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Technical Course
Slurry Wall Construction, Design,
Techniques, and Procedures
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SLURRY CUT-OFF WALLS DESIGN AND CONSTRUCTION

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ABSTRACT

Slurry cut-off walls are non-structural walls constructed underground to intercept and impede groundwater flow. Principal applications are site dewatering, pollution control, and seepage barriers in the foundations of water retaining structures. Two basic types of trench -- soil-bentonite and cement-bentonite, and the principal kinds of slurry trenching equipment are discussed. Examples of several recent projects are given. Slurry cut-off walls normally have a permeability in the range of 10^{-6} to 10^{-7} cm/sec. The primary purposes of quality control are to check the continuity and depth of the wall, and to ensure a slurry and backfill which falls within workable limits while satisfying design criteria. Temporary variations from optimum limits are permissible; later batches can be used to correct the values, and the digging action will mix the slurry to create a relatively homogeneous mixture. In the attached Appendix, a set of Annotated Specifications for soil-bentonite and cement-bentonite trenches is presented.

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INTRODUCTION

Slurry cut-off walls are increasingly being used on projects where a positive groundwater cut-off is required. Recent advances in the capacity of excavating equipment and refinements in technique have brought the cost of slurry walls down and they now compete economically on projects where wellpoints or sheeting would have previously been used. The types of walls discussed herein are non-structural; they are relatively impervious but are not capable of supporting bending moments or significant shear stress. Normally, their strength is of the same order as the surrounding ground.

All of the techniques discussed herein involve excavating a trench which is kept filled with slurry, whose primary ingredients are bentonite clay and water, and whose function is to maintain the trench open with vertical sides, even below the water table. The excavation is carried out from the ground surface using any equipment capable of the trench widths and depths required. Once the trench is excavated to its final depth, a mixture of soil and bentonite is placed in the trench, displacing the bentonite slurry. This type of construction is called a Soil-Bentonite (S-B) slurry cut-off wall and is otherwise known as the "American method".

With a variation on the above technique called a Cement-Bentonite (C-B) slurry trench or "European method", cement is added to the bentonite slurry just before it is introduced into the trench. The resultant slurry has properties substantially similar to normal bentonite slurry with respect to maintaining the sides of the trench. However, once excavation is complete, the C-B slurry remains in the trench, sets up, and forms the permanent watertight wall.

The extent and type of quality control on slurry wall projects has varied widely. In some recent cases, specifications have been too brief or incomplete to protect the owner's interests; in others, excessively rigid specifications on aspects of construction not pertinent to overall performance have led to higher than necessary project costs and sometimes to unnecessary burdens on the contractor. In a later section, the purpose of quality control is discussed and optimal ranges for key indicators are recommended. In the Appendix is a set of specifications for the S-B and C-B methods which may serve as a format for future specification writing. Key sections have been annotated to discuss available options.

CONSTRUCTION METHODS

Trench Backfill

The Soil-Bentonite slurry trench technique has been in use in the United States for about twenty years. Figure 1 shows the excavation for a S-B cut-off. On projects where the material excavated from the trench is suitable for use as backfill, the S-B system can be economical because of the minimum amount of materials required. After the trench has been excavated under a bentonite slurry, more slurry is mixed with the spoil adjacent to the trench. A bulldozer is used to work the material to a smooth consistency (Figure 2) and it is then pushed into the trench so that a wave of the backfill displaces the bentonite slurry forward. Excavation and backfilling are phased to make the operation continuous with relatively small quantities of new slurry required to keep the trench full and to mix backfill.

Cement-Bentonite slurry trenches have been in use in Europe for at least ten years and in the United States for about four years. Figure 3 shows a large C-B slurry mixing plant. Since the entire trench must be filled with slurry materials and a significant amount of slurry is wasted due to the excavation process and seepage losses through the sides of the trench, the backfill is considerably more expensive than under the S-B method. This increased cost is partially offset by the elimination of the backfill mixing operation. However, the C-B method does provide the following technical and construction advantages over the S-B method.

- The technique is not dependent on the availability or the quality of soil for backfill.

- The C-B system is more suitable in trenching through areas prone to failure. If the trench fails under the S-B system, a repair is very difficult. With C-B slurry, a failure of the trench actually improves the stability of the surrounding ground. After the slurry sets, the trench can be re-excavated through the failed section and tied into completed work at either end. Since the C-B slurry starts to set a few hours after excavation, the length of open trench is less than with the S-B method, thereby decreasing the chance of failure.

- Because of the cement content, the backfill sets up quickly to a stiff consistency. Trenches may be cut through the wall without sloughing of the backfill. Construction traffic can cross the trench after a few days. There is no significant consolidation with time. Where structures are to be founded over the wall, this can be an important advantage.

- Since the trench can be constructed in sections with later sections keyed-in by re-excavating a short section, the construction sequence is more flexible to meet site constraints. The long slope of the backfill under the S-B system requires trenching continuously in one direction.

- The C-B backfill is homogeneous and fills the trench completely. The constant action of the excavating equipment mixes the slurry so that small deviations of the quality of batches of slurry become unimportant. With the S-B system, poor backfill mixing or placement technique can result in slurry-filled voids in the trench. The width of the C-B slurry trench can be less than that required under the S-B technique to assure good backfill.

- No area adjacent to the trench is required for mixing, making the C-B system more suitable on projects with space limitations, e.g. working on the crest of a dam.

- There is no resultant mess alongside the trench. The C-B slurry mixed with the spoil sets up and the spoil can be easily removed and may be used as structural material elsewhere on the project. Under the S-B system, cleaning of the mixing area can result in damage to completed work.

Given the relative advantages between the two systems, the project requirements should be evaluated to determine the best method to be selected. Where possible, it may be most economical to specify both methods and allow the contractor to bid with the least expensive system.

Excavating Equipment

The primary requirement for the excavating equipment is the capability to excavate a trench of the design width, to the required depths, and within permissible verticality tolerances. A variety of equipment has, in fact, been used. In the following paragraphs, the principal types are discussed, along with their relative advantages.

The hydraulic excavator, or backhoe, has been used on many slurry cut-off wall projects in the United States (Fig 4). The depth limitation of the largest hoes is presently between 35-40 feet but new advances in equipment technology will undoubtedly extend this range. The backhoe, because of its fast cycle time, is the most economical means of excavation. Minimum trench widths are controlled by the thickness of the boom. For large hoes, this can mean 2.5 feet or more. The thickness of the wall is an important cost factor for C-B slurry cut-offs.

Draglines have been used on projects to depths of about one hundred feet (Fig 5). Specially weighted buckets are used to get the power required at depth. Draglines are usually the most economical means of excavation below the range of the backhoe; minimum bucket widths are in the range of five to eight feet ruling out using draglines with C-B slurry due to high material costs. To reach the deeper depths, very large draglines are required and mobilization can be expensive.

The clamshell bucket rigs which were originally developed for cast-in-place concrete slurry walls have been applied to slurry cut-off trenching. These buckets may be cable-mounted or attached to a rigid sliding kelly bar (Fig 6). They may be powered by mechanical means (cables) or by hydraulic cylinders operated by a remote power supply. These rigs have a maximum range up to 250 ft and can be used with buckets as thin as 1.5 feet. Their production is much lower than other methods, so unit costs for excavation are higher.

Another technique more recently introduced into the United States from Europe involves driving a beam into the ground with a vibrating pile-hammer while simultaneously jetting with C-B slurry to form a "thin-wall cut-off". The beam is withdrawn while more slurry is injected under pressure (Fig 7). The beam is driven in overlapping imprints to form a continuous wall. The result is a curtain about two inches thick with the additional protection of grouting coarse-grained strata with C-B slurry. Given the right soil conditions, production is rapid and the thin wall cut-off uses far less C-B slurry than conventional slurry trenching. However, the same narrow width mandates more careful quality control since each square foot of the wall is subjected to one pass of the beam which does not mix the slurry as in the case of slurry trenching. The principal problem of the vibrated beam has been assuring continuity between adjacent passes at depth. Its range is approximately 35-60 feet, but even within these depths slight deviations may leave "windows" in the wall. Soil profiles with cobbles or boulders are a particular problem and keying into underlying weathered rock or hardpan may not be possible to the extent feasible with excavated slurry trenches. The narrow width of wall makes this type of cut-off less suitable for applications in soil where movements due to settlement, subsidence, etc. can be expected later. Design parameters and quality control for thin-wall cut-offs are specialized topics, not treated in this paper.

APPLICATIONS

Dewatering

Slurry cut-off walls have been used on numerous projects in lieu of conventional dewatering by wells or wellpoints. They are particularly effective when an impervious layer lies at a convenient depth below the ground surface to key into. Even without such a layer, a cut-off wall can significantly decrease the amount of water inflow into excavations below the water table. Slurry walls offer the following advantages over systems involving pumping:

- Elimination of most maintenance costs. On a typical project, maintenance pumping is reduced to one shift to remove surface water and infiltration from below. Requirements for labor and power to operate a round-the-clock system are eliminated.

- Elimination of risk due to system breakdowns, strikes, power failures, etc.

- Elimination of damages due to draw-down of the watertable surrounding the site: settlement of adjacent structures, crop damage, etc.

- Elimination of headers and other obstructions around the perimeter of the excavation. Once the slurry cut-off wall is installed, it is below ground and does not interfere with the progress of construction.

A recent example was the installation of a C-B slurry wall around the site of the Braidwood Nuclear Power Station owned by Commonwealth Edison near Joliet, Illinois. The wall was selected over a pumping system due to a projected savings of about one million dollars. A C-B slurry wall was specified because of numerous pipelines, roadways and out-buildings to be constructed through and over the trench location. The cut-off wall was twenty to thirty feet deep and keyed two feet into a hard glacial till which underlies the site. The trench, almost a mile long, was installed in about one month with minimal disruption to on-going earth-moving operations. During construction of the wall, water for the slurry was obtained from a pit at the center of the site; a six inch pump was unable to lower the water level in the pit. After completion of the wall, the site was excavated to a depth of approximately sixty feet and kept dry by occasional use of a four inch pump.

In another case, Dow Chemical Company planned to extend a portion of its Midland, Michigan plant area into an existing flyash disposal pond. To dewater the pond area for the new construction, a construction dike was to be installed through the pond with steel sheeting driven through the dike to glacial till sixteen feet below. A C-B slurry trench competed favorably with the sheetpiling and provided a shorter construction schedule. Figure 8 shows construction of the trench from the temporary dike.

S-B slurry cut-offs have been used on numerous dewatering projects. The Oyster Creek power station in New Jersey incorporated an eighty foot deep wall. Several of the locks on Mississippi's Tombigbee waterways have had slurry walls specified for site dewatering.

Seepage Barriers

This application of slurry trench cut-offs encoumpasses two types of work: cut-offs under dams and pollution barriers. Slurry trenches have been used in numerous cases to extend the cores of dams downward into underlying strata (e.g. Wanapum Dam, Mission Viejo Dam in California, Lake Arrowhead Dam in Georgia as well as many European projects) and has been used to repair leaky dams (e.g. Balderhead Dam in England). In the realm of pollution control, slurry cut-off walls have been applied to, among others, the following problems:

- Sewage - The Columbus, Mississippi sewage treatment plant incorporates a slurry trench to isolate the effluent ponds from the local groundwater table and an adjacent river.

- Acid mine wastes - On projects near Dubois, Pennsylvania and Clarksburg, West Virginia, slurry cut-off walls through strip mine spoil serve to retain acid mine drainage for the purpose of reducing the pollution of nearby streams.

- Chemical wastes - On a project in Texas, a major chemical company selected a slurry cut-off wall to prevent contamination of the local river.

- Sanitary landfill - In Scituate, Massachusetts, a slurry trench specified by the consultant acted to isolate the town wells from leachates from a new sanitary landfill.

DESIGN AND QUALITY CONTROL

Design Parameters

The primary design parameters, in their usual order of importance, are permeability, strength, and compressibility. In the following paragraphs, each is briefly discussed and typical values are stated. The factors affecting each are described. In general, the amount of published research and field evaluation of the myriad possibilities of mix design and underground environment is limited. A fourth parameter, durability, has implicit importance in permanent installations. Little data is available, but slurry trenches are installed in many situations where permanence is a requirement. Bentonite is stable under most environmental conditions. In the case of C-B slurry, cement may be subject to attack by sulphates or other chemicals in the groundwater. The depth of penetration under low flow conditions in a chemically hostile environment, and its subsequent effect on a wall which still has a substantial bentonite content has not been studied in detail.

Permeability has been the best studied of the design parameters. Laboratory and field studies have repeatedly yielded measured permeabilities in the range of 10^{-6} to 10^{-7} cm/sec for both S-B and C-B cut-off walls. There has been some speculation about the role of the filter cake and how it differs between the two types of trench. The filter cake is the buildup of solids due to water seeping out of the slurry through the walls of the trench. After a certain point, the filter cake is thick enough to preclude further seepage losses. The higher concentration of bentonite is in the filter cake undoubtedly an important factor in bulk permeability of cut-off walls, but its relative importance is not known. In the case of the C-B slurry, the filtrate loss increases dramatically upon the addition of the cement. Some penetration of the cement-bentonite mixture into the more pervious zones may be possible. In either case, the definition of a good filter cake is not clear. A low filtrate loss means a thin cake which is not necessarily superior to the thicker filter cake obtained with higher filtrate loss. Specifications on maximum filtrate loss are associated with applications where a thin filter cake is required, e.g. oil well drilling and cast-in-place concrete slurry walls.

Under most conditions, the only strength requirement for slurry cut-off walls is to attain the approximate strength of the surrounding ground. The top of the trench is usually covered to prevent the application of wheel loadings or other concentrated loads. Not much data is available on the strength of S-B backfill; for design purposes it is usually assumed to have essentially no strength but high plasticity. In fact, the strength does increase with time. Normal S-B backfill will stand on a slope of about 10:1 (horizontal:vertical) at the time of placement, and this improves to about 2:1 after some time. A normal mix of C-B slurry yields a final strength of approximately 20 p.s.i. unconfined. The stiffer consistency of the C-B slurry backfill makes it easier to place the first few lifts of cover material over the trench.

The compressibility of slurry cut-off walls is high in most situations to allow for deformations without cracking. While essentially no data are available, the S-B backfill is normally assumed to be infinitely plastic. Even if subjected to displacements large enough to cause cracking, any cracks should heal themselves. In the case of C-B slurry backfill, a normal mix can withstand compressive strains of several percent under in-situ stress conditions without cracking. Slight changes in the mix can increase compressibility. A recent mix design for a cut-off under a dam allowed for the strains caused by settlement of the foundation material due to the weight of the dam. In a case in California, a mix was designed to withstand repeated cycles of several percent shear strain without cracking. The strain at failure of a C-B slurry is partially dependent on the cement/water ratio. In cases where high strains at failure are required, latitude must be provided in the design for increases in the cement/water ratio of the slurry due to filtrate losses. The distribution of these losses across the width and depth of the trench has not been studied. It is possible, for example, that the filtrate losses affect the cement/water ratio only in the cake and that the bulk of the backfill is unaffected. Another factor which may affect the behavior of the C-B slurry is suspended solids. The excavation of the trench, especially in sandy soils, leaves a considerable amount of material in suspension, most of which will not settle out. Tests have shown that suspended solids are not an important factor until concentrations are high enough to permit contact between particles. This point is reached at percentages (by volume) of about ten percent. In general, these solids will tend to increase strength and make the mix more brittle. The effect may become more important with depth as the concentration of suspended solids increases.

Quality Control

The primary functions of quality control during construction are to:

- Assure continuity of the completed trench to the widths and depths required.
- Control the composition and placement of the backfill to achieve the required design parameters.
- Control the quality of the slurry during construction to minimize the risk of trench failure (in cases where trench failures threaten adjacent structures).

The continuity of the trench with respect to the required dimensions is relatively easy to control. The excavating equipment should have a minimum width equal to or greater than the width of trench required. Depth is controlled by direct measurement and by observation of materials excavated from the trench. When the wall is excavated by a backhoe or dragline, the motions of the machine ensure longitudinal continuity. In the case of a clamshell which digs vertically, primary panels should first be dug and then overlapped by secondary panels. Once this process is completed, a slight sideways movement of the bucket in both directions is used as a final check on continuity before the machine is moved and a new primary panel is dug.

The most important requirement for the slurry during the excavation of the trench can be summarized as workability. If the slurry is too thin, the trench may collapse. If the slurry is too thick, excavation may become difficult and large lumps of soil may become suspended in the slurry. In the case of the S-B trench, a very thick slurry may interfere with the backfill process.

Experience has shown that an optimal slurry can be attained by controlling a few essential factors: hydration of the bentonite, viscosity, and specific gravity.

The time required to properly hydrate bentonite depends on the mixing mode, the quality of the bentonite, and the presence of "peptizing" agents. It may vary from a few minutes for a peptized bentonite mixed in a continuous high speed colloidal mixer, to several hours for bentonite "flash-mixed" in a venturi system and then held in a slowly-circulated pond. As the bentonite slurry hydrates, its filtrate loss will decrease and viscosity will increase to a steady value. Both tests can be used to determine the proper hydration of the bentonite. In the case of a C-B slurry, cement should not be added until the bentonite is hydrated. (The filtrate test results will change dramatically on the addition of cement, but these results have no application to quality control for slurry cut-off walls.)

Viscosity is the primary test to control the workability of the slurry. The standard test, the Marsh Funnel, consists of measuring the time required for a known volume of slurry to run out of a standard funnel. The ideal range for both S-B and C-B slurries is in the range of 40-45 seconds. Typical values measured in the trench may range as low as 35 seconds or as high as 80 seconds without causing problems. In the case of C-B slurry, the slurry may become so thick as not to pass through the cone, but still be acceptable. The fluctuations may be caused by variations in the slurry being added or changes in the underground environment, or simply setting time. Any specification on workability should recognize and allow for these variations and permit the contractor to add new slurry with the properties required to bring the slurry in the trench back to an optimum value. The continued action of digging will tend to mix the slurry to a homogeneous mass.

Specific gravity provides an additional control on workability. The principal application of a specific gravity criterion is to S-B slurry cut-off walls. If the mud becomes too heavy, it is difficult to assure good placement of the backfill because the backfill may fold over the heavy slurry, rather than displace it.

The composition and placement of the slurry trench backfill is a different problem for the S-B and C-B techniques. In both cases, the amount of bentonite in the original slurry is as required to acheive correct slurry properties. In the case of the C-B wall, cement is weighed and added in the correct proportions to the slurry as it is placed into the trench. The S-B backfill is composed of suitable soil material mixed with additional slurry to attain a smooth consistency with a slump of 4 to 6 inches and then is pushed back into the trench. Care is taken to assure the backfill moves continuously forward in the trench, displacing the slurry and not folding over it. Some specifications have required cleaning the bottom of the trench with an airlift or similar equipment to remove sediment before placing backfill to prevent sand pockets that could form flow channels through the wall. Since the soil particles are totally immersed in slurry, this is not likely. For permanent applications of the S-B slurry cut-off, the cleaning procedure may have some value in providing a totally homogeneous mix from top to bottom of the trench.

SUMMARY

Slurry cut-off walls have achieved wide recognition in a variety of applications as seepage barriers for dewatering and pollution control. The two principal techniques, soil-bentonite and cement-bentonite, have different relative advantages, but under some conditions are technically interchangeable. A design for a slurry cut-off wall should take into consideration whether the wall is for permanent or temporary use, the loadings anticipated, and other construction constraints in selecting the technique to be used and the extent to which the work should be controlled by the engineer. Specifications should take account of the built-in safety factors in slurry cut-offs (e.g. more thickness than required in most cases) and allow the variability in slurry properties

normally experienced during this type of work and give maximum flexibility to the contractor in selecting materials, equipment and technique. In the Appendix which follows, a sample set of specifications is presented. With all the variations on final properties available through different combinations of various bentonites, cements and other fillers, the slurry cut-off can be designed to meet a number of special loading and environmental conditions. Further research and evaluation is required to determine optimum design mixes under various constraints. The economy, convenience and positive control of seepage afforded by slurry cut-off walls will bring them acceptance and application on an increasing number of construction projects in the United States.

Figure 1 - Trench Excavation and Backfill Mixing Area (Courtesy of Brown & Lambrecht)

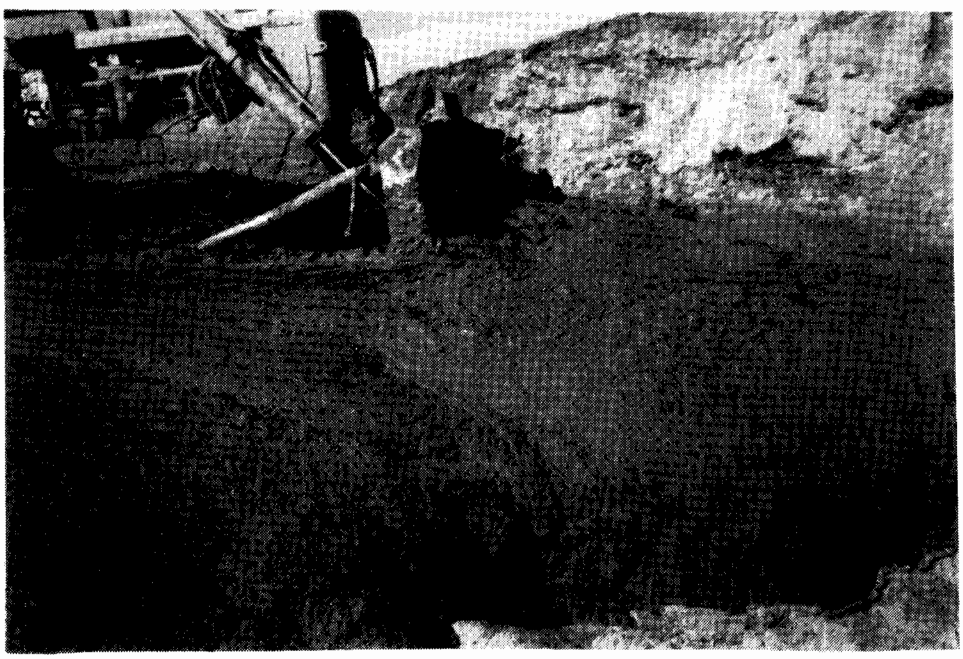

Figure 2 - Mixing Soil-Bentonite Backfill (Courtesy of Brown & Lambrecht)

Figure 3 - A Cement-Bentonite
Batch Plant

Figure 4 - Slurry Trenching with
a Backhoe

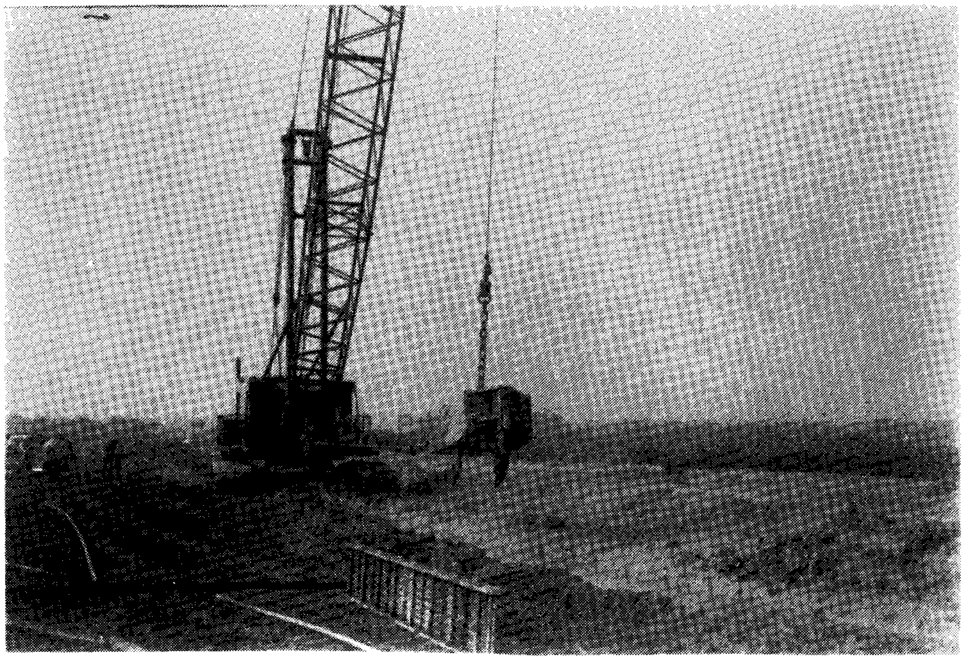

Figure 5 - Slurry Trenching with a Dragline (Courtesy of Brown & Lambrecht)

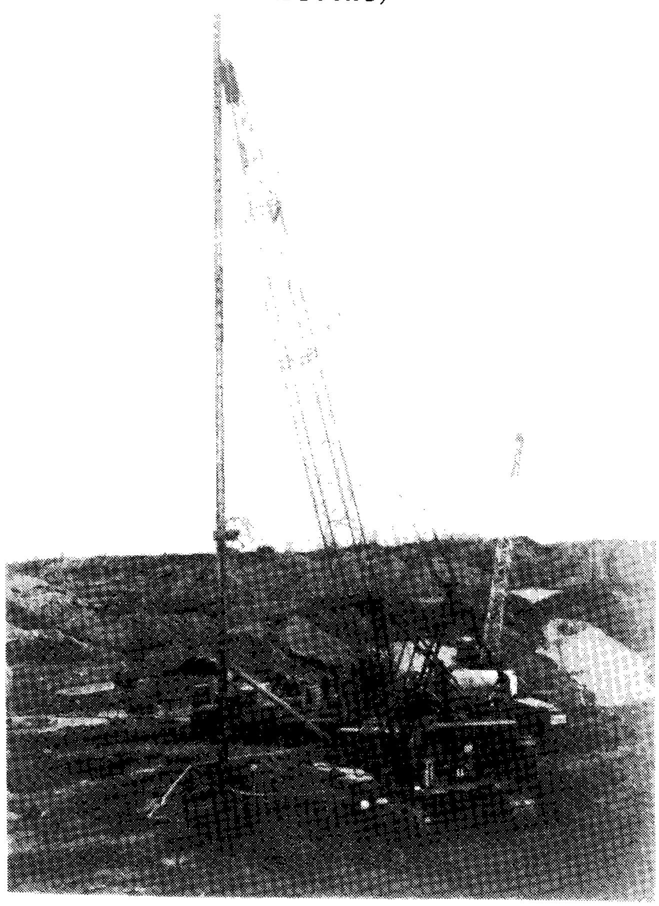

Figure 6 - Kelly-Clamshell Slurry Trenching Rig

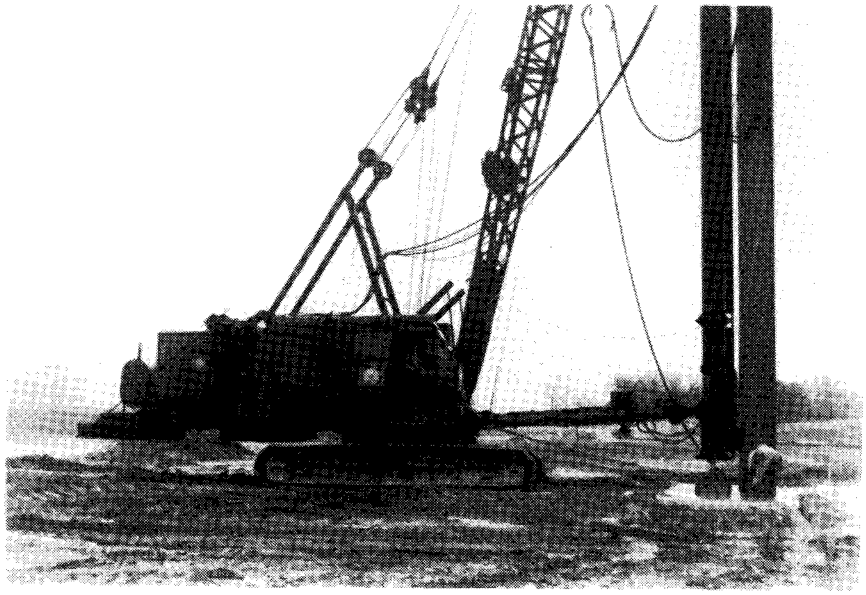

Figure 7 - Vibrating Beam
(Courtesy of Thatcher
Engineering)

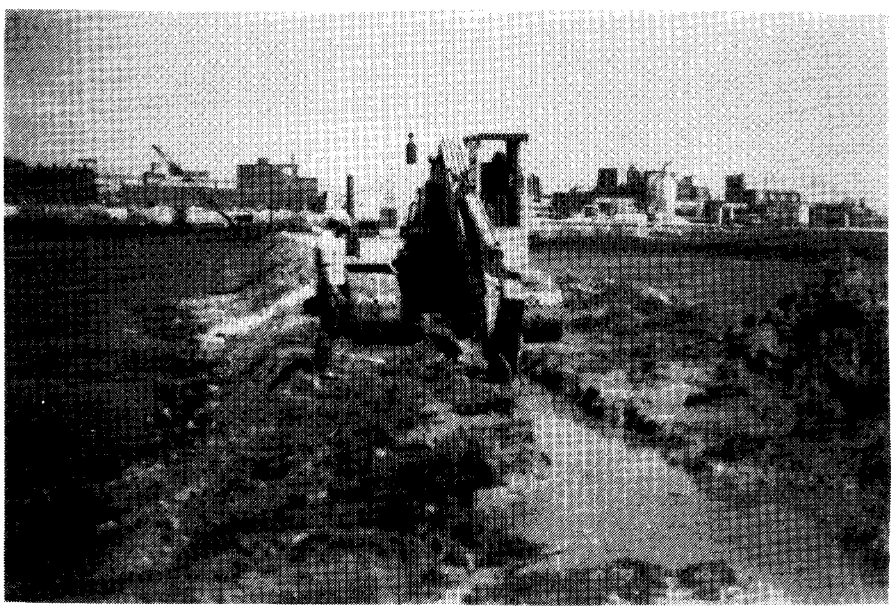

Figure 8 - Trenching Through
Construction Dike

APPENDIX

Annotated Specifications

Technical Requirements
Slurry Cut-Off Wall Construction

2-401. SECTION SCOPE

2-401.1 This section of the Specification includes requirements for the soil-bentonite (S-B) and cement-bentonite (C-B) slurry cut-off wall, as indicated on the drawings, as hereinafter specified, or as required to properly complete the work.

Note - These specifications are intended to serve as a guide to format and content for normal slurry wall installations. Every job has special features or requirements which should be incorporated in the project documents.

2-402. GENERAL

2-402.1 An impervious cut-off wall shall be constructed by means of the slurry trench method. The wall shall be constructed to the lines, grades and cross sections as indicated on the drawings. The trench shall have a minimum width of 1.5 feet in the C-B section and 3.0 feet in the S-B section, and shall extend down through the subsurface materials to the elevation indicated herein.

Note - The trench width specified for the C-B wall should be the minimum acceptable. The width of excavating equipment will dictate the width actually installed. For a S-B wall, the trench must be wide enough to permit free flow of the backfill material. This width is normally in the range of 2.5 feet for a trench thirty feet deep and five to eight feet for a trench eighty feet deep.

2-402.2 The installation of the slurry trench shall be carried out by, or under the supervision of, a qualified slurry trench contractor. A qualified contractor should have at least three years experience in slurry trench construction and have completed at least two projects of similar scope and magnitude.

2-403. EXCAVATION

2-403.1 The excavation shall be accomplished by suitable trenching equipment to the required depths. The width of the excavating bucket shall be at least the specified width of the cut-off wall.

2-403.2 Excavation shall be carried to final depth at the point where excavation is started, and the entire depth of cut shall then be carried along the trench line. Slurry shall be introduced into the trench at the beginning of excavation. The level of the slurry must always be above the existing water level and not more than 3 feet below the top of the slurry trench during excavation.

2-403.3 The Contractor shall maintain the stability of the excavated trench at all times for its full depth.

2-403.4 The rate of excavation of the slurry trench in the S-B section shall be controlled so that the excavation is at least 75 feet from the toe of the backfill being placed in the trench, unless directed otherwise. No backfill shall be placed until the trench has been inspected and approved by the Consultant.

2-403.5 The Contractor shall provide:

a. A suitable measuring device with projecting markers at 1-foot intervals.

b. Suitable means of access to the excavated trench.

c. Labor required to probe the entire bottom of the trench under the direction and observation of the Consultant.

2-403.6 In the S-B section, material suitable for backfilling the trench may be stockpiled for reuse. Excavated spoil from the C-B section may be disposed of alongside the trench. Spoil piles shall be located so that slurry draining from the excavated material will not contaminate natural surface runoff.

2-404. TREATMENT OF SLURRY TRENCH FOUNDATION MATERIAL

2-404.1 The slurry cut-off trench shall be keyed into ( ) at approximately EL ( ) to a minimum depth of 1 foot. The approximate location and depths of the ( ) are indicated on the boring logs shown on the drawings.

2-404.2 When the bottom of the slurry trench has been reached, the foundation surface shall be checked for boulders, gravel, or excessive sediment. Any such material shall be removed by an air lift pump, clamshell or similar equipment. If the density of the slurry exceeds the specified limits, or becomes unworkable, the slurry shall be cleaned by recirculating, screening, or any approved method to decrease the sand content.

Note - This last paragraph is probably unnecessary in all but critical applications of permanent installations.

2-405. MATERIALS

2-405.1 Bentonite used in preparing slurry shall be pulverized natural Wyoming sodium bentonite and shall meet API Standard 13A "API Specifications for Oil-Well Drilling-Fluid Materials".

Note - Some specifications have prohibited the use of chemically-treated high yield bentonite (peptized bentonite) because the bentonite content of the finished product can be reduced by as much as fifty percent. There is as yet no evidence to show that walls using peptized bentonite are of lower quality in any respect. For temporary installations, no restriction should be made.

2-405.2 The use of any admixtures, retarders, or plugging or bridging agents shall not be permitted without prior approval of the Consultant.

2-405.3 Cement used in preparing C-B slurry shall conform to ASTM Requirements for Portland Type I cement.

2-405.4 Fresh water shall be used to manufacture slurry. If water other than potable water is proposed for use, it shall be the responsibility of Contractor that the resulting slurry meets the necessary standards to insure a stable excavation and, in the case of the C-B slurry, proper setting properties.

2-406. MIXING BENTONITE SLURRY

2-406.1 Bentonite slurry shall be a stable colloidal suspension of pulverized Wyoming sodium bentonite in water. The bentonite may be initially mixed with water in a centrifugal digestor, colloidal mixer, venturi flash-mixer, or any method that achieves complete dispersion of the bentonite particles.

2-406.2 After mixing, the slurry shall be allowed to hydrate before introduction into the trench (S-B slurry) or mixing with cement (C-B slurry). This may be accomplished by maintaining high speed circulation until hydration is complete, or by storing the slurry in a tank or pond with a low speed circulation system. Hydration is defined as the stabilizing of the viscosity and filtrate loss properties. Bentonite slurry shall be stored under essentially constant circulation until used. Circulation may cease for short periods (overnight, weekends).

2-407. TESTING PROCEDURES -- SLURRY PROPERTIES

2-407.1 Testing procedures for the bentonite slurry are as defined in the API Specification RP-13B. The following properties shall be measured:

a. Viscosity (Marsh Funnel).

b. Filtrate Loss (Filter Press).

c. Specific Gravity (Mud Balance).

2-408. SLURRY FOR S-B CUT-OFF WALL

2.408.1 The bentonite slurry shall be proportioned to bring the slurry in the trench to within the following optimum ranges:

a. The viscosity shall be not less than 40 seconds (Marsh Funnel) at 68° F.

b. The filtrate loss shall be not more than 30 ml in 30 minutes.

c. The specific gravity of the slurry shall not be less than 1.03 gm/cc nor greater than 1.30 gm/cc or as approved by the Consultant.

d. The pH of the slurry shall not be less than 8.

When the slurry in the trench exceeds the limits in the optimum ranges, some recently made slurry shall be added for correction. Addition of water will not be permitted.

2-408.2 The properties of the slurry may be altered to meet the construction conditions by adding appropriate admixtures with the approval of the Consultant.

2-409. SLURRY FOR C-B CUT-OFF WALL

2-409.1 Cement shall be added and mixed with the bentonite-slurry at the rate of 282 lbs. per cubic yard.

Note - Cement content as per design.

2-409.2 C-B slurry shall be stored under constant agitation until placed in the trench. The bentonite slurry shall be hydrated to the point where the filtrate loss of the bentonite slurry for 30 minutes is not greater than 30 ccs. The bentonite slurry shall be proportioned so as to bring the C-B slurry to within the following optimum ranges:

a. The viscosity shall not be less than 40 seconds Marsh Funnel nor greater than 50 seconds Marsh Funnel at 68° F.

b. The pH of slurry shall be at least 8.

c. The specific gravity of the slurry shall not be less than 1.03 gm/cc nor greater than 1.4 gm/cc or as approved by the Consultant.

Should the properties of the C-B slurry be altered during the excavation, some recently-made C-B slurry shall be added as approved to correct the C-B slurry properties. Some additive agents may also be used, such as "setting time retarders" depending on the rate of excavation, but only under the condition that such additives have been previously approved by the Consultant. In no case shall the addition of water be permitted.

Note - C-B slurry properties begin to change within a short time after introduction into the trench due to the "setting" of the cement. The optimal ranges should be applied only to the section being actively excavated.

2-410. S-B TRENCH BACKFILL

2-410.1 Material for trench backfilling shall be composed of a mixture of slurry and soils obtained from the excavation of the trench or from an approved borrow source. Placement of backfill material shall not be made until the trench has been inspected and approved as specified above. Excavated materials shall be thoroughly mixed with the slurry to form a homogeneous mass just prior to the back-filling operation. The mass shall be free from lumps of clay or silt and pockets of sand or gravel. Sluicing with water shall not be permitted. The amount of slurry added to the backfill shall be a sufficient amount to produce a slump cone reading of 5 inches plus or minus 1 inch tested in accordance with ASTM C 143-66. Initially, the backfill shall be placed by lowering the material to the bottom of the trench in a clamshell bucket until the surface of the backfill rises above the slurry level and until a slope at the angle of repose has been formed from the bottom of the trench to the surface. Free dropping of backfill material directly into the slurry-filled trench or any other backfilling operation which will produce segregation of the material shall not be permitted. The backfill material shall be pushed into the trench in a manner that will cause the material to slide progressively down the slope of the previously placed backfill material. The backfilling operations shall follow the excavation operations as closely as possible to minimize sloughing. If necessary, the excavation shall be delayed sufficiently to permit backfilling operations to catch up. At no time shall the bottom of the excavation be farther than 200 feet ahead of the toe of the impervious backfill, unless otherwise directed.

2-411. CLEANUP

2-411.1 After completion of slurry trench cut-off, all remaining excavated material and slurry shall be removed and the surface cleaned to the satisfaction of the Consultant.