PDHonline Course C192 (3 PDH)

Subsurface Barriers for Contaminated Sites

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Advantages	Disadvantages
A long-term, economical method of ground-water control	Ground water or waste leachate may be incompatible with slurry material
No maintenance required over long term	Lack of near-surface impermeable layer, large boulders or underground caverns may make installation difficult or impractical
Materials inexpensive and available	Not practical with over 10 percent slope
Technology well proven	

3-17. Grout Curtains. Another method of ground-water control is the installation of a grout curtain. Grouting in general consists of the injection of one of a variety of special fluids or particulate grouts (Table 3-5) into the soil matrix under high pressure. The injection of the specific grout type is determined by conditions of soil permeability, soil grain size, chemistry of environment being grouted (soil and ground-water chemistry), and rate of ground-water flow. Grouting greatly reduces permeability and increases mechanical strength of the soil zone grouted. When carried out in the proper pattern and sequence, this process can result in a curtain or wall that can be an effective ground-water barrier. Because a grout curtain can be three times as costly as a slurry wall, it is rarely used when ground water has to be controlled in soil or loose overburden. The major use of curtain grouting is to seal voids in porous or fractured rock where other methods of ground-water control are impractical.

a. Description. The pressure injection of grout is as much an art as a science. The number of United States firms engaged in this practice is quite limited. The injection process itself involves drilling holes to the desired depth and injecting grout by the use of special equipment. In curtain grouting, a line of holes is drilled in single, double, or sometimes triple staggered rows (depending on site characteristics) and grouting is accomplished in descending stages with increasing pressure. The spacing of the injection holes is also site specific and is determined by the penetration radius of the grout out from the holes. Ideally, the grout injected in adjacent holes should touch (Figure 3-20) along the entire length of the hole. If this is done properly, a continuous, impervious barrier is formed (Figure 3-21).

b. Application.

(1) In general, grouts can be divided into two main categories- - suspension grouts and chemical grouts. Suspension grouts, as the name implies, contain finely divided particulate matter suspended in water. Chemical grouts, on the other hand, are true Newtonian fluids. Most of the grouting in the United States is done with suspension grouts, whereas about half of the grouting in Europe is done with chemicals. The principal grouts in use today are briefly described below.

Table 3-5. Significant Characteristics of Types of Grout

Type	Characteristic
Portland cement or particulate grouts	Appropriate for higher permeability (larger grained) soils Least expensive of all grouts when used properly Most widely used in grouting across the United States (90 percent of all grouting)
Chemical grouts	
Sodium silicate	Most widely used chemical grout At concentrations of 10-70 percent gives viscosity of 1.5-50 cP Resistant to deterioration by freezing or tPawing Can reduce permeabilities in sands from 10 to 10^{-8} cm/sec Can be used in soils with up to 20 percent silt and clay at relatively low injection rates Portland cement can be used to enhance water cutoff
Acrylamide	Should be used with caution because of toxicity First organic polymer grout developed May be used in combination with other grouts such as silicates, bitumens, clay, or cement Can be used in finer soils than most grouts because low viscosities are possible (1 cP) Excellent gel time control due to constant viscosity from time of catalysis to set/gel time Unconfined compressive strengths of 344-1378 KPa (50-200 psi) in stabilized soils Gels are permanent below the water table or in soils approaching 100 percent humidity Vulnerable to freeze-thaw and wet-dry cycles, particularly where dry periods predominate and will fail mechanically Due to ease of handling (low viscosity), enables more efficient installation and is often cost-competitive with other grouts
Phenolic (Phenoplasts)	Rarely used due to high cost Should be used with <u>caution</u> in areas exposed to drinking water supplies, because of toxicity Low viscosity Can shrink (with impaired integrity) if excess (chemically unbound) water remains after setting; unconfined compressive strength of 344-1378 KPa (50-200 psi) in stabilized soils

(Continued)

Table 3-5. (Concluded)

Type	Characteristic
Urethane	Set through multistep polymerization Reaction sequence may be temporarily halted Additives can control gellation and foaming Range in viscosity from 20 to 200 cP Set time varies from minutes to hours Prepolymer is flammable
Urea-Formaldehyde	Rarely used due to high cost Will gel with an acid or neutral salt Gel time control is good Low viscosity Considered permanent (good stability) Solution toxic and corrosive Relatively inert and insoluble
Epoxy	In use since 1960 Useful in subaqueous applications Viscosity variable (molecular weight dependent) In general, set time difficult to regulate Good durability Resistant to acids, alkalis, and organic chemicals
Polyester	Useful only for specific applications Viscosity 250 to several thousand cP Set time hours to days Hydrolyzes in alkaline media Shrinks during curing Components are toxic and require special handling
Lignosulfonate	Rarely used due to high toxicity Lignin can cause skin problems and hexavalent chromium is highly toxic (both are contained in these materials) Cannot be used in conjunction with portland cement; pH*s conflict Ease of handling Loses integrity over time in moist soils Initial soil strengths of 344-1378 KPa (50-200 psi)

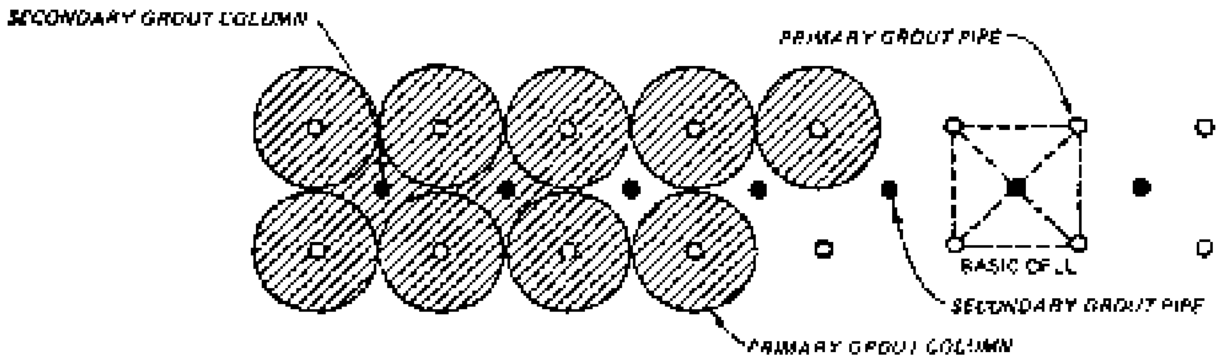

Figure 3-20. Grout Pipe Layout for Grout Curtain

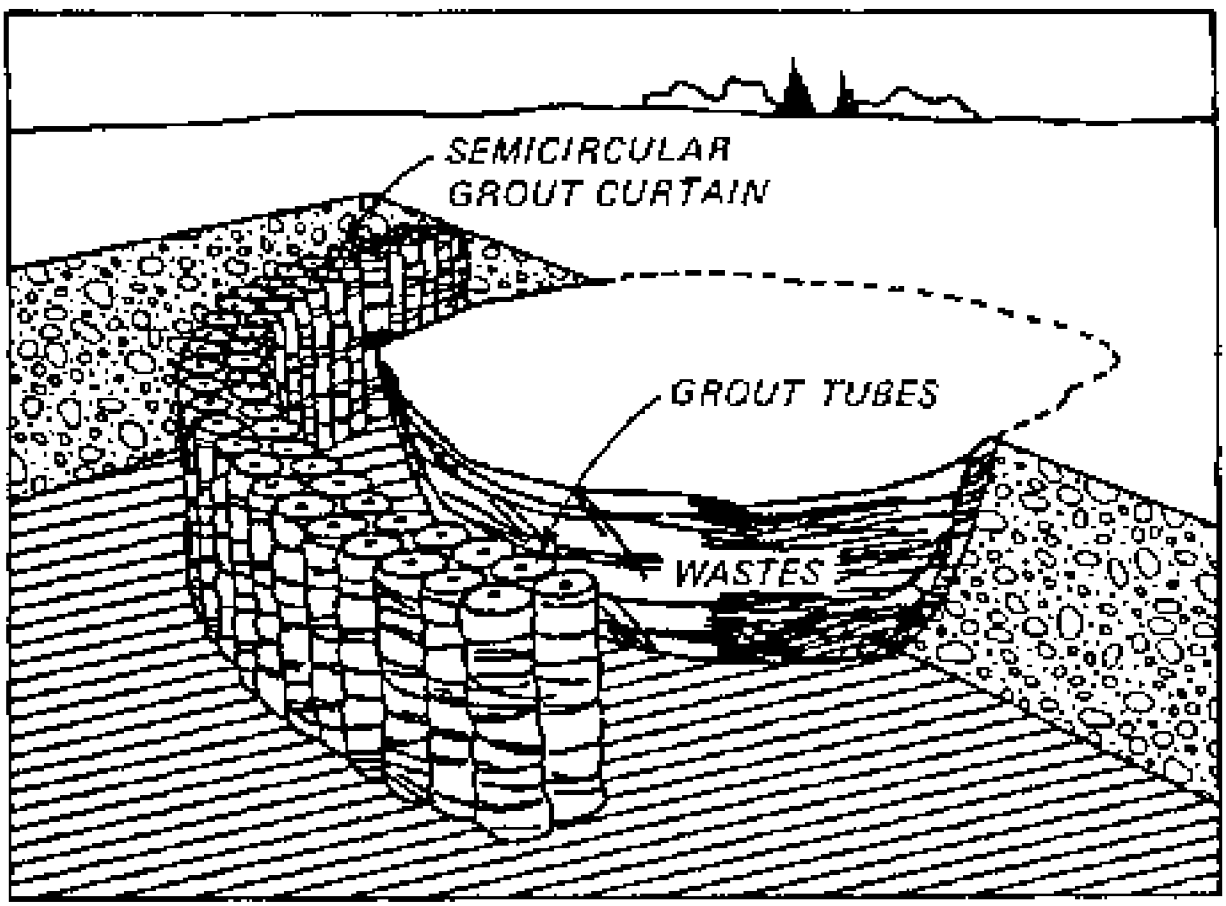

Figure 3-21. Semicircular Grout Curtain Around Waste Site

(2) Suspension grouts are for the most part either portland cement, bentonite, or a mixture of the two. Ultra-fine cement grouts are also available. Their primary use is in sealing voids in materials with rather high permeabilities, and they are often used as "pregrouts" with a second injection of a chemical grout used to seal the fine voids. If a suspension grout is injected into a medium that is too fine, filtration of the solids from the grout will occur, thus eliminating its effectiveness. Portland cement, when mixed with water, will set up into a crystal lattice in less than 2 hours. For grouting, a water-cement ratio of 0.6 or less is more effective. The smallest voids that can be effectively grouted are no smaller than three times the cement grain size. For this, it is clear that a more finely ground cement makes a more watertight grout. Portland cement is often used with a variety of additives that modify its behavior. Among these are clay, sand, fly ash, and chemical grouts.

(3) Of the clay minerals used for grouting, bentonite is by far the most common. Other locally available clays, especially those of marine or river origin, may be used but must be extensively tested and often chemically modified. Bentonite, however, because of its extremely small particle size (one micron or less), is the most injectable, and thus the best suited for grouting into materials with lower permeabilities. Medium- to fine-textured sands, with permeabilities of around 10 -10 cm/sec, can be sealed with a bentonite grout. Dry bentonite is mixed with water onsite at a rate of 5 to 25 percent by dry weight. In these ratios, bentonite will absorb large amounts of water and, with time, form a gel. This gel, although it imparts little if any structural strength, is an extremely effective water barrier.

(4) Placement of a grout curtain downgradient from or beneath a hazardous waste site requires consideration of the compatibility of the grout to waste leachate or other extremes of ground-water chemistry. Little information is available concerning the resistance of grouts to chemical attack. Should a case arise where grout must contact leachate or ground water of extreme, field tests should be performed to verify grout resistance.

(5) Quality control is a difficult issue since even small voids or breaks can greatly lessen the effectiveness of a grout curtain. By definition, a grout curtain is not amenable to inspection.

c. Design and Construction Considerations.

(1) Pressure grouting is a high technology endeavor. As with slurry trenching, extensive geotechnical and hydrologic testing must precede the placement of a grout curtain. Boring, pumping, and laboratory tests will determine whether or not a site is groutable and will provide the necessary ground-water, rock, and soil information to allow for the choice of the best-suited grout or grouts. They will further provide the designer with the information needed to plan the pattern and procedure for injection.

(2) For all grouts the closer the viscosity is to that of water (1.0 cP), the greater the penetration power. Grouts with a viscosity less than 2 cP, such as many of the chemical grouts, can penetrate strata with permeabilities less than 10 cm/sec. Higher viscosity grouts, like

particulate and some chemical grouts with a viscosity greater than j0 cP, can only penetrate coarse strata having permeabilities greater than 10 cm/sec. For suspension particulate grouts, the particle size will also influence the ability to penetrate voids.

(3) Short-term deterioration of the grout can be caused by rapid chemical degradation or by an incorrect setting time. The effect on setting time can be caused by a miscalculation of the grout formulation, dilution of the grout by ground water, or changes caused by chemicals contained within the grouted strata.

(4) Once a grout has set in the voids in the ground, it must be able to resist hydrostatic forces in the pores that would tend to displace it. This ability will depend on the mechanical strength of the grout and can be estimated by the grout*s shear strength. The shear strength of a grout will depend not only on its class, but also on its formulation. Thus, a class of grouts, such as silicates, can possess a wide range of mechanical strengths depending on the concentration and type of chemicals used in its formulation. The strength of the gel, then, can be adjusted, within limits, to the specific situation.

d. Advantages and Disadvantages.

(1) The advantage of grout curtain emplacement is the ability to inject grout through relatively small diameter drill holes at unlimited depths. The size of the pod or grouted column is a function of pore space volume and volume of grout injected. Grout can incorporate and/or penetrate porous materials in the vicinity of the injection well such as boulders or voids. Variable set times and low viscosities are also advantages.

(2) The major disadvantages of grouts are the limitations imposed by the permeability of the host material (soil or rock) and the uncertainty of complete cutoff, Specifically with particulate grouts only the most permeable units are groutable.

3-18. Sheet Pile Cutoff Walls. Sheet pile cutoff walls may be used to contain contaminated ground water, divert a contaminant plume to a treatment facility, and divert ground-water flow around a contaminated area. They constitute a permeable passive barrier composed of sheet piling permanently placed in the ground. Each section interlocks with an adjacent section by means of a ball/socket (bowl) union. The connection (union) may initially be a pathway for ground-water migration which may abate or cease if the ball/socket section is naturally or artificially filled with impermeable material. Sections of pilings are assembled before being driven into the ground (soil conditions permitting).

a. Description.

(1) Various sheet piling configurations are available. Application of specific configurations and fittings can be used for site-specific needs such as partitioning different sections of a waste-contaminated area or combination

of areas. Piling weight may vary from 1054 to 1820 Pa (22 to 38 lb/ft^2) depending upon the driving depth and soil materials.

(2) Keying in to a subsurface impermeable barrier is limited by depth to the barrier and composition of the barrier. Pile driving to a relatively shallow clay deposit and keying in to the clay without driving completely through the clay is relatively common in construction practices. However, keying in to a rock unit such as shale or other sedimentary unit is difficult. The physical tightness of such a bedrock/piling key is poor and may require additional sealing (grout, etc.). Pile testing and borings to an impermeable horizon can be used to determine the effectiveness of the barrier and piling interlock (ball/socket) damage.

b. Applications.

(1) As a remedial action at a hazardous waste site, sheet piling cutoff walls can be used to contain contaminated ground water. Piling driven to an impermeable layer can retain an existing contaminant(s) that may be released during cleanup actions.

(2) If ground-water flow rates and volume moving toward a hazardous waste site are sufficient to potentially transport a contaminant plume or impede site cleanup operations, a piling barrier can be used to divert the ground-water flow.

(3) Installation of sheet pilings at a hazardous waste site may present special problems related to buried tanks or drums that may be ruptured, unless care is taken to investigate the proposed piling alignment with magnetometers or other metal-locating devices. Drums at depth may not be detected and pose special problems.

c. Design and Construction.

(1) Maximum effective depth is considered to be 14.9 m (49 feet). Although under ideal conditions, pile sections have been driven up to depths of 29.9 m (98 feet).

(2) Steel sheet piling is most frequently used. Concrete and wood have also been used. Concrete is expensive but is attractive when exceptional strength is required, and, although less expensive, wood is relatively ineffective as a water barrier.

(3) Sheet piles are typically used in soils that are loosely packed, and predominantly sand and gravel in nature. A penetration resistance of 13 to 33 blows/m (4 to 10 blows/foot) for medium- to fine-grained sand is recommended. Cobbles and boulders can hinder pile placement.

(4) Piling lifetime depends on waste characteristics and pile material. For steel piles pH is of particular importance. A pile life up to 40 years (depending on other leachate characteristics) can be expected where pH ranges between 5.8 and 7.8. A pH as low as 2.3 can shorten the lifetime to 7 years or less.

d. Advantages and Disadvantages.

(1) Sheet pilings require no excavation. Thus, the construction is relatively economical. In most cases, no maintenance is required. The disadvantages of sheet pilings are the lack of an effective seal between pilings and problems related to piling corrosion.

(2) At hazardous waste sites, corrosion of sheet pilings can be a severe problem. Many sites contain mineral acids that react readily with iron. Standard cathodic protection may not be effective if local concentrations of acid materials are present. Any reaction of metal with acid can produce hydrogen gas that may diffuse from the soil and create a fire or explosion hazard at the surface.

3-19. Membranes and Synthetic Sheet Curtains. Membranes and other synthetic materials have been used extensively as pond and lagoon liners. The impervious nature of the liner and its general resistance to corrosive chemicals have been proven to exceed the qualities typical of clay liner material used in landfills. The key factor in the use of membrane liners is to produce an effective seal between adjacent sheets of membrane.

a. Description. Synthetic membrane materials (PVC, butyl rubber, polyethylene) may be used in a manner similar to clay or sheet pile cutoff walls. The membrane can be inserted in a slit or a V-shaped trench to facilitate anchoring at the top of the trench. Membrane liners require some special handling for effective use. Membrane materials are usually not laid with any stress on the membrane. All seams are heat- or solvent-welded using manufacturer-approved techniques to ensure the seams are as strong as the material itself.

b. Applications. Membrane curtains can be used in applications similar to grout curtains and sheet piling. The membrane can be placed in a trench surrounding or upgradient (ground water) from the specific site, thereby enclosing the contaminant or diverting the ground-water flow. Placing a membrane liner in a slurry trench application has also been tried on a limited basis.

c. Compatibility. Compatibility of the membrane material with contaminated ground water or soil should be considered before emplacement of the membrane.

d. Design and Construction. Emplacement of the liner in conventional style requires a trench of sufficient size and slope that crews can lay the liner and transverse the liner with sealing equipment. The trench needs to be excavated to an impervious zone wherein the membrane is keyed in and sealed to prevent leakage at the membrane bottom. In conditions of contaminated, unstable, or saturated soils, special safety and construction practices must be established. Lowering a prepared liner into a narrow vertical trench is not feasible. The narrow trench in most cases will not be able to remain open without caving debris interfering with keying in conditions. Suspending the lines may cause stretching or tearing.

e. Advantages and Disadvantages.

(1) The membrane provides an effective barrier if it can be emplaced without puncture or imperfect sealing. Sealing is a difficult process that requires material handling and manipulation not afforded by trench emplacement. Keying the membrane adequately to the impervious layer is also difficult. The key zone must be disturbed and membrane material may not be conducive to adhering to concrete or other sealing material.

(2) Installation of liners is also restricted to climatic conditions. Liner membranes generally should not be installed at temperatures colder than about 45 °F. Soil temperature as well as atmospheric temperatures affect the flexibility as well as sealing character of the membrane. Adverse moisture conditions also may inhibit successful sealing of seams.

3-20. Combination Barrier/Pumping Systems. Barrier and pumping systems can be used in combination to ensure containment of contaminated ground water. When used in combination, the general approach is to use the barrier system to minimize the quantity of ground water that must be pumped and treated. The most common application of a combination barrier/pumping system is the use of a circumferential slurry wall, keyed into an underlying aquiclude, combined with an interior pumping system to maintain an inward hydraulic gradient. Design criteria are similar to those previously discussed for the individual systems.

3-21. Subsurface Drains and Drainage Ditches.

a. Background.

(1) Subsurface French drains are trenches filled with gravel that are used to manage surface or ground-water flows in shallow subsurface materials. At most hazardous waste sites, standard French drains are of limited use because close control of ground-water flow is required, and care must be exercised in preventing contaminated water from reaching lower aquifers.

(2) Well-designed underdrains that can intercept ground water flowing into a waste site have been helpful in reducing the water treatment problem where extraction systems are employed. Where the water table is relatively shallow (30 feet below the surface or less), a waste site can be isolated by trenching down into the water table and introducing a barrier and a vertical permeable layer with a drain at the bottom. This system acts to intercept small springs or seepage that may enter a buried waste pit. By diverting the ground water before it enters the site, the growth of the pollution plume exiting the site is reduced without pumping.

(3) When applicable, the barrier/underdrain system is a permanent low-cost remedial option. It requires small maintenance efforts to ensure the drains are clear. The intercepted ground water is usually tested periodically to ensure that no pollutant is discharged. The only disadvantages observed with this system relate to possible movement of contaminant through the ground-water barrier and into the drains. If this occurs, all of the discharge from the underdrains may require treatment before discharge. This