosifiers). None of these other grouts or grouts with the aforementioned admixtures are recommended in this Guide for sealing exploratory holes because of concerns about them being potential sources of contamination (e.g., fly ash, polymers, and chemicals used in chemical grouts).

All grouts should be mixed on a gravimetric basis rather than volumetric, and careful field control of the mix proportions, especially the mixing water, is essential. In all cases, the mixing water should consist of potable water with low solids content and pH values not significantly different from 7. This is important because some seals will not function according to expectations if unsuitable mixing water is used. The following paragraphs and Table 3 give specific details regarding the mix proportions for the recommended grouts and typical values of the API Marsh Funnel viscosity and mud weight.

8.1.1 Neat Cement

Neat cement grouts are often specified in terms of the amount of mixing water in gallons required for one standard 42.7-kg (94-lb) bag of Portland cement. An acceptable neat cement grout should consist of 19.0 to 26.5 L (5 to 7 gal) of water to one standard 42.7-kg (94-lb) bag of Type I/II Portland cement. These mix proportions can also be expressed in terms of the water:cement ratio (w/c), which is based on the weight of mixing water to weight of cement. For example, 6 gal of water to one 42.7-kg (94-lb) bag of Portland cement represents 22.7 kg (50 lb) of water and, therefore, a w/c of 0.53. Often it is more convenient in the field to determine the correct amount of mixing water by measuring its volume. Table 3 gives mixing water requirements for standard 42.7-kg (94-lb) bags of cement.

8.1.2 Neat Cement/Bentonite

As previously described, small amounts of bentonite (2 to 5 percent by weight of cement) are sometimes added to neat cement grout to reduce the tendency for volumetric shrinkage that may occur when using neat cement. The bentonite also acts as a plasticizer to reduce the frictional losses present in the grout tube, thus allowing lower grout pressures to be used. It is important that the bentonite consists primarily of sodium montmorillonite. The grout is prepared using the same mix proportions for typical neat Portland cement grouts as noted above with the addition of a small amount of bentonite. Table 3 lists the mix proportions for 5 percent added bentonite powder, which should be weighed in the field using a balance prior to mixing, or prepared in bags that are preweighed prior to field operations.

TABLE 3. Mix proportions for cement and bentonite grouts

Mix	Proportions			Marsh Flow (sec./L)	Mud Weight (kg/L)
1.	Neat Portland Cement 42.7 kg bag cement				
w/c	Water	Cement	Bentonite		
0.71	30.3L	1 sack	0	45	1.681
0.62	26.5L	1 sack	0	67	1.753
0.53	22.7L	1 sack	0	156	1.813
0.44	18.9L	1 sack	0	*	1.921
2.	Portland Cement +5 % Bentonite 42.7 kg bag cement				
w/c	Water	Cement	Bentonite		
0.71	30.3L	1 sack	2.2 Kg	47	1.657
0.62	26.5L	1 sack	2.2 Kg	57	1.753
0.53	22.7L	1 sack	2.2 Kg	278	1.837
0.44	18.9L	1 sack	2.2 Kg	*	1.945
3.	High Solids Bentonite 22.7 kg bag bentonite				
% Solids	Water	Cement	Bentonite		
20	91.0L	0	1bag	60	1.141
25	68.2L	0	1bag	448	1.177
30	53.1L	0	1bag	*	1.225
35	41.7L	0	1bag	*	1.261
40	34.1L	0	1bag	*	1.273
4.	Na+ Montmorillonite Powder 22.7 kg bag bentonite				
% Solids	Water	Cement	Bentonite		
5	432.1L	0	1 bag	30	1.033
10	204.7L	0	1 bag	*	1.057
15	128.9L	0	1 bag	*	1.081
20	91.0L	0	1 bag	*	1.117

*** Too thick to determine viscosity**

Note: 1 gal of water = 3.79 L= 8.34 lb. To convert kg/L to lbs/gal multiply by 8.327
94-lb-bag of cement = 42.7 kg 50-lb-bag of bentonite = 22.7 kg

8.1.3 High Solids Content Bentonite Grouts

Proprietary high solids content bentonite grouts developed specifically for abandonment of water wells and boreholes have solids contents ranging from 30 to 40 percent when mixed according to manufacturers' specifications. Within this range of solids content, these mixtures are relatively thick, with viscosities too high to be measured by the Marsh Funnel Flow Test, but are still pumpable with a positive displacement pump that is available on many drill rigs. The Marsh Funnel flow time for water at room temperature is about 26 sec for the standard 946 mL (1 qt) container. Slurries have much higher flow times. For exploratory hole seals, the Marsh Funnel flow time should not be less than 57 sec per L (60 sec per qt). A flow time of 114 sec per L (120 sec per qt) is preferred; however, the slurry may be too thick to use, especially in holes smaller than 60 mm (2½ in.). The pumpability, however, is time dependent because the inhibitors contained in these grouts will only delay hydration of the bentonite for a relatively short time before it becomes stiff. Results of laboratory hydraulic conductivity tests performed on different bentonite grout mixtures show that the hydraulic conductivity is directly related to the solids content of the mixture. Therefore, higher solids content mixes are preferred for producing lower hydraulic conductivity seals, provided the mixture is pumpable. Bentonite grout may consolidate in the hole, resulting in the need for more material.

Most high solids content bentonite grouts are sold as one-sack grouts only requiring the addition of mixing water. Typical bags contain 23 kg (50 lb) of powdered mix and, therefore, a 30 percent solids content grout will require 53.1 L (117 lb or 14 gal) of mixing water (Table 3). Various products can successfully be used; however, it is important to evaluate individual products carefully because not all materials sold as bentonite grouts have the same physical properties nor do they have the same behavior. High solids bentonite grouts can commonly be premixed in large batches and can be remixed and used even after sitting for several days. It is particularly important to distinguish among bentonite grouts sold as high solids content grouts versus other types of bentonite grouts, such as pure sodium montmorillonite powder and viscosifiers.

8.1.4 PCC

A typical mixture of PCC consists of one bag of Portland cement (42.7 kg or 94 lb) for each 19.0 to 22.7 L (5 to 6 gal) of water to which not more than two parts of aggregate to one part cement is added. For use in sealing exploratory holes, it is recommended that the maximum aggregate size used in the mix be no greater than about 25 percent of the hole diameter. For example, for sealing a 100-mm (4-in.) hole, the maximum aggregate size should not exceed 25 mm (1 in.). Also, to ensure good flow characteristics so that the mix will conform to the sides of the hole, the mix should have a slump of between 152 and 205 mm (6 and 8 in.) when measured with a standard concrete slump cone.

8.1.5 Other Portland-Cement-Based Grouts

Other Portland-cement-based grouts have proven successful in sealing small-diameter holes. A common mixture of Portland cement, fine sand, and water to produce a cement mortar can be used. A typical mixture would be similar to that of PCC. As with PCC, it is important to have a flowable mixture in order to allow easy placement and conformity of the mix.

8.2 MIX EQUIPMENT AND PROCEDURES

The equipment and procedures used to mix the previously mentioned grouts are important for placing these materials successfully as borehole seals. When preparing a grout for sealing, it is generally recommended that dry powder be added to the mixing water either by using a venturi funnel and a mud bath or by hand into a paddle mixer. In the case of neat cement/bentonite grout, the bentonite should be added to the mixing water first. The rate of adding bentonite and/or cement should be carefully controlled to eliminate the creation of excessive lumps and clogging of the venturi if a venturi mixer is used. To minimize these potential problems, bentonite powder generally will have to be added to the mixing water at a slower rate than cement powder. During mixing, the grout should be circulated using the same pump that will be used for placement. A separate mixer should always be used, i.e., the grout should not be mixed by hand or by using only the drill rig pump.

A positive displacement pump is highly recommended for mixing and placing all grouts. Mixing should continue until the grout meets quality control specifications (i.e., viscosity and/or mud weight) and should not exceed a total time of approximately 20 min. For shallow holes or when mixing small volumes, a battery-powered, portable electric drill fitted with a dry-wall-compound or paint-mixing paddle (available at most hardware stores) works well. Mixing can take place in a plastic pail.

For PCC, either use preordered ready-mix or mix on site with a small, portable concrete mixer. Portland cement/sand grout should be mixed on site with a concrete mixer. Charts of required volume of grout for sealing holes are presented in Appendix A.

CHAPTER 9

SEAL PLACEMENT

Often, seal placement can be more important than the seal material itself in the success of a seal. An improperly placed seal can result in voids and internal seal erosion. Improper placement can also mean lost time because of having to remove and replace the defective seal. Some proven methods of placing seals in small-diameter holes are described in this section.

9.1 PLACING DRY SEALS

The primary objective in placing dry seal materials in a hole is to deliver as much dry material as possible to the desired location and allow the seal to hydrate and swell in place. This has been shown to provide the best seals. Several techniques have been used to accomplish this successfully.

9.1.1 Surface Pouring

The simplest, most common method of placing dry bentonite (chips, pellets, or granules) is by pouring them into a dry or water-filled hole of sufficient diameter. In open holes, with or without standing water, bentonite products (such as pellets, chips, or granules) can be used depending on the depth of the water column in the open hole. If bridging occurs, a tamper can be used to break down the blockage.

For placing bentonite chip seals, a 12 mm ($^1/_4$ in.) mesh size pouring chute is recommended to remove fines. Chips and pellets should be poured at a rate of not more than 9 kg/min (≈20 lb/minute) to prevent the formation of either down-hole bridges or mud as the chips and pellets settle through the water column. This corresponds to one 22.7-kg (50-lb) bag in about $2^1/_2$ min.

In holes with no standing water, water of potable quality should be added to every 0.3 to 0.6 m (1 to 2 ft) thickness of solid bentonite placed in the hole, to initiate hydration and swelling. Sufficient water should be added to just cover the bentonite placed in the hole. Typically, this takes on the order of 23.7 L (6 gal) of water per 22.7-kg (50-lb) bag of bentonite. Any special instructions provided by the manufacturer of the selected seal material should also be followed as applicable for the sealing condition encountered in the hole. Verification of proper placement should be made by checking the depth to the surface of the seal periodically and comparing this depth with the theoretical quantity. The use of a weighted tape measure or similar device is generally adequate for checking the depth to the top of the seal. Product literature should be checked to see if any restricted substances (e.g., retardants or polymers) have been added to the material.

9.1.2 Gravity Feed Tremie Pipe

Another common method of placing bentonite chips and pellets in holes with no standing water is to use an appropriately sized plastic tremie pipe with a funnel attached to the top. The dry material flows out the end of the pipe under gravity. This generally reduces the potential for material to hang up on the sides of an open hole and ensures placement to the proper location. Occasional taps on the sides of the pipe help the flow of material.

9.1.3 Placement Using Water-Soluble Bags

Water-soluble plastic bags are available in various sizes. When filled with a dry seal material, they measure about 75 mm (3 in.) wide by 200 mm (8 in.) long by about 50 mm (2 in.) in thickness. Sealant-filled bags can be dropped from the surface into open water-filled holes. Field tests show that full hydration of the dry sealant material is slowed or incomplete. Water-soluble bags may be used in holes that are at least 150 mm (6 in.) in diameter and preferably more than 200 mm (8 in.). Surface-dropped water-soluble bags may rotate as they settle and block the hole. The main advantage to using these bags is that a large quantity of unhydrated seal material can be delivered into the hole in a relatively short time.

9.1.4 Dry Injection

The dry injection method was established in an effort to prevent problems associated with bridging, jetting of seal material into filter packs, long material fall times in deep

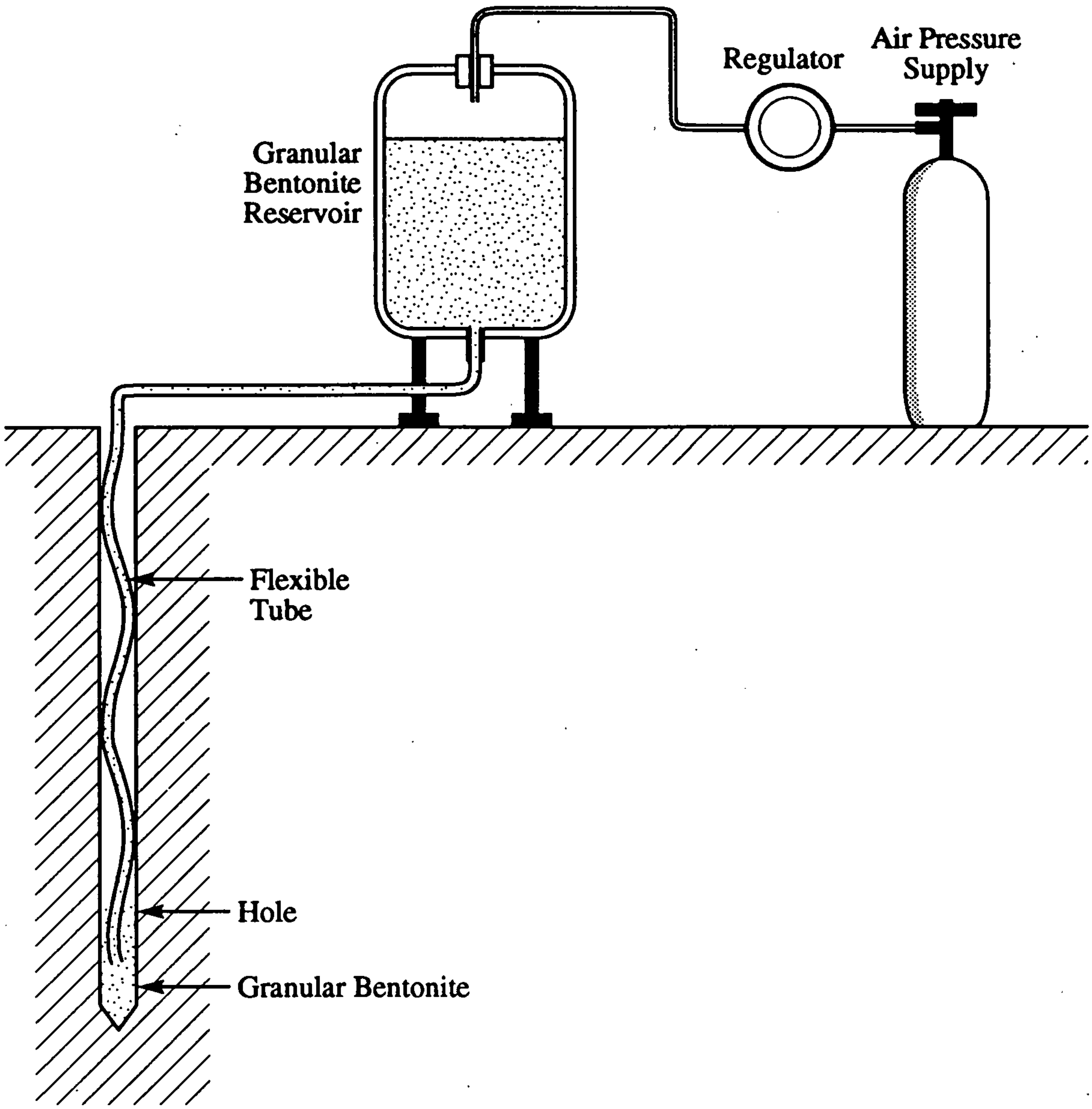


Figure 6. Air injection of dry sealant materials.

water columns, and cross contamination. A schematic of the apparatus is shown in Figure 6. The depth of the hole or annular space and the volume of material required to seal the opening fully is determined. Small-diameter, nylon or polypropylene injection tubing (with an attached, stainless-steel, leader pipe) is placed down the hole to just above the first zone to be sealed. The injector system is mounted on the drill rods or a tripod, and the injection tubing is attached to the bottom outlet.

The injector unit is connected to a pressurized source of air or inert gas having an in-line trap and pressure gauge. While air is passing through the injection tubing the required volume of filter pack or annular seal material is poured into the tank through a continuous loading valve. Dry seal material in the hopper is pressure injected into the hole. A depth rod indicator at the base of the injector monitors the level of the injected material. A 0.3 m (≈1 ft) minimum distance is kept between the end of the injection tubing and the final level of each pack or seal unit prior to installation of subsequent layers. The dry injection placement method delivers dry sealants and allows for maximum expansion and sealing quality. It eliminates bridging, delivers the seal material to the desired location more quickly than gravity feed methods, and can be used to avoid problems associated with tremie pipe systems. A system based on the dry injection principle has been commercially developed to provide seals at desired locations for both shallow and deep instrumented holes.

9.2 PLACING LIQUID SEALS

Liquid seal materials are usually placed using surface pouring or grouting methods; however, as noted herein, there are several methods of grout delivery for field conditions where surface pouring of fluid slurries and grouts is not acceptable.

9.2.1 Surface Pouring

In shallow holes less than about 5 m (15 ft) in depth, surface pouring to place liquid seals is usually adequate, provided that the hole remains open and has no standing water.

9.2.2 Grouting Under Gravity

The most common method used is the tremie pipe method. This method of grouting, shown in Figure 7, requires a suitable length of tremie pipe with attached hopper to deliver the grout to the required depth. The conductor pipe is placed just above the bottom of the hole, and the hopper is filled with grout. Once flow of grout is initiated, the hopper is kept full to prevent air entrapment. The tremie pipe is lifted up slowly keeping its lower discharge end below the free surface of the rising grout. The tremie method is not suitable under freezing conditions, nor is it recommended for use where the grout slurry can invade a filter pack. The tremie method may also result in the loss of full expansion and sealing qualities of the grout because of the low solids content required to facilitate gravity feed through the tremie pipe. For thicker mixtures, pressure grouting may be necessary.

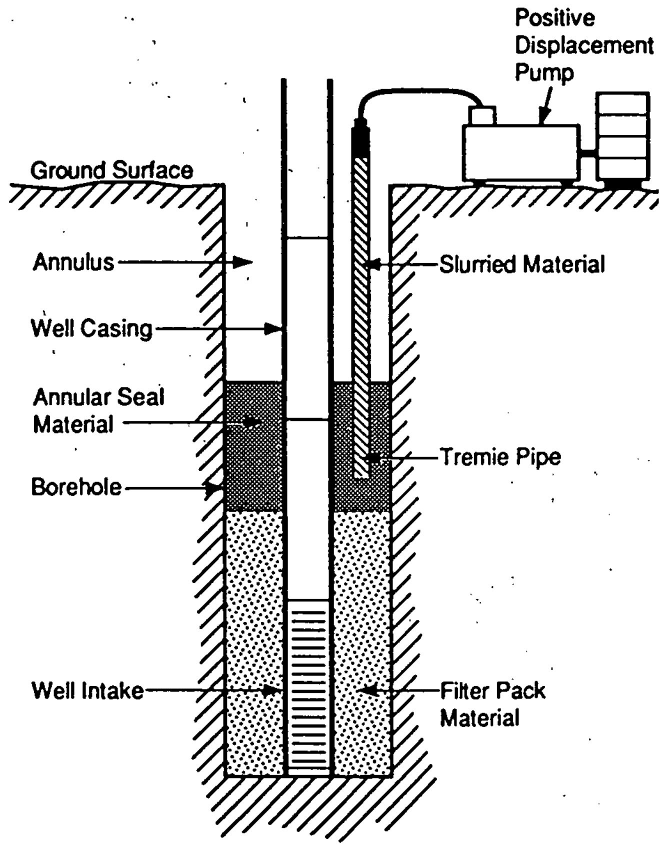


Figure 7. Conductor (tremie) pipe gravity method.

9.2.3 Grouting Under Pressure

There are two types of pressure grouting techniques, "open" and "closed." In an open system, the grout attains penetration through the available static head. In a closed system, external pressure is applied in excess of static head and maintained for a time to allow complete penetration and a partial set.

Typically, grouts are placed under pressure using various grout pumps, such as the screw (or Moyno), rotor, piston, or diaphragm types, powered by either a gas engine or an air compressor. Grout pumps generally can develop pressures ranging from 690 kPa to 860 kPa (≈100 to 125 psi) or greater. To avoid clogging, the grout should pass through a screen before reaching the pump intake.

In closed-system pressure grouting, the grout is pumped through a capped casing with or without a tremie pipe. In open-system pressure grouting, the grout should be placed under positive pressure through a tremie pipe of 25- to 38-mm (1- to 1½-in.) diameter made from galvanized steel or PVC and inserted to the bottom of the hole. The base of the tremie pipe should remain below the surface of the grout while the pipe is pulled up.

CHAPTER 10

PENETRATION HOLES

Holes created by displacement types of in situ testing equipment (such as the electric cone, piezocone, dilatometer, and various types of piezometers) are smaller in diameter than those created by augering or conventional drilling and sampling. The diameters usually range from 38 to 60 mm (1½ to 3 in.). There are three ways of sealing these holes: hole reentry, retraction grouting, and sealing during advance.

10.1 HOLE REENTRY METHOD

In hole reentry, the hole is sealed after all the rods have been pulled up. A grout slurry is poured down the hole if the hole is open and stable; otherwise, a tremie pipe is used. The tremie pipe can be a flexible hose (12 to 15 mm or ½ in.), similar to a garden hose. The tremie pipe is lowered carefully to the base of the open hole. The slurry is transferred to the hole through the pipe by gravity feed or by pumping. This method is used for holes ranging from 3 m (10 ft) to no more than about 6 m (20 ft) deep.

In holes 6 to 15 m (≈20 to 50 ft) deep, a rigid tremie pipe of 12 to 25 mm (½ to 1 in.) diameter can be used, with the tip end plugged temporarily or kept free of plugging by air pressure or water until the pipe end reaches the base of the hole. Grouting commences from the bottom up. A typical arrangement of this technique is shown in Figure 8.

10.2 RETRACTION GROUTING METHOD

The retraction grouting technique consists of grouting the hole after completion of the cone test and while the rods are being withdrawn as shown in Figure 9. These procedures require an opening or grout exit port either at the end of the cone device or along the first rod section. Several retraction grouting techniques in use include the sacrificial cone tip and the friction reducer port.

In the sacrificial cone tip method, the cone tip can be removed from the end of the cone test assembly following completion of the cone test. Grout is pumped through 6- to 8-mm (¼-in.) tubing located within the cone rods and out the end as the cone is withdrawn. A potential problem with this method is that significant redesign and machining may be required to relocate electrical components of the cone tip, especially in the case of a piezocone.

Grouting through the friction reducer ports can be accomplished using various port locations on the cone penetration assembly. Problems with this technique include clogging of the grout ports. The limited space within the cone rods requires the use of small-diameter grout tubing, which can only accept thin-mix grouts—potentially not the best sealant material. To overcome these problems, sacrificial blowout plugs are sometimes used to cover the grout ports during the cone test to prevent clogging.

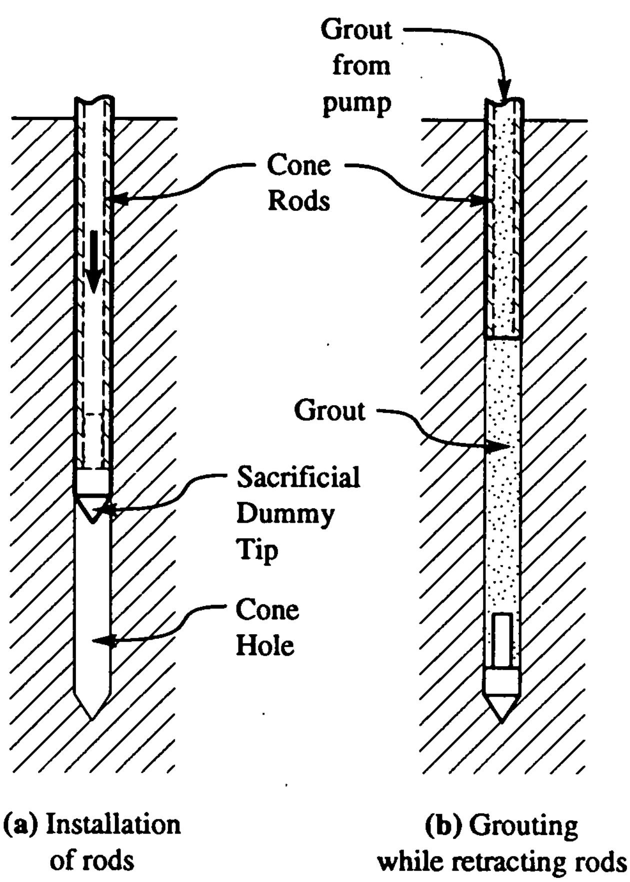


Figure 8. Reentry method of grouting.

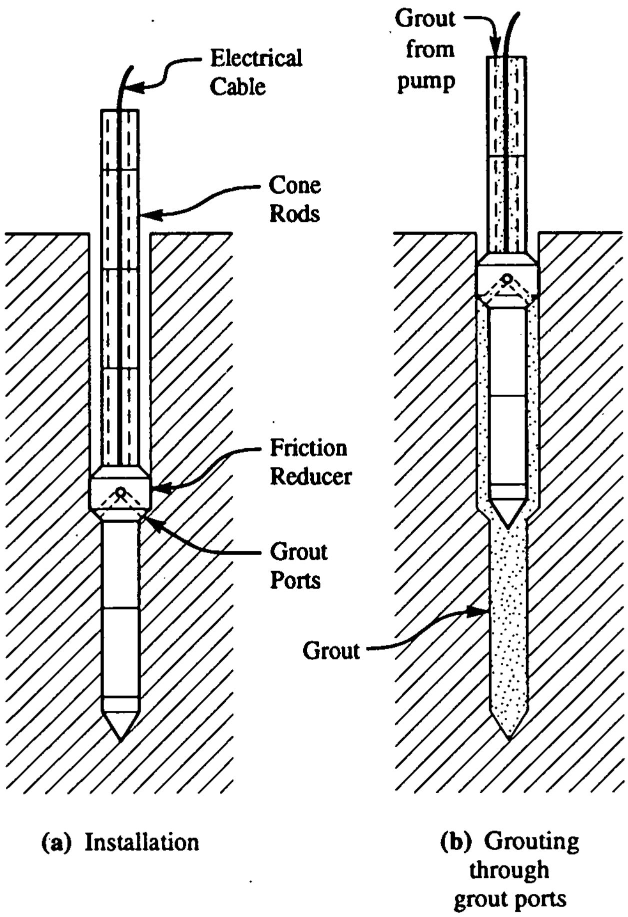


Figure 9. Retraction grouting method.

10.3 SEALING DURING ADVANCE METHOD

Sealing of cone penetration holes can also be accomplished during advance by using a sealed, pressurized casing system. During testing, a friction ring on the lead rod displaces soil so that a small annular space is created between the cone rods and the soil as the ring passes by. This method usually requires the use of a capped or air-tight casing through which the cone and rods can pass. Before the cone test starts, the casing is filled with grout under pressure. The pressure and supply of grout are maintained from the start of the cone test to the end of the sealing operation. Upon completion of the test, the cone is slowly withdrawn, causing the sacrificial friction ring to drop off. Grout then fills the hole as the cone is withdrawn. By grouting during the cone advance, the annular space is kept filled at all times, preventing the migration of contaminated liquids through the soil profile. A typical grouting on advance arrangement is shown in Figure 10.

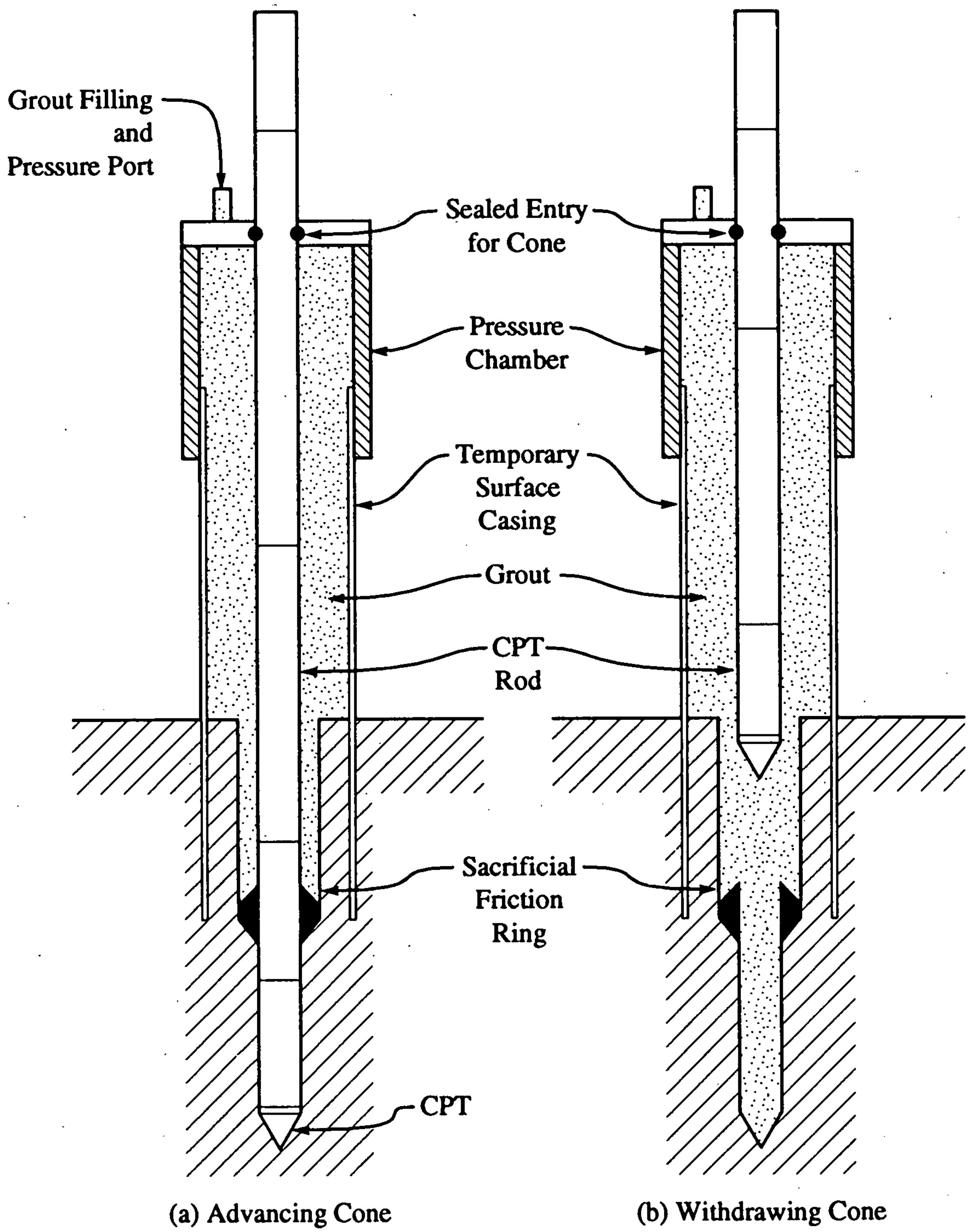


Figure 10. Grouting during advance.

CHAPTER 11

SEAL VERIFICATION—QUALITY CONTROL

The best way to ensure that an installed seal will remain effective is to perform several quality control checks during its preparation and installation. The methods of quality control are different for different types of seal materials. *Common to all types of seals is the requirement for good record keeping and full documentation of the methods and materials used in creating the seal.*

11.1 RECORD KEEPING

Sealing of holes should be performed conscientiously with sufficient documentation to prove that the work has been performed to high quality standards and with quality controls in place. To verify that seals have been properly placed, the materials, site and weather conditions, and methods of seal placement should be fully documented. The information to be documented should include the following:

- Project number, location, date, weather, and so forth
- Hole number, final depth, how made, and diameter (both with and without casing or hollow stem augers)
- Depth of caving, if known
- Sequence of soil strata encountered
- Depth to the water table, if known
- Artesian or subartesian conditions, if any, and from what depth or stratum
- Seal materials used, including manufacturer and mix proportions
- Quantity of seal material used and percent difference from calculated hole volume
- Surface pour rate for bentonite solid products
- Slurry Marsh Funnel flow time (both initial and after 10 min)
- Slurry mud balance density
- pH of water and mix
- Description of seal placement method
- Description of seal (e.g., full depth, up to ground water level, and partial)
- Type of materials used in instrumented hole (e.g., tubing)
- Record of official visitors, stop work orders, and so forth
- Start and finish times for seal placement.

The documentation will help to develop a valuable data base in addition to serving as verification of sealing. A sample hole sealing form is presented in Appendix D.

11.2 VOLUME BALANCE

One of the most important quality control checks on the use of solid sealants (such as bentonite chips, pellets, and granules) is to perform a volume balance check calculation on the amount of sealant placed versus the volume of the hole. If the two values match within ± 15 percent, bridging has probably not occurred. The depth of the hole should be checked before the solid sealant is placed in the hole, followed by depth checks after every bag of sealant used. This permits frequent checks on bridging or hang up of the sealant material in the hole above the base. If bridging should occur, a tamper may be used to clear the passage for the following batch of seal material.

11.3 MUD WEIGHT

In the drilling industry, drilling muds are specified according to "weight" as "so many pounds slurry." The mud weight is obtained on a mud balance. A Baroid mud balance, a calibrated weighing scale, is shown in Figure 11. The slurry mixture is placed inside the cup and the lid closed. The excess material is wiped off, and the cup and lid weighed. From the weight and known volume of the cup, a density value is read off the precalibrated beam scale. When checking the mud weight of grout slurries placed using the tremie pipe or pressure grouting methods, the return flow coming out of the hole should be periodically tested as the pipe is withdrawn.

11.4 VISCOSITY

The viscosity (or ease of flow) of a slurry can be estimated by allowing a known volume of mixture to flow out of a standard orifice at the base of a conical container. A common apparatus to measure the consistency of a slurry is the Marsh Funnel flow cone, illustrated in Figure 12. After wetting the funnel with water, the slurry is poured through

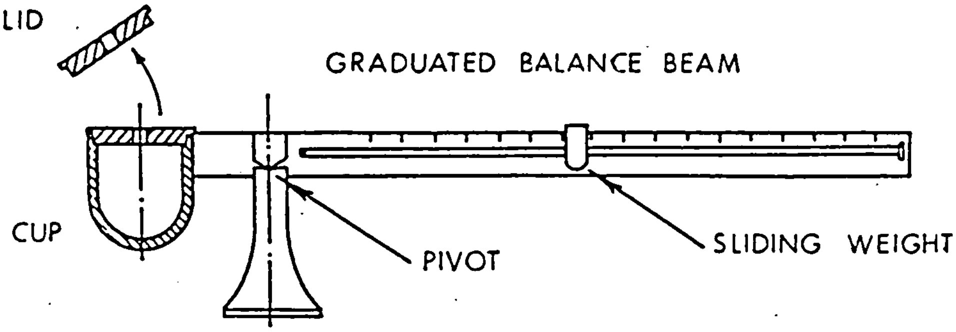


Figure 11. Baroid mud balance.

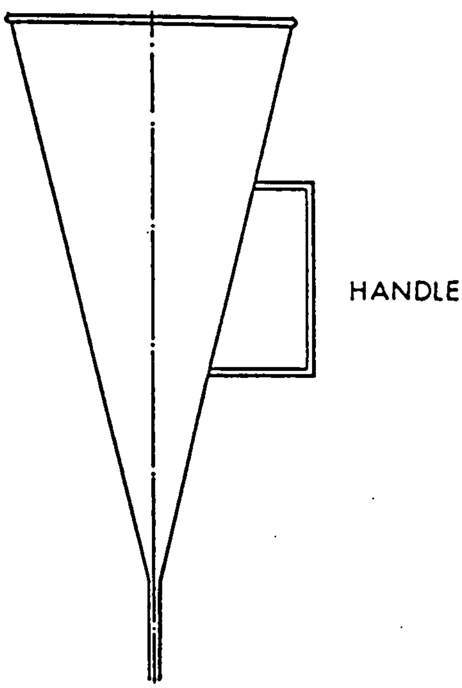


Figure 12. Marsh Funnel flow cone.

a screened section at the top of the funnel to a specified level (normally 25 mm [1 in.]) below the rim of the funnel). The discharge orifice is blocked with a finger. A receiving measuring cup is placed below the discharge end. The flow time is measured with a stop watch as soon as the finger is removed from the funnel discharge end. The time to fully empty the Marsh Funnel flow cone and fill a 946 mL (1 qt) measure is referred to as the Marsh Funnel flow time, reported in sec per L or sec per qt.

The Marsh Funnel flow cone and the mud balance are two convenient, inexpensive items of equipment to have when using slurries to create seals. Such instruments can be used for quality control, as well as absolute design tools for creating seal mixes. The quality of premixed slurry seal can be controlled by periodic measurements using the mud balance and/or the Marsh Funnel flow cone. For slurries that tend to set up or "gel" with time, reagitation may be required before measurements are made. Viscosity should not be used as the sole quality control measure for bentonite grouts because the measured viscosity can change with time and, at higher solids content, the mixture may be too thick to allow a measurement to be made.

11.5 GEL STRENGTH

A rough measurement of the "hardening" property of a grout mixture can be made by comparing the Marsh Funnel flow cone viscosities of a mixture, tested immediately after pouring it onto the funnel, and the same mixture, placed and allowed to rest in the funnel for 10 min prior to conducting the test. The difference between the two viscosity readings is reported as the gel strength and can be used as an estimate of the ability of the grout mix to set up or self-harden.

11.6 WATER CONTENT

A more direct, but more time-consuming, measurement of the solids content of bentonite-based grout mixtures can be made by measuring the water content of the mixture. Water content is defined as the mass of water divided by the mass of dry soil. The procedure outlined in ASTM D2216 should be used for this purpose and essentially involves obtaining a known mass sample of the mix (approximately 100 gm), placing it in an oven for 24 hours at a temperature of 110± 5° C and obtaining a dry mass. Unfortunately, this test can only serve as a backup to other tests because a 1-day waiting period is needed to obtain the results.

APPENDIX A

USEFUL SEALING CHARTS

CHART A

QUANTITIES OF BENTONITE CHIPS/GROUT NEEDED TO FILL HOLES

Hole Diameter cm (in.)	Coarse Chips		Medium Chips		30% Solids Grout	
	Kg per meter of hole	Meters of Hole/Bag	Kg per meter of hole	Meters of Hole/Bag	Liters per meter of hole	Meters of Hole/Bag
6.3 (2½)	3.2	7.2	3.7	6.1	0.3	20.7
8.9 (3½)	6.3	3.6	7.5	3.0	0.6	10.4
10.2 (4)	8.2	2.7	10.1	2.3	0.8	7.9
11.4 (4½)	10.4	2.1	12.7	1.8	1.0	6.2
12.7 (5)	13.0	1.8	16.0	1.5	1.2	5.2
14.0 (5½)	15.7	1.7	18.6	1.2	1.4	4.2
15.2 (6)	18.6	1.2	23.1	1.0	1.7	3.4
16.5 (6½)	22.0	1.1	30.6	0.8	2.0	3.0
20.3 (8)	33.6	0.7	41.8	0.5	3.0	2.0

Note: Coarse chips weigh approximately 1,030 kg/m^3 (64 lbs/ft^3).
Medium chips weigh approximately 1,090 kg/m^3 (68 lbs/ft^3).
One bag of bentonite grout yields approximately 64.3L (17 gal) of slurry when mixed at 30 percent solids.

CHART B

WEIGHT OF BENTONITE PELLETS NEEDED TO FILL HOLES

Lenth of Hole m (ft)		Hole Diameter cm (in)									
		5.1	(2)	7.6	(3)	10.2	(4)	15.2	(6)	20.3	(8)
		kg	(lbs)	kg	(lbs)	kg	(lbs)	kg	(lbs)	kg	(lbs)
1.5	(5)	3.6	(8)	*8.0*	*(18)*	*14.3*	*(31)*	*32.1*	*(71)*	57.2	(126)
3.0	(10)	7.3	(16)	16.1	(35)	28.6	(63)	64.3	(141)	114.3	(251)
4.6	(15)	10.9	(24)	24.1	(53)	42.9	(94)	96.4	(212)	171.5	(377)
6.1	(20)	14.1	(31)	32.1	(71)	57.2	(126)	128.6	(283)	228.7	(503)
7.6	(25)	17.7	(39)	40.2	(88)	71.5	(157)	160.8	(354)	285.8	(629)
9.1	(30)	21.4	(47)	48.2	(106)	85.8	(189)	193.0	(424)	343.0	(755)
10.7	(35)	25	(55)	56.3	(124)	100.0	(200)	225.1	(495)	400.2	(880)
12.2	(40)	28.6	(63)	64.3	(141)	114.3	(251)	257.3	(566)	457.3	(1006)
13.7	(45)	32.1	(71)	72.4	(159)	128.6	(283)	289.4	(637)	514.5	(1132)
15.2	(50)	35.7	(79)	80.4	(177)	142.9	(314)	321.5	(707)	571.7	(1258)

Note: Bentonite pellets weigh approximately 1,150 kg/m^3 (72 lbs/ft^3).
One 50-lb bag or pail of bentonite pellets weighs 22.7 kg.

USEFUL CONVERSIONS

1 meter = 3.281 ft
1 foot = 0.305 m
1 inch = 25.4 millimeters = 2.54 cm
1 kilogram = 2.2 lb
1 pound = 0.455 kg
1 quart = 0.946 L
1 gallon = 3.785 L
1 94-lb bag of cement = 42.7 kg
1 50-lb bag/pail of bentonite = 22.7 kg
1 5-gal bucket = 18.92 L.
1 gal of water weighs 8.34 lb.

Volume of a hole = $\pi r^2 L$
where: π = 3.1416
r = Radius of the hole (half the diameter)
L = Length of the hole

COMMON SIZES OF HOLLOW STEM AUGERS

Inside Diameter	5.71 cm (2¼ in.)	8.25 cm (3¼ in.)	10.80 cm (4¼in.)	15.87 cm (6¼ in.)	23.49 cm (9¼ in.)	31.11 cm (12¼ in.)
Outside Diameter	14.29 cm (5⅝ in.)	16.83 cm (6⅝ in.)	19.37 cm (7⅝ in.)	24.45 cm (9⅝ in.)	34.92 cm (13¾ in.)	45.08 cm (17¾ in.)

EXAMPLE

A 9.14 m (30 ft) hole has been drilled with 8.25 cm (3¼ in.) inside diameter hollow stem augers. The hole is to be filled with medium-sized bentonite chips. How many bags (pails) of chips are needed to fill the hole entirely to the surface?

Method 1
The outside diameter of 8.25 cm (3¼ in.) inside diameter augers is about 16.83 cm (6 ⅝ in.) According to Chart A in this appendix, 30.6 kg of medium-sized chips are needed to fill each 1-m length of a 16.5-cm (6½-in.) diameter hole.
This means that it would take:

9.14 m x 30.6 kg/m = 279.7 kg

This means that it would take:

279.7 kg/22.7 kg/bag = 12.3 bags

Method 2
According to Chart A in this appendix, medium-sized bentonite chips will fill about 0.8 m (2½ ft) of

hole per 22.7-kg (50-lb) bag for a 16.5-cm (6½-in.) diameter hole. This means that it would take:

$$9.14 \div 0.8\text{m/bag} = 11.4 \text{ bags}$$

This is lower than predicted using Method 1 but within about 10 percent.

Method 3

The radius of the hole is (0.165 m)/2 = 0.083 m
The volume of the hole would be:

$$3.1416 \times (0.083 \text{ m}) \times (0.083 \text{ m}) \times (9.14 \text{ m}) = 0.198 \text{ m}^3$$

Since each m^3 of bentonite chips weighs 1,090 kg:

$$0.198 \text{ m}^3 \times 1090 \text{ kg/m}^3 = 215.8 \text{ kg}$$
$$(215.8 \text{ kg})/22.7 \text{ kg/bag} = 9.5 \text{ bags}$$

This is lower than both Methods 1 and 2.

APPENDIX B

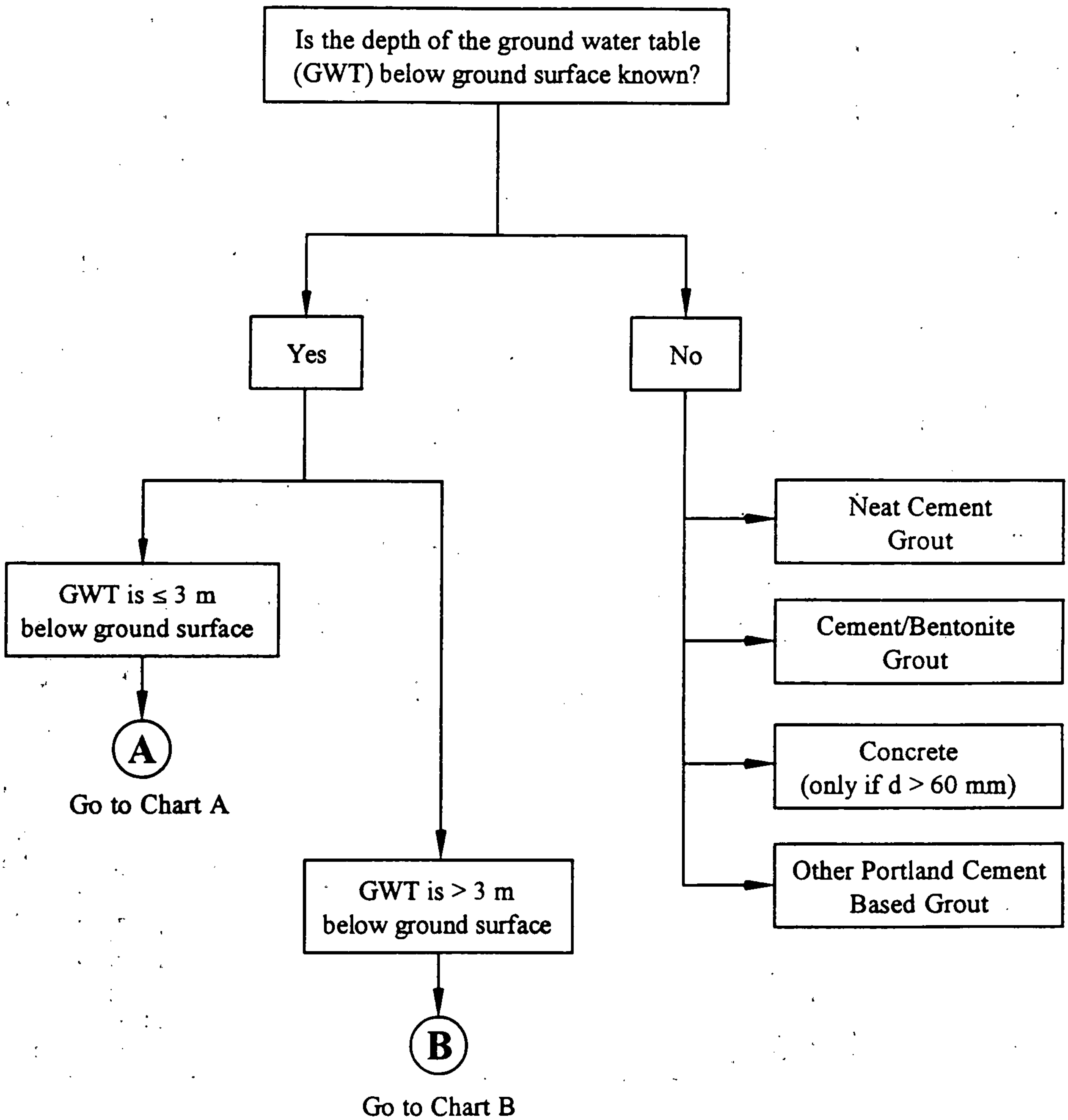
SEAL SELECTION FLOW CHARTS

Borehole Sealant Selection Main Chart

1. Nominal diameter (d) of borehole (mm) = ____________

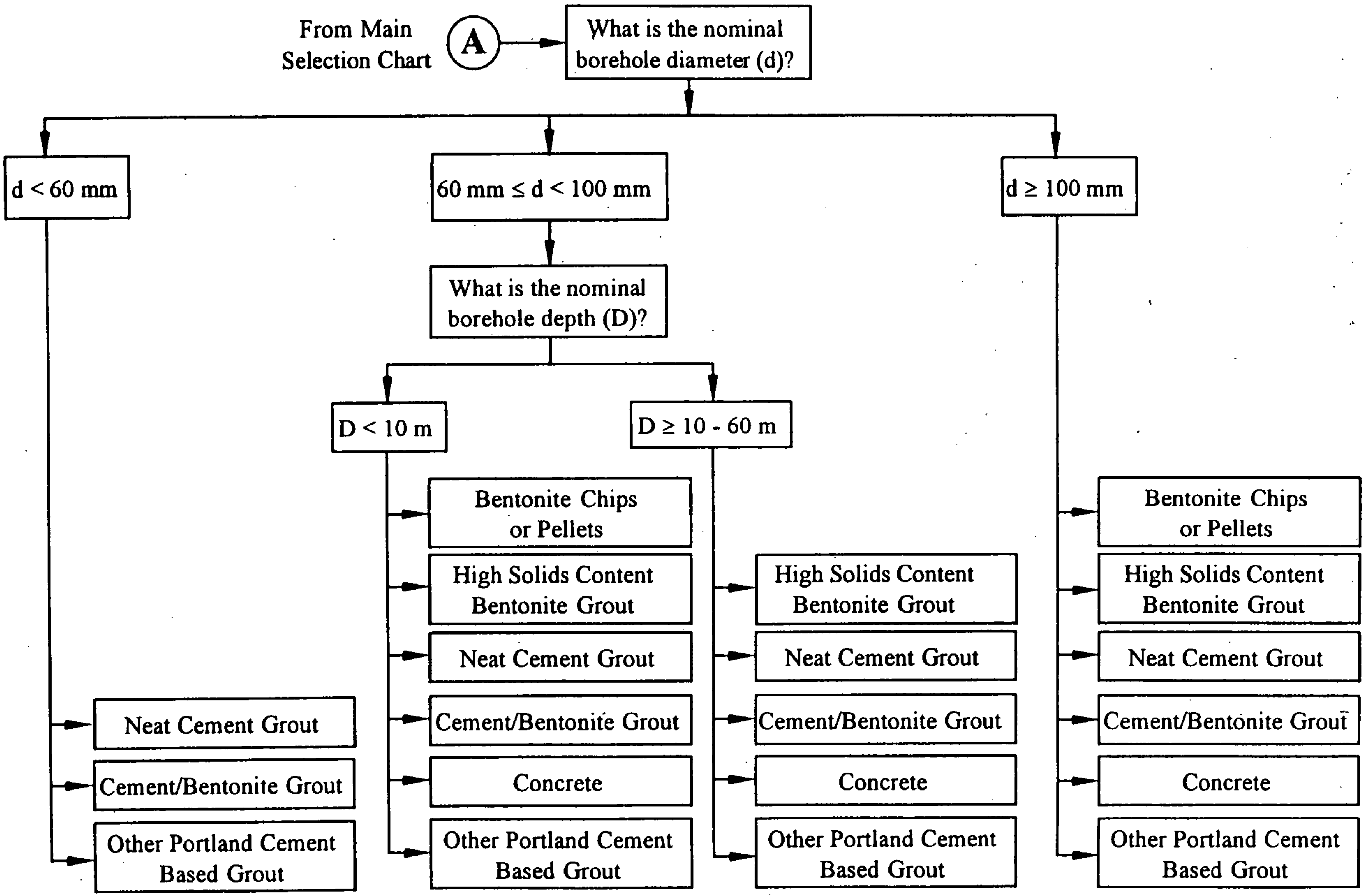
2. Nominal depth (D) of borehole below ground surface (m) = ______________

3. If known, depth of ground water table (GWT) below ground surface (m) = __________



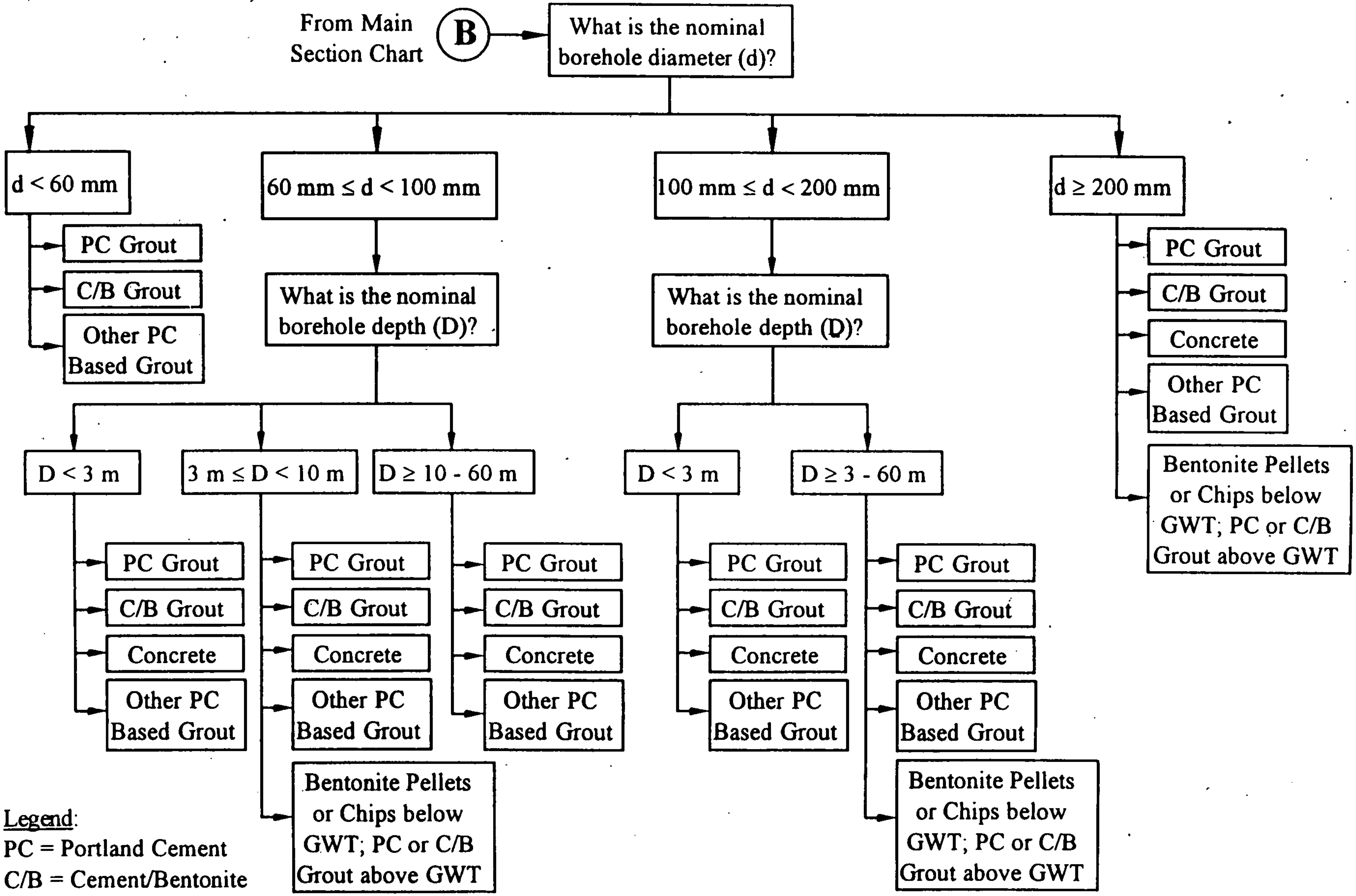
Borehole Sealant Selection Chart A

(Ground water table is known to be ≤ 3 m below ground surface)



Borehole Sealant Selection Chart B

(Ground water table (GWT) is known to be > 3 m below ground surface)



Legend:
PC = Portland Cement
C/B = Cement/Bentonite

APPENDIX C

EXAMPLES OF SEAL SELECTION

CASE NO. 1

Stratigraphy: 0 to 3 m stiff clay
3 to 5 m dense sand

Water Table: Water encountered at 4 m.
Test Boring: 100-mm-diameter hole drilled with rotary wash boring using open hole technique

Seal: Since water was encountered at a depth of 4 m, it must be assumed that the water table is located greater than 3 m below surface. This means that the seal selection will fall in Chart B. Since the hole diameter is between 100 mm and 200 mm and the depth is greater than 3 m, the choices of seals are:

(1) PC grout
(2) C/B grout
(3) Concrete
(4) Other PC-based grout
(5) Bentonite pellets or chips below the water with either PC or C/B grout above

If additional information becomes available about the position of the water table the selection chart would need to be reviewed to see if bentonite pellets or chips or bentonite grout could be used full length in the hole. Since the hole was drilled using wash boring techniques, the hole should be flushed with clean water prior to placing the seal. If the lower 1 m of the hole collapses, this should not affect the seal. Seal placement should be by tremie pipe for liquid seals.

CASE NO. 2

Stratigraphy: 0 to 3 m stiff clay
3 to 5 m dense sand

Water Table: Unknown; no water encountered
Test Boring: 100-mm-diameter hole drilled with rotary wash boring

Seal: Since no information is available about the position of the water table, the choices of seal are:

(1) PC grout
(2) C/B grout
(3) Concrete
(4) Other PC-based grout

CASE NO. 3

Stratigraphy: 0 to 18 m stratified loose to medium dense sands and gravels

Water Table: Water encountered at 2 m
Test Boring: 156-mm-inside-diameter hollow stem auger

Seal: If a seal is placed through the hollow stems, Chart A can be used and since the inside diameter of the augers is greater than 100 mm, the choice of seals is:

(1) Bentonite chips or pellets
(2) High-solids bentonite grout
(3) PC grout
(4) C/B grout
(5) Concrete
(6) Other PC-based grouts

Placement of the liquid seals should be by tremie pipe. Placement of the bentonite chips or pellets should be accompanied by withdrawal of the augers.

CASE NO. 4

Stratigraphy: 0 to 10 m loose sand
10 to 18 m very stiff clay
18 to 50 m soft clay

Water Table: Perched water encountered at 4.5 m
Test Boring: 125-mm-inside-diameter cased wash boring

Seal: Since water was encountered at a depth of 4.5 m, unless additional information can be obtained to verify the location of the water table at a depth of 3 m or higher, Chart B would be used. Since the inside diameter of the casing is between 100 mm and 200 mm and the length of the hole is greater than 3 m, the choice of seals is:

(1) PC grout
(2) C/B grout
(3) Concrete
(4) Other PC-based grout
(5) Bentonite pellets or chips below water table with either PC or C/B grout above

CASE NO. 5

Stratigraphy: 0 to 5 m stiff clayey silt

Water Table: Water table known to be located at 6 m
Test Boring: 76-mm-diameter continuous flight augers

Seal: Since the water table is located at a depth greater than 3 m, use Chart B. The diameter of the borehole falls between 60 mm and 100 mm and the depth of the hole is between 3 m and 10 m. The choice of seals is:

(1) PC grout
(2) C/B grout
(3) Concrete
(4) Other PC-based grout

CASE NO. 6

Stratigraphy: 0 to 20 m stratified dense sand with occasional clay seams

Water Table: Water encountered at 6 m
Test Boring: 200-mm-diameter rotary wash boring
Instrumentation: Slotted screen piezometer with 50-mm-diameter riser pipe to surface

Seal: With the water located at a depth of 6 m, use Chart B. Since the standpipe would presumably be located in the centre of the hole, the minimum clear distance which now becomes the size of the hole for seal selection is 75 mm (one-half of [200 minus 50]). Since this is between 60 mm and 100 mm and the length of the hole is greater than 10 m, the seal choices are:

(1) PC grout
(2) C/B grout
(3) Concrete
(4) Other PC-based grout

CASE NO. 7

Stratigraphy: 0-40 m stratified medium dense sand and gravel

Water Table: Water table known to be located at 50 m
Test Boring: 105-mm-inside-diameter hollow stem augers

<u>Seal:</u> The seal choices are:

(1) PC grout
(2) C/B grout
(3) Concrete
(4) Other PC-based grout

CASE NO. 8

Stratigraphy: 0 to 4 m silty clay

Water Table: Unknown; no water encountered
Test Boring: 76-mm-diameter hand auger

<u>Seal:</u> Since the location of the water table is unknown, the seal choices are:

(1) PC grout
(2) C/B grout
(3) Concrete
(4) Other PC-based grout

APPENDIX D

EXAMPLE OF SEALING FORM

GEOTECHNICAL EXPLORATORY HOLE SEAL VERIFICATION REPORT

Project Information
Project No.____________ Location:____

Client:________________________________ Client Ref:____________________________

Drill Contractor:_______________________ Field Work Dates:____________ to ___________

Driller: _______________________________ Supervisor: ____________________________

Borehole No. __________________________

Drilling
Equipment: ____

Hole Advance: Cased washboring ☐ Solid Stem Augers☐ Hollow Stem Augers☐ Other☐ _____
In Situ: No☐ Yes ☐ Type: DMT☐ CPT☐ CPTU☐ SBP☐ BAT☐ Other:_______________
Hole dia: Max.______ mm (in.) Min.______ mm (in.) Vertical☐ Inclined☐______°dip angle
Hole length:__________m (ft.)

Ground Water
Depth below ground level (m, ft.)____

Describe Soils Encountered in Drilling

____
____
____
____
____
____

Sealing Materials
Bentonite No☐ Yes☐ Powder☐ Granules☐ Pellets☐ Chips☐ Name:__________________
Swelling (in ground water sample): No☐ Yes☐ Est. swell (%)________ @ _______ hrs.
Portland Cement☐ Type:____________________ Neat☐ Cement + ____________ % bentonite☐
Sand: Native☐ Imported☐ Gradation: Fine☐ Medium☐ Coarse☐ Source:__________________
Water: Hole ☐ Stream☐ Tap☐ Tank☐ Cl (mg/L)_________ TDS (mg/L)________ pH________
Seal Mix: No☐ Yes☐ If Yes, proportions used:
Cement:_________ Bentonite:__________ Water:________ Sand:_________ in kg (lbs.)
Additives: No☐ Yes☐ Name:_______________ Quantity used:________ per_______ of seal mix
Other:____

Mixing: Nil☐ Mechanical☐ Manual☐ Other:_____________________________________

Placement: Pour☐ Tremie☐ Pipe Dia.____mm (in.) Pumped: No☐ Yes☐ Pump Type:_________
Viscosity_______________sec./L Mud weight_______________ rng/m^3

Seal Placement
Full depth on all holes: Yes☐ No☐ If no, provide details below:

Sealing Interval From	To		Hole Vol. V_T (m^3)	Seal Vol. V_A (m^3)	Ratio $(V_T - V_A)/V_T$
______	______	m (ft.)	________	________	________
______	______	m (ft.)	________	________	________
______	______	m (ft.)	________	________	________
______	______	m (ft.)	________	________	________

Describe sealing procedures used:

____
____
____
____
____

Sealing Difficulties (summarize):____
____
____
____
____

Declaration of Seal Verification:
We confirm that we have installed seals in accordance with prescribed guidelines and procedures in order to protect the subsurface environment, and that our work was done conscientiously to the best of our ability, given the prevailing site, climate and other conditions at the time the seals were installed. This declaration does not constitute an admission of liability with respect to the long term effectiveness of the seals due to reasons beyond our control.

________________________________ ________________
Authorized Signature Date

THE TRANSPORTATION RESEARCH BOARD is a unit of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. It evolved in 1974 from the Highway Research Board which was established in 1920. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society. The Board's purpose is to stimulate research concerning the nature and performance of transportation systems, to disseminate information that the research produces, and to encourage the application of appropriate research findings. The Board's program is carried out by more than 270 committees, task forces, and panels composed of more than 3,300 administrators, engineers, social scientists, attorneys, educators, and others concerned with transportation; they serve without compensation. The program is supported by state transportation and highway departments, the modal administrations of the U.S. Department of Transportation, the Association of American Railroads, the National Highway Traffic Safety Administration, and other organizations and individuals interested in the development of transportation.

The National Academy of Sciences is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Bruce M. Alberts is president of the National Academy of Sciences.

The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research and recognizes the superior achievements of engineers. Dr. Harold Liebowitz is president of the National Academy of Engineering.

The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Kenneth I. Shine is president of the Institute of Medicine.

The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purpose of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Bruce M. Alberts and Dr. Harold Liebowitz are chairman and vice chairman, respectively, of the National Research Council.

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