concrete INFORMATION

Cement-Bentonite Slurry Trench Cutoff Walls

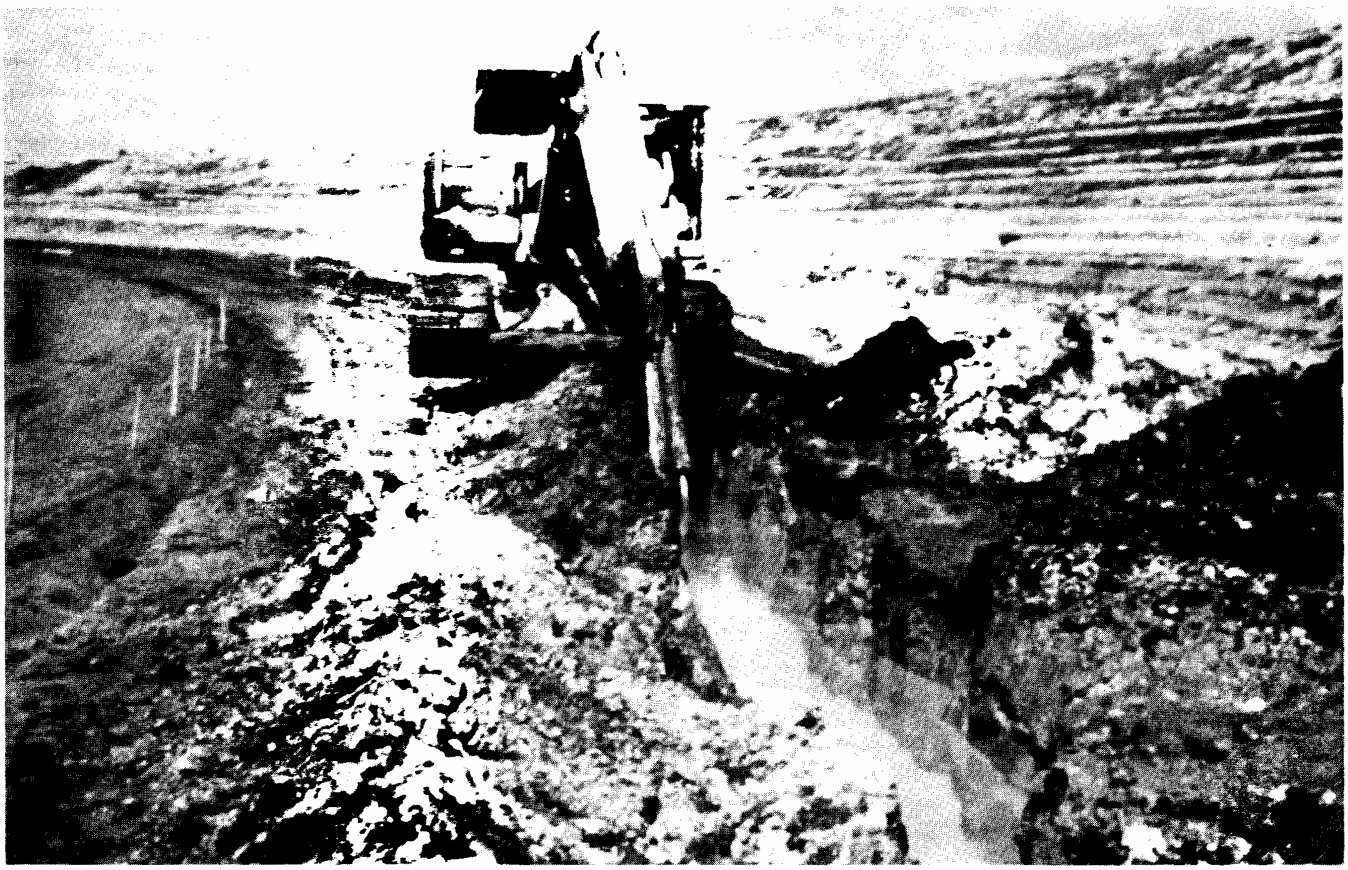

Fig. 1. Constructing cement-bentonite slurry trench along interior toe of slope for cooling water reservoir at Martin Power Plant, Fla. Note soil-cement slope protection in background.

A slurry trench is a nonstructural underground wall that serves as a barrier to the horizontal flow of water and other fluids. It is constructed with the aid of a viscous stabilizing fluid known as slurry (Fig. 1). The two most common types of slurry trenches are referred to as soil-bentonite (S-B) and cement-bentonite (C-B). In the S-B method, a bentonite-water slurry is introduced into the trench during excavation to provide side wall support. After the trench is excavated to its required depth, a mixture of soil, bentonite, and water is placed into the trench displacing the bentonite-water slurry. Generally the excavated soil is used in the backfilling operation; however, if it contains an excessive amount of contaminated or undesirable material such as cobbles or clay lumps, a selected backfill material may be required.

In the C-B method, cement is added to the bentonite-water slurry just prior to its introduction into the trench. In addition to serving as a stabilizing fluid to maintain an open trench during excavation, the cement-bentonite slurry remains to set up and form the permanent cutoff wall. Although in most cases either method can be used, a C-B slurry trench offers many advantages over the S-B method as indicated in Table 1.

Table 1 - Advantages of C-B Slurry Trench Method Over S-B Slurry Trench Method (Adapted from Ryan[1])

The C-B method is not dependent on the availability or the quality of soil for backfill.
The C-B method is more suitable in trenching through weak soils where trench stability may be a concern. The C-B slurry has a higher density than S-B slurry and begins to set within hours after excavation, thereby reducing the chance of failure.
The C-B slurry sets up to a stiff claylike consistency. Trenches may be cut through the wall without sloughing. Construction traffic may cross the trench after a few days.
The construction sequence is more flexible. The C-B method permits trench construction in sections to meet site constraints. It adapts to hilly surfaces where a step-type construction can be performed. With the S-B method, the long open trench necessary to accommodate the flat slope of the backfill normally requires trenching continuously in one direction at a constant elevation.
With a C-B slurry trench, construction may proceed during subfreezing temperatures. With the S-B method, special precautions are required to keep the backfill from freezing.
The width of a C-B trench is generally less than for a S-B trench. For the S-B method, the trench must be wide enough to permit free flow of the backfill material.
With the C-B method an area adjacent to the trench is not required for mixing, making it more suitable on projects with space limitations such as the crest of a dam. Also, cleanup is easier with the C-B method.

Applications

Since the early 1970's, several hundred slurry trench cutoff walls have been constructed. Applications have included excavation dewatering, containment of solid and liquid wastes, and reduction of seepage through embankments and foundations of water storage structures. Fig. 2 presents some typical applications.

Slurry trenches have many advantages over other seepage control techniques such as grouting, sheet-piling, and pumping well systems. Slurry trenches provide a continuous, uniform seepage barrier. They extend to greater depths than most other methods and require no maintenance or operating costs after installation. For dewatering applications only the water level within the confines of the slurry trench is affected. With a pumped dewatering system, however, drawdown of the water table may extend well beyond the limits of excavation and cause problems, especially in environmentally sensitive areas.

At Commonwealth Edison's Braidwood Nuclear Power Station, Braidwood, Ill., slurry trenches were used both for excavation dewatering and as a cutoff through and beneath the exterior dikes of the 2640-acre (1070-ha) cooling water reservoir. Prior to foundation excavation a cement-bentonite slurry trench was constructed along the perimeter of the main plant. The trench was constructed through 30 ft (9 m) of fine to medium sand and keyed into the underlying glacial till. Considering the length of time the excavation would need to be dewatered, a slurry trench proved much more economical than a conventional pumping well system. In addition, the slurry trench eliminated the need for headers and other obstructions. Any water entering the excavation was removed by intermittent use of a sump pump.

A C-B trench was chosen rather than an S-B trench due to the limited working area available at the time of installation. Also, pipes and other underground connections to the plant required numerous penetrations through the cutoff wall. A C-B trench was less likely to slough during excavation for these connections and would be easier to reseal following installation.

For the cooling water reservoir (Fig. 3), both C-B and S-B slurry trench methods were used. A large portion of the reservoir is situated over abandoned coal strip-mining operations. This strip-mining area consists of spoil piles and hydraulic fills of low shear strength with depths to 120 ft (37 m). A test cell was installed to evaluate the feasibility of excavating through the mine spoils and also to determine the adequacy of both the S-B and C-B slurry trench methods. The C-B method was chosen because the test showed it was more stable than the S-B method. The C-B trench was also used beneath the spillway and makeup/discharge structures located in the undisturbed portion of the dike. For the remainder of this portion, an S-B slurry trench was used.

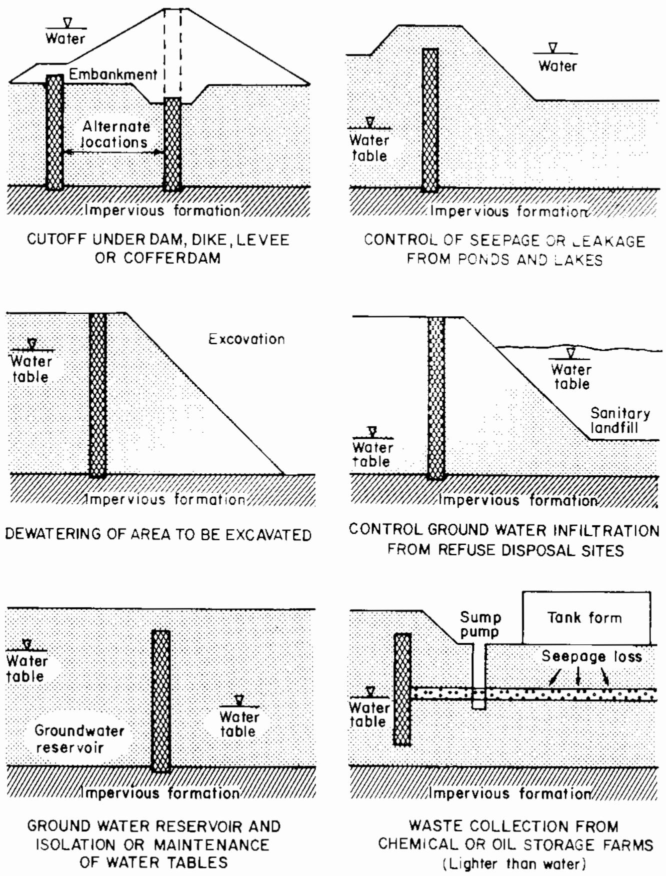

Fig. 2. Typical applications for slurry trench cutoff walls. (From Millet and Perez[2])

Fig. 3. Aerial view of cooling water reservoir at Braidwood Nuclear Power Station, Ill.

Slurry trenches have been used for repairing failures of water control structures. The most notable is the 18-mile-long (29-km) upstream cutoff wall for the locally washed-out embankment of the Martin Power Plant in Florida. The method was also used to help repair the failed Walter B. Bouldin Dam in Alabama and the leaking S-B cutoff trench at the Lake Chicot Pumping Plant in Arkansas.

Groundwater contamination due to seepage from landfills, lagoons, and other waste disposal sites can be a serious problem. If a continuous impervious strata exists below these areas, a slurry trench can effectively contain further migration of the leachate.

At the Puente Hills Sanitary Landfill in Los Angeles County, Cal., a slurry trench was constructed to prevent leachate from escaping and contaminating the groundwater. The 30-in-wide (76-cm) trench, which has a maximum depth of 75 ft (23 m), was constructed along the toe of a 300-ft-high (91-m) existing landfill. Trench stability, especially during excavation, was a concern; therefore, a C-B slurry trench was selected. In addition to its greater stability, laboratory tests showed the C-B slurry to be compatible with the wastes.

The first "Superfund" project administered by the U.S. Environmental Protection Agency, which involved a physical barrier to stop pollution, utilized a slurry trench. Coal tar emissions were seeping into a nearby creek in Stroudsburgh, Pa. To block further seepage, a narrow 12-in.-wide (30-cm) C-B slurry trench was installed between the toxic coal tar deposits and the creek. The 638-ft-long (194-m) trench, which ranged in depth from 18 to 23 ft (5.5 to 7 m), was constructed along a limited working platform of only 11.5 ft (3.5 m). A narrow C-B slurry trench was chosen for this project because of high disposal costs for the excavated contaminated soil and the limited work area.

Not all applications require an impervious layer to key into. Seepage from petroleum facilities such as oil tank farms can be contained by extending the slurry trench below the minimum expected water table as shown in Fig. 2. The oil will float on top of the groundwater, and a collector sump installed inside the contained area may be used to collect the oily wastes for reprocessing or disposal.

Design

The parameters usually considered when designing a C-B slurry trench are: permeability, strength, and deformability. Other factors of importance may be durability and permanence or, in the case of waste containment, the compatibility of the slurry trench to the waste.

Permeability is the most important factor. Both laboratory and field tests indicate permeabilities of C-B slurry trenches range from 1 to 0.1 ft/yr (10^{-6} to 10^{-7} cm/sec).

Since a C-B slurry trench is not intended to support bending moments or significant shear stresses, strength usually is not a primary consideration. The trench is generally designed to achieve a strength equivalent to that of the surrounding soil. However, on projects where slurry trenches are constructed through unstable material such as peats and mine spoils, trench stability, especially during excavation, is a critical consideration. The cement-water ratio has a significant effect on the strength of the C-B slurry trench. Also, as with concrete, strength increases with age. The effect of both the cement-water ratio and age on strength are shown in Fig. 4a.

The deformability or compressibility of a slurry trench is important when considering its application beneath large dams or in seismic areas where displacements may occur. The slurry trench must be able to accommodate the displacements without cracking. A major factor that affects the deformability of C-B slurry trenches is the cement-water ratio. Laboratory tests indicate that higher strength, or a higher cement-water ratio, results in a stiffer, less deformable wall. Fig. 4b shows the relationship between ultimate uniaxial compressive strength and triaxial strain at failure. The high strain capacity of the C-B slurry is significant even for uniaxial compressive strengths of 50 psi (0.3 MPa).

Slurry trenches may or may not be permanent applications. When used as a temporary dewatering method in lieu of a wellpoint or deep well system, the slurry trench may be needed for only a short time. On the other hand,

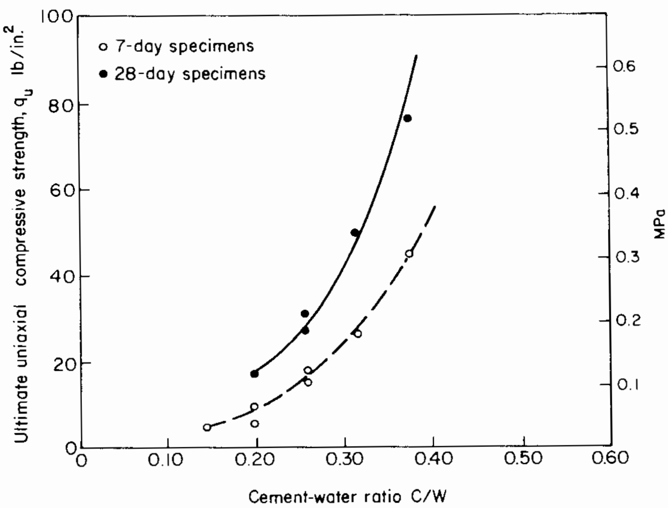

Fig. 4a

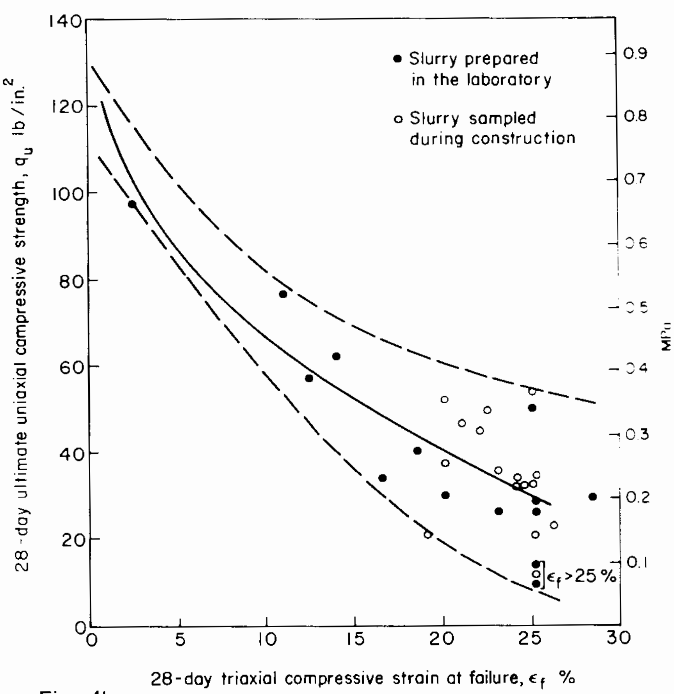

Fig. 4b

Fig. 4. Typical strength deformation test results for cement-bentonite slurries.

a slurry trench constructed as a cutoff or seepage barr beneath a dam must perform for the life of the structu When constructed with and exposed to clean wat slurry trenches should be considered permanent r gardless of the application.

For applications that involve contaminated water exposure to pollutants, it is important to check the effe the liquid has on the slurry trench. For example, aci will dissolve the cement components of a C-B slur trench. Sulfates may also be harmful; however, the atta by sulfate soils or wastes may be reduced or prevent by using cement containing a low tricalcium alumina (C_3A) content. Type II cement with a maximum C content of 8% is used for moderate sulfate exposu (150 to 1500 ppm). Type V with a maximum C_3A conte of 5% is for severe sulfate exposure (1500 to 10,0 ppm).

The rate and extent of chemical attack is also impo tant. If the concentration of an aggressive chemical low or if it is not replenished, the effect on the trench m be insignificant. Publications by the American Concre Institute and Portland Cement Association (3,4) provi information on substances that may attack concret

Occasionally an instantaneous and significant i crease in viscosity will occur following the addition cement to the bentonite-water slurry. This chemical r action causes the bentonite to flocculate and thicke the slurry making it difficult to pump. Additives are som times used in C-B slurries to prevent premature thicke ing and to increase workability or delay setting acti In general, the additives are used in a concentrati between 0.01 to 0.5% of the weight of cement. Disper ing agents have been used effectively to maintain slur viscosities within workable limits. Retarding agen which can delay setting times up to 72 hours, are esp cially useful for deep trenching where work may contin in the same area for several days. No addivites shou be used, however, that will adversely affect the perfo mance of the completed slurry wall. A list of typic additives and their effect on the fluid slurry properties a listed in Table 2. A complete description of many of the

Table 2 - Effect of Additives on Fluid Slurry Properties

Additive	Effect
Sodium bicarbonate Sodium carbonate (Soda ash)	Water softener. Promotes bentonite-water hydration by precipitating calcium, magnesiu and iron in hard water.
Sodium carboxymethyl cellulose (SCMC) Pregelatinised starch Industrial gums	Increases bentonite-water viscos and gelation where salt contami nation has inhibited hydration a water absorption. Reduces loss of fluid.
Phosphates	Removes calcium and disperses clay solids. Decreases pH. Redu viscosity but does not reduce fl loss.
Sulfonated lignins Polyhydroxy polycarboxylic compounds Polyglycerols Tannins	Set retarders. Dispersive agents Reduces viscosity, gelation, and fluid loss. FCL best where high concentrations of salt or calciu are present.

additives and their effect on fluid slurry properties can be found in references by Boyes and Xanthakos.[5,6]

Slurry mix designs will vary depending upon the type of application, materials used, and mixing and construction techniques. Occasionally, a mix design, especially the bentonite quantity that has been established in the laboratory, may require modification in the field to improve workability and facilitate construction. A typical mix consists of 3 sacks (282 lbs) of portland cement and one sack (100 lbs) of bentonite per cubic yard of water (1685 lbs).* This results in a cement-water ratio of about 0.17.

Construction Methods

Mixing Methods

Cement-bentonite slurry is prepared in a two-step process. First, bentonite is mixed with water to form a bentonite-water slurry. A standard practice is to mix and store the bentonite-water slurry in a cement-free environment until the bentonite platelets have fully hydrated. The bentonite-water slurry is then transferred into a mixing chamber where cement is added and homogeneous cement-bentonite slurry is obtained.

The three basic types of mixers generally used for slurry trench construction, either alone or in combination, are:

1. Venturi or flash mixer
2. Colloidal mixer
3. Paddle mixer

The venturi or flash mixer is used in preparing the bentonite-water slurry (Fig. 5). Water is pumped under high pressure through a venturi system, which causes a pressure drop. The pressure drop creates a suction action that draws the bentonite powder into the venturi. The bentonite is metered so its flow is proportioned for the volume of water. The resultant mix is then stored in ponds or tanks until hydration is complete, which is generally overnight. Usually a two-pond operation is employed with one pond for fine-tuning the mixture and a second for storing properly hydrated slurry. The slurry in both ponds is kept homogeneous with recirculating pumps. Hydration time is rather long because the slurry is subjected to high-shear mixing for only a fraction of a second; however, large quantities can be blended with this type of mixer. After the bentonite has fully hydrated, the bentonite-water slurry is usually transferred into a colloidal or paddle mixer where cement is added.

Colloidal mixers are high-shear mixers. Water is metered into a mixing chamber and recirculated by means of a high-speed/high-shear centrifugal pump. The mixing chamber may also be equipped with rotary propellers to assist in the mixing (Fig. 6). Bentonite, which is slowly added to the circulating water, disperses and hydrates quickly under the high-shearing action. Once hydrated, cement is then added. The bentonite-water slurry may also be pumped to a storage tank or transferred to an adjacent mixer where cement is added (Fig. 7). Additives such as dispersing agents, if used, are introduced into the hydrated bentonite-water slurry just before cement is added. Many colloidal mixers are capable of mixing slurry continuously as well as in individual batches.

Paddle mixers are generally low-shear mixers that may be used to prepare the bentonite-water slurry or simply to mix the cement into an already hydrated bentonite-water slurry (Fig. 8). The mixing time required to hydrate the bentonite fully depends upon the type and grade of bentonite and type of paddle mixer. It usually takes longer than a colloidal mixer; therefore, its use is generally confined to smaller slurry trench sites or in combination with the venturi mixing method.

*Equivalent metric conversion: 167 kg of cement and 59 kg of bentonite per cubic meter (1000 kg of water).

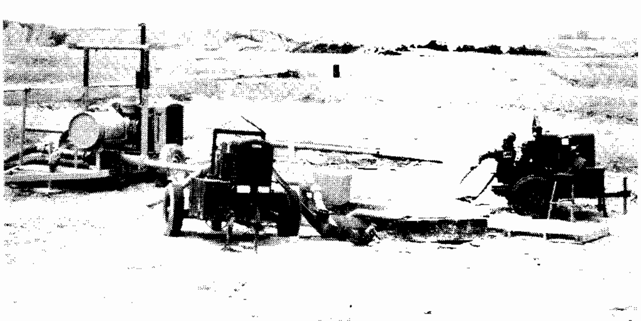

Fig. 5. Flash mixer with circulating pumps. Bentonite slurry holding pond in background.

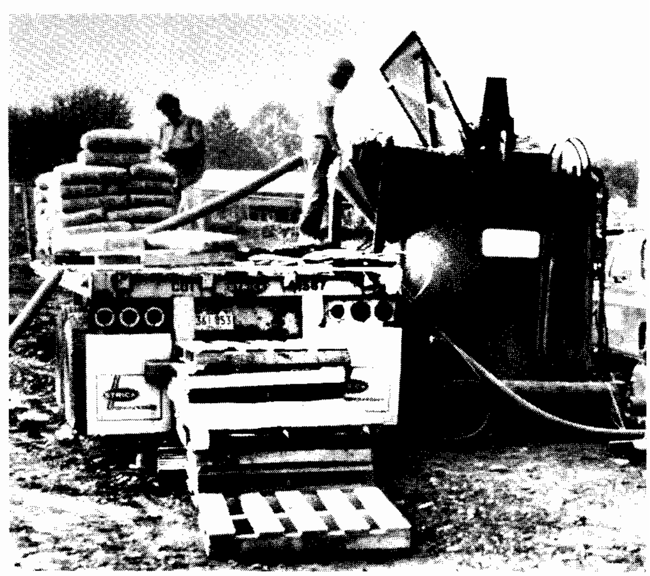

Fig. 6. Five-cu-yd capacity colloidal mixer. Vertical shaft with propellers located in center of tank assists slurry mixing. (Courtesy of Geo-Con Inc., Pittsburgh, Penn.)

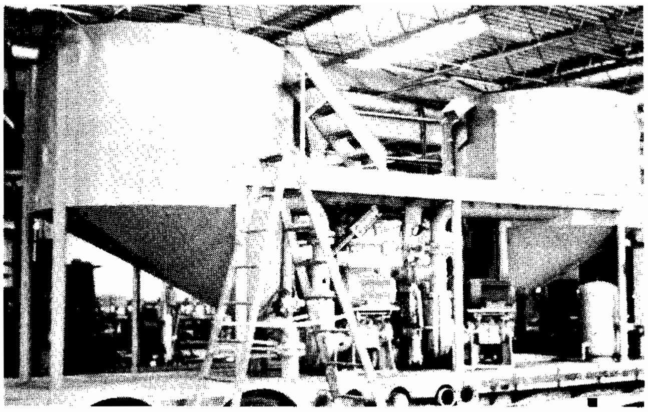

Fig. 7. Colloidal mixing plant equipped with two 6-cu-yd capacity mixing chambers. (Courtesy of Great Lakes Construction Co., Spring Lake, Mich.)

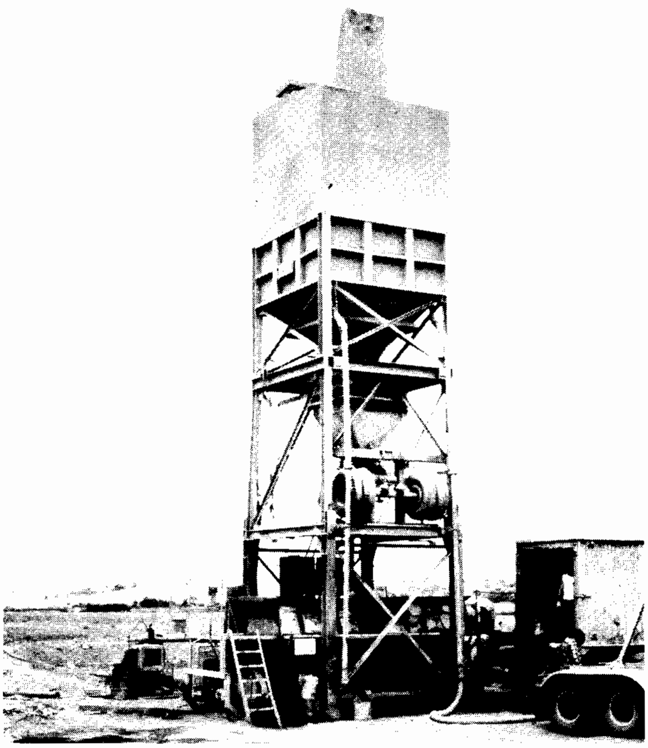

Fig. 8. Paddle mixing plant. Cement scale, surge hopper, and storage silo located above two 6-cu-yd capacity mixing chambers.

Excavating Techniques

The excavating methods for slurry trenches depend upon the required depths, design widths, and subsurface materials. Principal types of excavating equipment include the backhoe, dragline, and clamshell.

The backhoe is the fastest and most economical method of excavation. Standard backhoes have depth limitations of about 40 ft (12 m); however, some slurry trench contractors have modified standard backhoes to excavate effectively to depths more than 70 ft (21 m) (Fig. 9). Minimum trench widths are controlled by the thickness of the boom, dipper stick, and bucket. For shallow trenches using small backhoes, this width may be as little as 1.0 ft (0.3 m). Deeper trenches require larger, more powerful backhoes equipped with wider booms resulting in minimum trench widths between 2.0 to 3.0 ft (0.6 to 0.9 m).

Draglines excavate trenches to depths of 80 ft (24 m) but have limited use in C-B slurry trenching. To reach these depths requires specially sized and weighted buckets with minimum widths ranging from 5 to 8 ft (1.5 to 2.4 m). Because material costs are higher for the C-B slurry than the S-B method, draglines are seldom used for conventional C-B slurry trenches.

For depths beyond the reach of a backhoe, hydraulic or mechanically operated clamshells used in combination with a backhoe are the most efficient and economical method of excavation. Originally developed for structural diaphragm wall construction, these specially designed clamshells have excavated to 250-ft (76-m) depths. They may be either free-hanging (Fig. 9) or kelly-guided grabs (Fig. 10). The major economic advantage of the clamshell over the dragline is that the width of the clamshell may be as little as 1.5 ft (0.5 m).

The typical method for excavating deep trenches is shown in Fig. 11. The upper 40 to 70 ft (12 to 21 m) of trench is excavated with a backhoe and the deeper portions with clamshells. An "alternating panel" method is employed. A series of primary panels are initially excavated. Following completion of at least two adjacent primary panels, excavation of the secondary panels can begin. Secondary panels are narrower to allow a minimum overlap into the primary panels and assure continuity of the trench.

A type of C-B slurry wall that does not involve excavating a trench is the vibrating beam method. A specially designed crane-mounted I-beam is driven into the soil to the required depth with a vibratory hammer (Fig. 12). To help advance the beam a C-B slurry is jetted downward

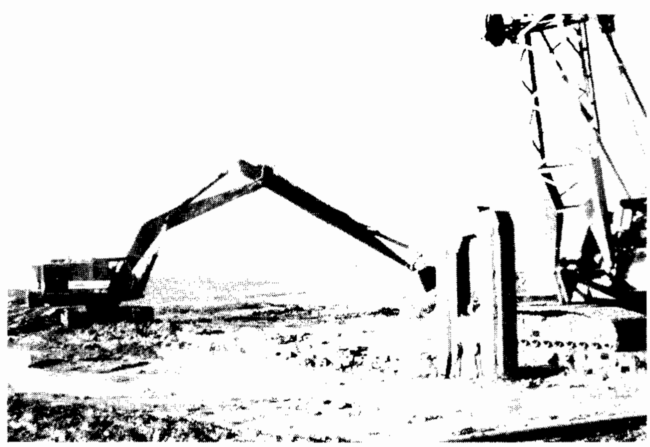

Fig. 9. Equipment used for excavating deep slurry trenches includes a free-hanging clamshell and a modified backhoe capable of excavating to 52 ft. Braidwood Nuclear Power Station, Ill.

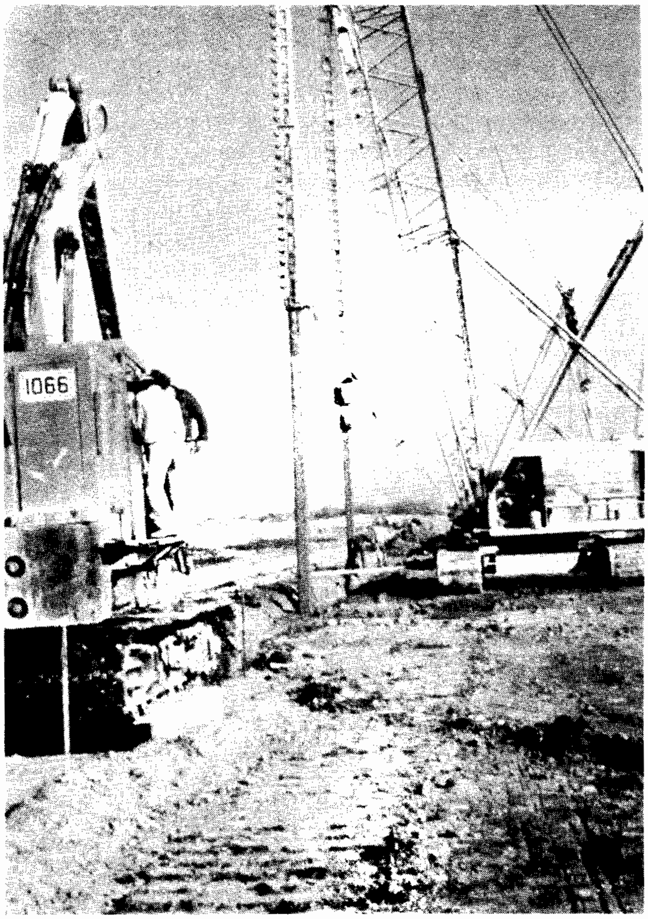

Fig. 10. Two kelly-guided clamshells excavating deep portion of slurry trench. Initial 50-ft depth being excavated with modified backhoe in foreground. Braidwood Power Station, Ill.

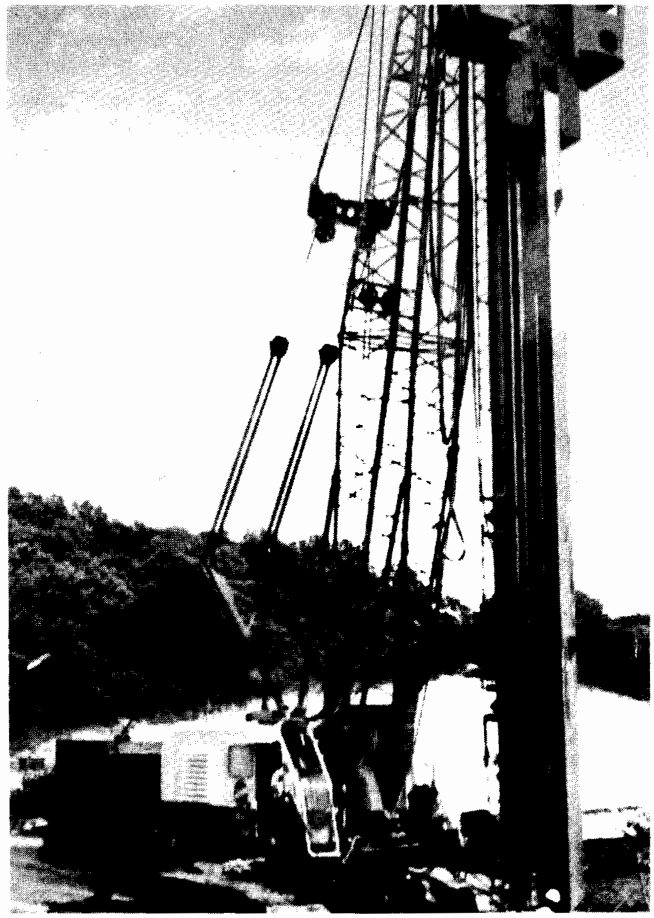

Fig. 12 Vibrating beam technique for installation of cement-bentonite slurry wall. (Courtesy of Slurry Systems, Inc., Gary, Ind.)

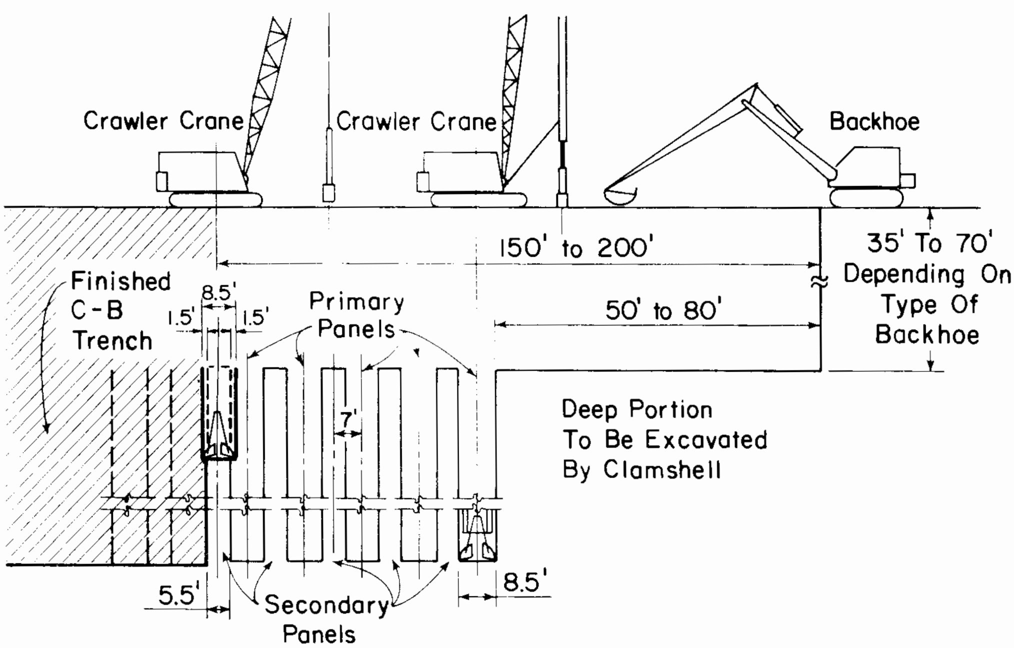

Fig. 11. Typical method of excavating deep slurry trenches.

through one of the spray nozzles located at the tip of the beam. Once the beam has reached its required depth, it is extracted at a controlled rate while simultaneously injecting a C-B slurry through additional spray nozzles mounted along the tip of the beam (Fig. 13). This injected slurry fills the void left by the beam. After the beam reaches the surface, it is moved along the wall and the process is repeated allowing a suitable overlap to assure continuity. The result is a thin C-B slurry wall, usually about 4-in. wide (10-cm). It is limited, however, to depths less than 60 ft (18 m), and in very dense soils or soils that contain boulders it may be more difficult to construct than conventional trenching.

Quality Control

Field inspection of C-B slurry trench construction involves the control of two basic factors:

1. Fluid slurry properties
2. Trench excavation including alignment, continuity, width, and depth

The American Petroleum Institute (API) has developed standards (7, 8) for determining bentonite quality and various slurry properties. These standards, which were developed for the oil-well drilling industry, are being applied in slurry trench construction. Many standards, while important to the oil-well drilling industry, may have little or no significance in slurry trench construction.* Two slurry properties that are important are viscosity and density.

Viscosity is the resistance to flow of a slurry in motion. It relates to the workability of the slurry and settling rate of suspended solids in the trench. The test consists of filling a standard-size funnel, called a Marsh funnel, with 51 oz (1500 ml) of slurry. Viscosity is defined as the time it takes for the slurry to flow through the funnel and fill a 1-qt (946 ml) container (Fig. 14). For water this takes approximately 26 seconds. With C-B slurries the viscosity increases as the slurry begins to set; therefore, viscosity tests should be performed soon after final mixing. Also, as previously mentioned, when cement is added to the bentonite-water slurry, a chemical reaction occurs. This often causes an immediate increase in viscosity. Dispersing agents may be used in these cases to control the reaction. Normally, C-B slurry viscosities are in the range of 40 to 50 seconds; however, acceptable slurries have been used that are so thick they cannot pass through the orifice of the Marsh funnel.

Initial slurry density gives an indication of the quantity and type of hydrated solids in the slurry mixture. The standard instrument used to check density is a mud balance (Fig. 14). A typical bentonite-water slurry has a density between 64 to 67 pcf (1.03 to 1.07 gm/cm^3). The addition of cement significantly influences slurry density. Depending upon the quantity of cement specified in the mix design, C-B slurry densities can range from 68 to over 90 pcf (1.09 to over 1.44 gm/cm^3). A typical 3-sack mix (282 lb cement per cubic yard [167 kg/m^3] of water) has a density just over 70 pcf (1.12 gm/cm^3).

In addition to viscosity, comparing in-trench slurry densities at various depths provides another means to determine the settling rate of suspended solids. In-trench densities that are relatively similar from top of trench to the bottom indicate good suspension characteristics. A dramatic density increase with depth may indicate a slurry with poor suspension characteristics causing excess sand and other solids to settle to the trench bottom. This could cause increased seepage.

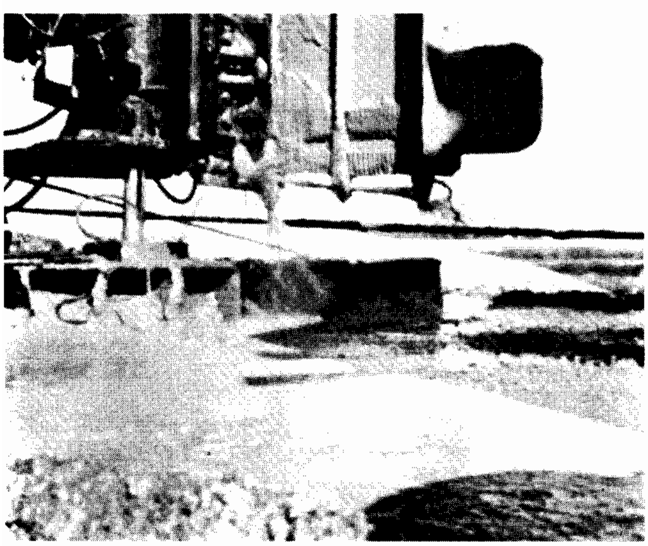

Fig. 13. Spray nozzles and "trailing fin" located at tip of beam. Slurry injected through nozzle at left assists the beam in penetrating the soil. (Courtesy of Slurry Systems, Inc., Gary, Ind.)

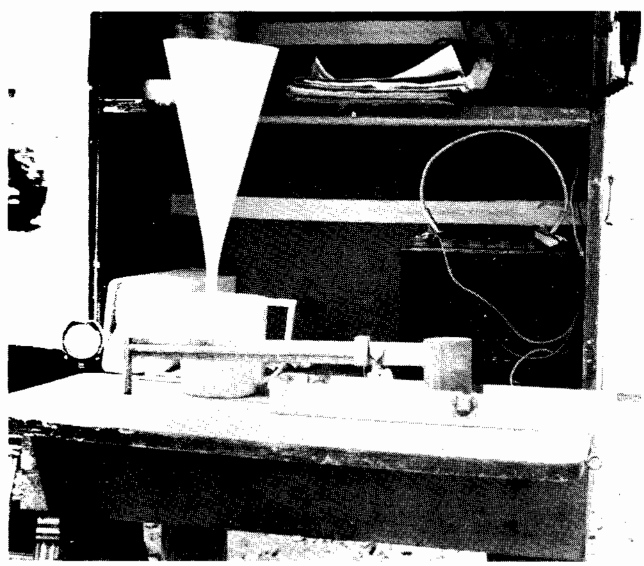

Fig. 14. Standard test equipment used to measure density and viscosity of slurry.

*The American Society for Testing and Materials (ASTM) is presently drafting testing standards for both bentonite-water and cement-bentonite slurrries. These standards closely follow those of API but relate more to slurry trench construction.

In addition to controlling slurry quality, the inspector must also check to ensure that the slurry trench is continuous and satisfies the dimensional requirements of the plans and specifications. The width of the excavating equipment should be equal to or greater than the minimum design width of the trench.

Design depths are generally estimated by interpreting soil borings taken near or along the trench alignment. Because possible variations may exist in the location of the impervious layer, the inspector frequently must check the excavated material at the bottom of the trench to be sure it represents the intended tie-in impervious material. The inspector should also check that the trench bottom is cleaned of all loose rock, sand, and other sediments. The use of a jet pipe and air lift pump may be required. Final depth measurements should be made at regular intervals, generally every 10 to 25 ft (3 to 7.5 m) along the trench.

When the trench is excavated by a backhoe, the nature of the machine ensures longitudinal continuity. With clamshell equipment, primary panels are dug initially and serve as guides for the secondary panels. Upon completion of the secondary panel, a slight sideways movement of the bucket in both directions is used as a final check on continuity before the equipment is moved.

Specifications

The basic purpose of a slurry trench is to serve as a low-permeability seepage barrier. Specifications should be prepared with this in mind. They should set forth requirements that are considered essential to the design and eventual performance of the slurry trench. They should also adequately define the scope, configuration, and quality of the completed project.

The following specifications are suggested as a general guide to format and content for normal slurry trench construction. Many projects have special requirements or conditions that should be included but are not covered by these specifications. Every project should be reviewed based on individual needs and requirements. Notes have been added, where appropriate, to explain various sections.

1.0 Scope

The work shall consist of furnishing materials, equipment, and labor and performing all operations connected with constructing a cement-bentonite slurry trench according to the plans and specifications or as required to complete the work properly. The contractor shall be required to submit evidence that he is competent to construct such a slurry trench.

2.0 Materials

2.1 Bentonite. Bentonite shall consist of pulverized, natural, Wyoming sodium montmorillonite clay and comply with API Specification 13A, "Oil-Well Drilling Fluid Materials." Peptized or other specially treated bentonites will not be allowed unless approved by the engineer.

2.2 Cement. Cement shall be portland cement Type meeting the requirements of ASTM C150.

Note—For sulfate exposure, Type II (moderate sulfate-resistant) or Type V (high-sulfate-resistant cement may be specified.

2.3 Water. Water shall be fresh, clean, and free of oils acids, alkalines, salts, organic matter, or other deleterious substances. Treatment of hard water by approved chemical softening methods is permitted.

Note—The water supply should be checked prior to start-up to be sure it will not adversely affect the swelling of the bentonite. Hard water may have to be softened to ensure adequate swelling capacity of the bentonite.

2.4 Additives. Pozzolans such as fly ash, if used, shall comply with the requirements of ASTM C618. Retarders or other types of additives may be used only with prior approval by the engineer.

3.0 Proportioning

3.1 Bentonite-Water Slurry. Bentonite-water slurry shall be a stable, fully hydrated, colloidal suspension of bentonite and water. Prior to the addition of cement the bentonite-water slurry shall be periodically mixed or recirculated to keep it homogeneous. It shall meet the following requirements as tested in accordance with API RP 13B, "Standard Procedure for Testing Drilling Fluids."

Note—ASTM testing standards should be used. At time of publication they had not yet been approved.

3.1.1 Density shall be a minimum of 64 pcf (1.03 gm/cm^3).

3.1.2 Viscosity shall be a minimum of 35 seconds as measured by the Marsh funnel.

Note—Bentonite-water slurry should be considered fully hydrated when the viscosity has stabilized.

3.2 Cement-Bentonite Slurry. Cement-bentonite slurry shall be composed of bentonite, portland cement, water, and any approved additives or admixtures. Cement shall be added to the fully hydrated bentonite-water slurry just before introduction into the trench. When introduced into the trench, the cement-bentonite slurry shall meet the following requirements as tested in accordance with API RP 13B. (Refer to previous note on ASTM testing standards.)

3.2.1 Cement-water ratio of 0.17.

3.2.2 Density shall be a minimum of 70 pcf (1.12 gm/cm^3).

3.2.3 Viscosity shall be a minimum of 40 seconds as measured by the Marsh funnel.

Note—A cement-water ratio of 0.17 corresponds to about 282 lb of cement per cubic yard (167 kg/m^3) of water, which is a typical mix design. The cement-water ratio can be higher or lower depending on design requirements. The density is principally dependent on the quantity of cement; therefore, if the cement-water ratio is changed, the density requirement must be adjusted accordingly.

4.0 Mixing

4.1 General. All slurry shall be mixed in a colloidal, paddle, or other suitable mixer that can completely disperse the bentonite and cement particles and produce a stable, colloidal suspension of cement-bentonite slurry. No slurry shall be mixed by hand or in the trench. The contractor shall also have the necessary storage, sumps, pumps, valves, hoses, supply lines, and other equipment required to supply adequately a continuous quantity of slurry to the trench.

4.2 Bentonite-Water Slurry. Mixing of water and bentonite shall continue until the bentonite particles are fully hydrated and the resulting slurry appears homogeneous. Prior to addition of cement the bentonite-water slurry shall satisfy requirements of Section 3.1.

Note—If flash mixers are used, storage tanks or ponds will be required to provide additional mixing time for full hydration. A common practice is to have two storage facilities, one for fine-tuning the slurry mixture and a second for storing properly hydrated bentonite-water slurry. All storage facilities should be equipped with circulating pumps or other methods to mix the slurry periodically and keep it homogeneous.

4.3 Cement-Bentonite Slurry. Cement-bentonite slurry shall be mixed in a colloidal, paddle, or other suitable mixer equipped with accurate meters and scales for measuring the quantity of materials used. Additives shall be introduced into the bentonite-water slurry and thoroughly mixed prior to the addition of cement. Cement shall be thoroughly blended into the slurry until the mixture is homogeneous and the cement particles are fully dispersed. The resulting cement-bentonite slurry shall be mixed and stored under constant agitation until introduction into the trench. Indiscriminate addition of water to a stiff and unworkable mix will not be allowed. Immediately before introduction into the trench the cement-bentonite slurry shall satisfy the requirements of Section 3.2.

5.0 Excavating

5.1 General. The trench shall be excavated by backhoe, clamshell, or other suitable trenching equipment. It shall be vertical with a maximum deviation in the vertical plane of 1%. Excavation shall be carried to the full depth and width indicated on the drawings or directed by the engineer. The contractor shall maintain the stability of the excavated trench at all times for its full depth.

Note—When excavating with a backhoe, specifying a tolerance on verticality should not be necessary, but for the panel vibrating beam methods it can be an important factor affecting continuity of the wall.

5.2 Slurry. Cement-bentonite slurry shall be introduced into the trench at the beginning of excavation. The slurry shall always be above groundwater level and not more than 3 ft (0.9 m) below the top of trench during excavation.

If the slurry in the trench begins to set or becomes unworkable before excavation is completed, then freshly made slurry shall be added to correct the situation. With prior approval from the engineer, additives such as retarding agents may also be used. Addition of water to the slurry in the trench will not be permitted.

5.3 Trench Bottom. The slurry trench shall be keyed a minimum of __ ft (see note below) into the impervious material located at __ elevation (see note below). The approximate depth of trench is indicated from boring logs or drawings.

Any suspended sand, gravel, or other sediment that may settle out of the slurry or fall to the bottom of the trench shall be removed by an air lift pump or other suitable equipment approved by the engineer.

Note—Consideration must be given to the type of material the slurry trench is to key into. A common practice is to specify a 2- to 3-ft (0.6- to 0.9-m) penetration into a clay layer; however little or no penetration may be necessary when tieing into solid impervious rock. Although depths are noted on the drawings or stated in the specifications, actual final depths should be determined in the field.

5.4 Top of Trench. After initial slurry set, the top of the completed trench shall be checked for free water or surface depressions. Any free water shall be removed, and the trench shall be filled with slurry to the elevation indicated on the drawings. Following initial set of this additional slurry, the top of the trench shall be covered with material approved by the engineer to prevent drying of the slurry. No cover material shall be placed until the trench has been inspected and approved by the engineer.

6.0 Cleanup

Material excavated from the trench shall be stockpiled or disposed of in areas designated on the drawings or as directed by the engineer. After completion of the slurry trench, the surface shall be cleaned of all excess slurry to the satisfaction of the engineer. No slurry shall be left in ponds, and all ponds shall be pumped dry and backfilled.

7.0 Measurement and Payment

7.1 Measurement. Measurement of the slurry trench will be based on the square-foot area of the trench projected on a vertical plane through its centerline. It shall be computed as the product of length and average depth of excavation measured at regular agreed upon intervals, from the top of slurry trench as indicated on the drawings to the bottom as approved by the engineer.

7.2 Payment. Payment will be at the contract unit price per square foot of completed and accepted slurry trench as determined by actual measurements made in the field and approved by the engineer. Such payment will constitute full compensation for all work necessary to complete the slurry trench. This includes mixing, excavating, cleaning trench bottom, stockpiling and spoiling excavated materials, placing protective cover over trench, cleaning area after completion of trench, inspection and testing assistance, and material costs for bentonite, portland cement, and any additives used.

Note—Some slurry trench projects include a separate unit price per ton (tonne) or hundredweight (kg) for material costs of bentonite and cement. This is especially advantageous on projects where the mix design has not been specified or may change during construction.

Two other items that may need special consideration for unit pricing are depth and soil conditions. Shallow trenches are generally more economical than deep trenches. For deep excavations where clamshells are required, higher unit costs should be expected. The subsurface soil conditions will also affect project costs. Excavating through very hard soil, removing boulders, and keying into weathered bedrock are examples of difficult soil conditions that would require additional effort by the contractor. Rather than include special conditions in the overall square-foot unit cost of the trench, they can be listed as separate unit price items.

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