JACOBSON TERMINALS, INC
5355 28TH NW OR 5350 30TH NW
SEATTLE, WA 98020

Construction and Soil Management Plan
Zero-Valent Iron Wall
Groundwater Remediation System
Jacobson Terminals Site
Seattle, Washington

HARTCROWSER
Delivering smarter solutions

Prepared for
A&B Jacobson, LLC

September 14, 1999
J-4063-10

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CONSTRUCTION AND SOIL MANAGEMENT PLAN
ZERO-VALENT IRON WALL
GROUNDWATER REMEDIATION SYSTEM
JACOBSON TERMINALS SITE
SEATTLE, WASHINGTON

SUMMARY OF REMEDIATION WORK

The Jacobson Terminals site is located at 5355 28th Avenue NW, in the Ballard district of Seattle. This plan applies to construction activities for the installation of a funnel-and-gate reactive iron wall system for treatment of groundwater. Tetrachloroethylene (PCE), trichloroethylene (TCE), cis-1,2-dichloroethylene (cis-DCE), and vinyl chloride (VC) have been detected in groundwater beneath the site. Hazardous constituents have not been detected in soil in the proposed excavation area; however, due to the presence of contaminated groundwater, the potential for minor contamination in excavated soils does exist. This plan outlines proper construction practices at the site and provides for the proper handling and disposal of excavated soils.

GENERAL REQUIREMENTS

Health and Safety

A site-specific health and safety plan has been prepared for Hart Crowser employees. The Contractor may elect to adopt the Hart Crowser plan, but remains solely responsible for his or her employees' health and safety. Access to the site shall be controlled by security fencing, and a 24-hour guard watch shall be provided if deemed necessary. Protection shall be placed over open trenches not actively worked.

Environmental Protection

Spill Control. The Contractor is responsible for control, cleanup, and disposal of soil, water, fuel, lubrication oil, or other material resulting from spills, accidents, or other events during this work that are not associated with existing site conditions. Spill response materials shall be kept on site. As soon as a vehicle or equipment leak is detected, the equipment shall be stopped immediately and cleanup commenced as soon as safety permits.

Equipment Decontamination. Equipment that has contacted potentially contaminated soil (see **SOIL MANAGEMENT** section) shall be decontaminated with a pressure washer. Wash water from equipment decontamination shall be contained, collected into a temporary wastewater holding tank, and legally disposed of by the Contractor.

Groundwater Containment. Groundwater from the excavation shall be contained in-place if possible. Groundwater removed from the excavation shall be contained, collected into a temporary wastewater holding tank, and legally disposed of by the Contractor. The Contractor shall not allow groundwater to flow off the site or to enter on-site storm drains.

Monitoring Well Protection. Existing groundwater monitoring wells shall be protected and maintained during the remedial action. Existing monitoring wells that significantly interfere with the remedial action, such as JT-1, shall be abandoned in accordance with Chapter 173-160 WAC.

Environmental Emergency Notification. For environmental emergencies not covered by this plan or the Contractor's health and safety plan, the Contractor will stop work and notify:

Contact	Contact Name	Phone Number
Site Owner	Al Jacobson	(206) 669-4300
Hart Crowser Representative	Doug Hillman/ Barry Kellems	(206) 324-9530
Seattle Fire Department		911

Dust and Erosion Control

The Contractor shall prevent fugitive emissions of soil or solid materials during on-site activities. No visible dust shall be generated. Soil erosion due to precipitation runoff or run-on to or from excavations, stockpiles, paving areas, or other soil areas exposed or disturbed by Contractor activities shall be controlled using berms, surface water control, straw bales, temporary visqueen covers, or other appropriate control measures. The Contractor shall also make provisions for adequate drainage to prevent accumulation or ponding of non-contaminated run-on/runoff in surface areas affected by construction.

SITE WORK

Site Preparation

Protection of Utilities

The Contractor shall field verify the locations and elevations of existing pipelines and utilities within 50 feet of the planned excavation area prior to commencing work, and take precautionary measures as necessary during excavation to protect active pipelines and utilities. Note in particular that the intended excavation crosses or closely borders water lines, sanitary sewer lines, and storm sewer lines.

Protection of Railroad

The Railroad Owner shall be responsible for removing and replacing rails and ties in the area of construction. The Contractor shall either coordinate excavation below the railroad right of way with the train schedule or make alternative arrangements with the Railroad Owners. After completion of the excavation and backfilling beneath the railroad right of way, the tracks shall be reinstalled to their original condition.

Utilities for Construction

Limited water shall be provided by the site owner. The Contractor shall obtain a permit to use a fire hydrant for tasks requiring large amounts of water.

Excavation

Soil Handling

Potentially impacted soils shall be handled in a manner as to minimize spills and the release of dust. Soil removed from excavations shall be stockpiled and disposed of as specified in the **SOIL MANAGEMENT** section.

Water in Excavations

The Contractor shall prevent surface flow from entering the excavations. If water must be removed from excavations, it will be pumped into a temporary wastewater holding tank and legally disposed of.

Backfill

Excavations shall be backfilled to the existing surface grade according to Drawing C-2 using suitable material. Hart Crowser will provide field and laboratory testing of backfilled materials to ensure compliance with compaction and gradation standards. Contractor shall contact Hart Crowser 24 hours in advance of any testing needs. Backfill gradation and compaction standards are presented for each backfill material.

Laboratory Maximum Density and Optimum Moisture Content. Laboratory compaction standards and optimum moisture content will be in accordance with ASTM D 1557, Laboratory Compaction Characteristics of Soil Using Modified Effort (1991). Tests shall be made for each type of material or source of material to determine laboratory maximum density values and optimum moisture content. One representative test shall be performed per 500 cubic yards of fill and backfill, or when any change occurs which may affect the laboratory maximum density or optimum moisture content.

Field Compaction Testing. In-place densities shall be determined in accordance with ASTM D 2922, Density of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth) (1996). In-place density tests shall be performed every 100 linear feet, or fraction thereof.

Gradation Testing. Gradation of fill and backfill material shall be determined in accordance with ASTM D 422, Particle-Size Analysis of Soils (1963; R 1990). One test shall be performed per 200 cubic yards of material.

Moisture Content. During backfilling, the Contractor shall control the moisture content of fill materials to within 2 percent of the optimum moisture content per ASTM D 1557. Moisture content shall be determined in-place in accordance with ASTM D 3017, Water Content of Soil and Rock in Place by Nuclear Methods (Shallow Depth) (1988: R 1993).

<u>Wall Cap</u>

Underlying the roadway, the wall shall be capped in such a manner as to support intermittent heavy truck traffic. The Contractor shall complete the trench backfill to the existing grade and provide an asphalt cap. Underlying the railroad, the wall cap shall be designed to adequately support railroad loads (specifications to be provided by the Railroad Owner). Excavated soils designated suitable for on-site fill following chemical testing may be used provided they provide adequate structural support for potential loadings. Excavated soils may also be used in the soil-bentonite cap above the reactive

gates. Backfill beneath the roadway and railroad shall be compacted to 95% of maximum laboratory density in accordance with ASTM D 1557.

Iron/Sand Mixture

Specifications for the composition and placement of the iron/sand mixture are provided in Attachment A and on the cross section on Drawing C-2.

Cement-Bentonite Wall Material

Specifications for the composition and placement of the cement-bentonite wall material are provided in Appendix B. The hydraulic conductivity of the cutoff wall shall be a maximum of 10^{-6} m/s within 90 days of installation.

Utility Trench Backfill

Water Line Protection

During excavation, the Contractor shall provide suitable support and protection of the water line the excavation crosses. Bedding as described below will be installed from 1 foot below to 1 foot above the water line. General backfill will be used as the remainder of the fill.

Material. Bedding shall be the cement-bentonite wall material if the water line is below the top of the cement-bentonite wall. If the water line is above the top of the wall, CDF with a minimum unconfined compression strength of 50 psi will be used.

The remainder of the backfill shall consist of suitable material, as described in the ***General Backfill for Regrading*** section. Fill underlying the railroad must meet the specifications in the ***Wall Cap*** section.

Storm Drain Protection

During excavation, the Contractor shall provide sufficient support and protection for the storm drain crossing the wall. The storm drain currently is surrounded by a protective sleeve. The Contractor will remove all soil adhering to the drain line collar and provide a flow barrier around the collar to prevent groundwater flow along the drain line pathway. The cement-bentonite wall material will be placed around the utility and shall provide sufficient support.

General Fill for Regrading

Material. Excavated soils designated suitable for on-site fill following chemical testing may be used as fill for regrading in areas not beneath the railroad or roadway. Fill should be free of debris. Fill surrounding the wall shall be geotechnically suitable for supporting necessary equipment and shall meet compaction requirements as described below.

Compaction Fill. Fill around the proposed wall location shall be compacted to 90% of maximum laboratory density in accordance with ASTM 1557.

SOIL MANAGEMENT

The presence of PCE, TCE, cis-DCE, and VC in groundwater beneath the proposed excavation area will require testing and appropriate handling, transportation, and disposal of excess soils generated. This section specifies soil stockpile segregation, sampling, laboratory analysis, and waste designation procedures to be used for this project.

Soil Stockpile Segregation

To isolate potentially contaminated soils from non-contaminated soils, soils shall be segregated, stockpiled, and tested based on their origin. Drawing C-1 delineates the area to be used for stockpiling. Soil stockpiles shall be constructed to isolate stored contaminated material from the environment. The maximum stockpile size will be 200 cubic yards. Stockpiles will be constructed to include:

- A chemically resistant geomembrane liner. Non-reinforced geomembrane liners shall have a minimum thickness of 20 mils. Scrim reinforced geomembrane liners shall have a minimum weight of 40 pounds per 1,000 square feet. The ground surface on which the geomembrane is placed shall be free of rocks greater than 0.5 inch in diameter and any other object which could damage the membrane.

- Geomembrane cover to prevent precipitation from entering the stockpile. Non-reinforced geomembrane covers shall have a minimum thickness of 10 mils. Scrim reinforced geomembrane covers shall have a minimum weight of 26 pounds per 1,000 square feet. The cover material shall be anchored to prevent it from being removed by wind.

- Berms surrounding the stockpile shall be a minimum of 12 inches in height. Vehicle access points shall also be bermed.

- Storage and removal of liquid which collects in the stockpile. Collected liquid shall be temporarily stored and legally disposed of.

The following soil classifications shall be segregated for testing:

Potentially Contaminated (PC) Soils. PC soils consist of soil excavated from beneath the seasonal high water table (a depth of approximately 10 feet) within the estimated limits of contaminated groundwater. The estimated volume of PC soils is 150 cubic yards.

Potentially Non-Contaminated, Geotechnically Suitable (PNCS) Soils. PNCS soils consist of soils excavated above the seasonal high water table and soils excavated below the water table and outside the estimated limits of contaminated groundwater, and conform to the fill standards listed in the ***Backfill*** section. The estimated volume of PNCS soils is 550 cubic yards.

Potentially Non-Contaminated, Geotechnically Unsuitable (PNCU) Soils. PNCU soils consist of soils excavated above the seasonal high water table and soils excavated below the water table and outside the estimated limits of contaminated groundwater, but do not conform to the fill standards listed in the ***Backfill*** section. A volume of PNCU soils is not estimated; however, these materials shall comprise a subset of the non-contaminated soils.

Soil Designation

Designation Soil Sample Collection

Soils will be excavated and temporarily stockpiled on site until designation samples can be collected, analyzed, and the results confirmed with the Contractor. The stockpile soil sampling frequency will be based on Ecology guidance calling for three samples for up to 100 cubic yards of stockpiled soil, and five samples for up to 500 cubic yards. The appropriate number of samples will be determined by Hart Crowser based on a visual estimate of stockpiled soil volume and homogeneity.

Each stockpile designation soil sample will be a representative, discrete, grab sample collected from a depth of at least 12 inches beneath the surface of the stockpile and placed in a laboratory cleaned glass jar. Each sample will be labeled and placed in a cooler for transport to the laboratory under chain of custody protocols. The sampling equipment will be decontaminated between sampling events to prevent cross contamination. Samples will be analyzed on site by a mobile laboratory when possible.

Soil Analytical Testing

Soil samples collected from the stockpiles shall be analyzed for volatile organic chemicals (VOCs) according to EPA Method 8010. Several soil samples will also be analyzed for total metals (arsenic, cadmium, chromium, copper, lead, nickel, and zinc). If the concentration of PCE exceeds 14 mg/kg, a split of the sample will be submitted for toxicity characteristic leaching procedure (TCLP) analysis of PCE to determine if the soil needs to be managed as a characteristic dangerous waste.

Additional analytical testing information is presented in Table 1.

Soil Designation

Concentrations of PCE detected in site soils are not known to be from listed dangerous waste sources. Soil designation procedures are as follows (MTCA Method A and B and TCLP criteria are presented in Table 2):

- If none of the constituents are detected, and the soil is geotechnically suitable, the soil may be used as on-site fill. If the soil is not geotechnically suitable, it will be transported off site and managed in a manner protective of human health and the environment;

- If any constituents are detected in a representative designation soil sample but below MTCA standards for groundwater protection, the soil will be used as on-site fill material provided it is geotechnically suitable. If the soil is not geotechnically suitable, it will be transported off site and managed in a manner protective of human health and the environment.

- If any constituents are detected above MTCA Method B protection of groundwater standards, and the soil does not fail the TCLP test for these compounds, the soil will be transported off site and managed at a solid waste facility regulated under Chapter 173-351 WAC;

- If a representative soil sample fails the TCLP test for any constituent, or if it fails one or more of the Dangerous Waste Criteria, the soil will be designated and managed as a dangerous waste in conformance with Chapter 173-303 WAC.

Soil Disposal

Transport and Off-Site Disposal

The site owner shall provide for off-site disposal of contaminated soils in accordance with all local, state, and federal regulations governing solid/hazardous/dangerous wastes.

On-Site Backfill

Soils designated for on-site fill will be used to backfill the depression to the north of the railroad tracks in the unpaved area. The integrity of monitoring wells impacted by soil placement must be maintained, and the wells completed to the new grade with a flush-mounted monument. The monitoring wells may be located and marked prior to backfilling and then excavated and completed to the new grade after backfilling activities are finished.

QUALITY CONTROL AND REPORTING

Hart Crowser will use methods outlined in the following sections to document field practice, review quality assurance data, and interpret the information for reporting purposes.

Field Measurements and Documentation

The field personnel will use consistent sampling techniques and documentation protocol while executing this work. Soil sampling will be completed using stainless steel equipment which will be decontaminated between samples. The decontamination process will consist of a detergent wash, tap water rinse, and DI water wash-down. Samples will be collected in laboratory-supplied jars and held in coolers with ice pending laboratory delivery. All samples shall be transmitted to the chemistry laboratory in accordance with chain of custody protocols.

Field documents shall include daily stockpile location diagrams, sample location diagram, chain of custody, health and safety monitoring data, and a narrative field report.

Quality Assurance and Lab Report Review

Data packages will be checked for completeness upon receipt from the laboratory to ensure that sample data and QA/QC information requested are present. A cursory level of review will be made considering the following:

- Holding times;
- Surrogate spike results;
- MS/MSD or MS/duplicate results;
- Method blanks; and
- Detection limits.

Presentation of Results

Soil designation testing results will be communicated verbally to the Contractor as soon as the results have been confirmed with the laboratory. Hard copies of laboratory and field reports will also be provided to the Contractor. The field observations and chemical testing data will be used to produce a focused technical memorandum at the end of the project. The document will include appendices which present a compilation of technical information used in developing the environmental interpretation.

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Table 1 - Analytical Methods, Containers, and Holding Times

Analytes	Method	Container [1]	Holding Time
PCE, TCE, cis-DCE, VC	8010	GT, 4 ounces	14 days
TCLP for PCE, TCE, cis-DCE, VC	Extraction by 1311 Volatile analysis by 8260	GT, 4 ounces	14 days
Metals - As, Cd, Cr, Cu, Pb, Ni, Zn	EPA 7000 Series	glass, 4 ounces	6 months

Notes:

(1) GT - Borosilicate of quartz glass with PTFE caps.
Samples will be collected with no headspace and preserved at 4°C.

Table 2 - Soil Designation Criteria

Analyte	Groundwater Protection in mg/kg (2)	Direct Contact in mg/kg (2)	TCLP in mg/L
PCE	0.5 (1)	19.6	0.7
TCE	0.5 (1)	90.9	0.5
cis-DCE	8	800	NA
VC	0.0023	0.526	0.2
Arsenic	20 (3)	20 (3)	5
Cadmium	1.6	80	1
Chromium	100 (4)	100 (4)	5
Copper	59.2	2,960	NA
Lead	250 (5)	250 (5)	5
Nickel	32	1,600	NA
Zinc	480	24,000	NA

Notes:

1 MTCA Method A standard.
2 MTCA Method B standard unless otherwise noted.
3 MTCA Method A standard based on Washington background levels.
4 MTCA Method A standard based on inhalation of suspended dust.
5 MTCA Method A standard based on unacceptable blood levels.
NA Not Applicable

4063-10\Tables1and2.xls

ATTACHMENT A
GENERAL TECHNICAL SPECIFICATIONS
FOR BIODEGRADABLE SLURRY TRENCH METHOD
GRANULAR IRON, SAND MATERIAL AND MIXING

envirometal technologies inc.

Memorandum

To: Barry Kellems, Hart Crowser Inc., Fax No. 206-328-5581
Al Jacobson, Jacobson Terminals, Fax No. 425-744-2791

From: EnviroMetal Technologies Inc.

Date: 12 August 1999

Re: **General Technical Specifications for Biodegradable Slurry Trench Method, Granular Iron, Sand Material and Mixing – 31530.10**

(A) Considerations Involved in Bioslurry Trench Field Applications

It is suggested that the delivery of the iron/sand mixture into the bio-slurry trenches should assure minimal iron/sand bio-polymer contact and assure that the iron and sand do not separate during placement. To achieve this, the mixture could be placed into the trench through the slurry, in a tremie tube. The iron/sand mixture could also be saturated with water to displace the bio-polymer during placement, minimizing bio-polymer infiltration into the reactive material.

Other guidelines include the following:

1. Amount of slurry used in construction should be documented.

2. Chemical constituents of the slurry should not present a threat to downgradient groundwater quality, the reactivity of the granular iron, or the hydraulic conductivity of the iron or aquifer sediments. Cores or hydraulic tests may be needed to confirm the lack of effect of the slurry on system hydraulics.

3. If required, an enzyme may be added to the slurry to speed the natural biodegradation process. However, this enzyme should also not negatively impact downgradient water quality or iron reactivity.

745 Bridge St. West, Suite 7
Waterloo, Ontario
Canada N2V 2G6
Tel: (519) 746-2204
Fax: (519) 746-2209

4. Design should include a means of evaluating whether the slurry has "broken" in-situ (e.g. by groundwater sampling).

5. Contractor should describe a method of verification that iron is placed to the required limits.

6. Contractor should minimize the amount of slurry which will "leak off" into the formation on either side of the wall.

7. Chemical and geotechnical characteristics of the biopolymer slurry mixture should be monitored to ensure the slurry is sufficient to support the walls of the excavation.

8. During excavation and placement of the granular iron, the level of the slurry should be maintained at a sufficient height above the saturated zone (static groundwater level) to prevent the trench walls in the saturated zone from caving or sloughing. Caving or sloughing could result in a potential discontinuity in the iron wall.

9. Iron placement method should minimize the potential for the creation of voids in the wall. This may involve the use of tremie tubes or other delivery systems.

10. As the granular iron is being placed, excess slurry should be pumped out of the trench into a frac tank or other appropriate storage container.

(B) Granular Iron Specifications

1. Granular iron should consist of approved dry material free from contamination oils, greases, or other foreign organic substances. The iron shall be obtained from one of the following sources:

   - Peerless Metal Powders and Abrasives; Detroit, MI; Phone: (313) 841-5400 Product: ETI 8/50

- Connelly-GPM Inc. Chicago, IL; Phone: (773) 247-7231. Product: ETICC-1004.

- Master Builders, Inc.; Cleveland, Ohio; Phone: (216) 831-5500: Product: -8 to +50 mesh, US Screen Size.

2. Suppliers should be queried as to the buyback of reactive material, in the event excess material exists at end of construction.

3. The engineer should reserve the right to specify purchase from a particular source, if required.

4. The gradation of granular iron should approximate the range specified in Table 1, and be approved by the project engineer.

5. Direct exposure to moisture, mixing with foreign matter, or a change in material size can adversely affect the performance of the granular iron for the intended application.

6. The iron unloaded at site should be protected from contact with water at all times. Stored iron should be covered with impermeable sheets anchored or tied in place, if stored outdoors. If possible, iron should also not be stored directly on the ground surface.

7. Granular iron should be shipped in packaging or bulk, as specified by the engineer.

8. Granular iron should be transported and arrive on site at ambient temperatures.

9. Protective packaging should not be removed from the granular iron until final placement in the treatment wall. Unused portions of granular iron shall be returned to storage and protected in accordance with the above requirements.

Table 1: Granular Iron Gradation

US Standard Sieve Size	Percent Passing by Weight
Number 8	95-100
Number 16	75-90
Number 30	25-45
Number 50	0-10
Number 100	0-5

(C) Manufacturing Quality Control

1. The iron Manufacturer and/or contractor should perform grain size analyses at the request of the contractor, on representative samples collected during the production run.

2. All involved parties should reserve the right to visit the Manufacturer during the production run to visually inspect the manufacturing process and collect random samples at that time. The Manufacturer should provide reasonable assistance to obtain these samples.

3. Oil and grease testing, if required, can be performed on representative samples.

(D) Sand Materials and Materials Mixing

A. Quality Control Testing For Sand/Granular Iron Mixture

1. The contractor document should specify whether the proportion of iron to be used in the mixture is given as weight % or volume %.

2. Quality control testing of the mixed sand and the granular iron materials should be conducted to verify compliance with the specifications.

3. Quality control testing should consist of visual inspection and/or separation of the mixed material using a magnet and accurately measuring each material to ensure it falls within the specification.

B. Sand Materials

1. Sands should be of similar grain size as the iron.

2. Sand shall be free of stones, clay particles, debris, organic matter, and other foreign material.

3. Sand shall be in a dry condition (ideally 5% moisture or less) prior to mixing with granular iron.

C. Sand/Granular Iron Mixture

1. Mixing should be carried out to obtain the desired sand/iron ratio plus or minus some tolerance. The mixing contractor should be made aware of iron handling and storage issues (i.e. keeping it covered and dry), if the mixing is to occur at their facility. The iron/sand mixture should also be stored in a manner similar to the granular iron. All equipment should be clean of foreign materials (e.g. cement mix, soil, stones, etc.) and no water should be used during mixing. During transport and handling, care should be taken to minimize vertical drop and vibration of the finished product to prevent separation/segregation.

2. The iron/sand mixture should be stored no more than 48 hr prior to installation. This time period can be increased according to the moisture content of the sand.

(E) Health and Safety

1. The Contractor should ensure adequate protection for all on-site personnel and prepare and implement a complete site-specific Health and Safety Plan in accordance with all applicable federal, state, and local regulations. The plan should cover the Contractor, subcontractors, and visitors while on the site.

2. The granular iron material is a dust nuisance and adequate personal protective equipment should be worn at all times while handling or being in close proximity to iron material. MSDS data sheets are available from the manufacturer

technologies inc.

Table 4: Sand Moisture Content and Iron/Sand Maximum Recommended Storage Times

Sand Moisture Content (Percent)[a]	Iron/Sand Mixture Maximum Recommended Storage Times (hr)
0	NA
0 to 3	72
3 to 6	48
6 to 9	24
greater than 9	8

a If you assume 100 lb/ft^3 for sand, 3, 6 and 9 correspond to 5, 10 and 15% porosity or 1/6, 1/3 and ½ of the total porosity; sand is assumed to have 30% porosity.

NA = Not Applicable

ATTACHMENT B
CEMENT-BENTONITE PROPERTIES AND SPECIFICATIONS

concrete INFORMATION

pca

Tech File
SCOW -
Cement-bentonite.

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.

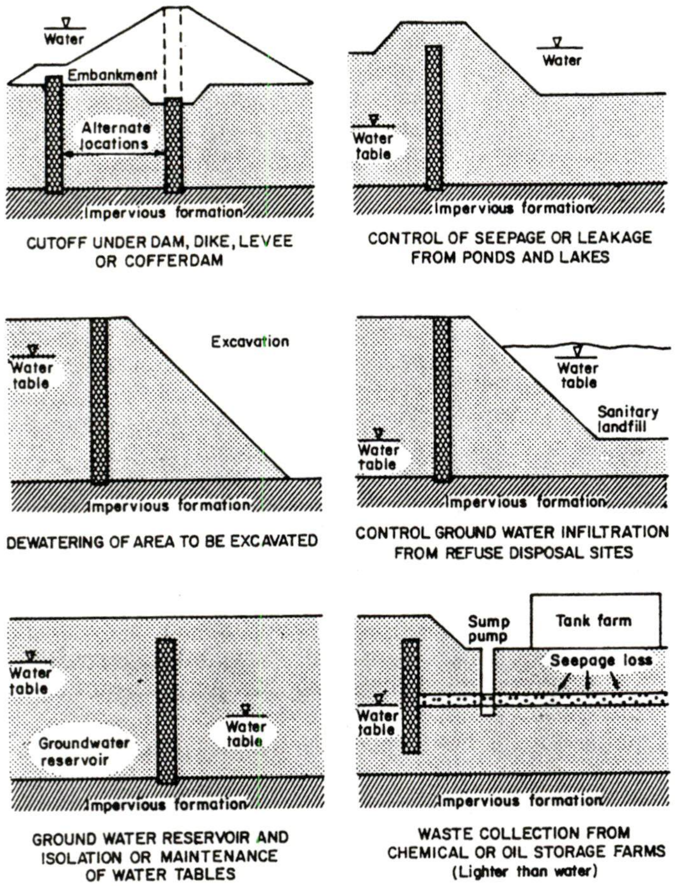

Fig. 2. Typical applications for slurry trench cutoff walls. (From Millet and Perez[2])

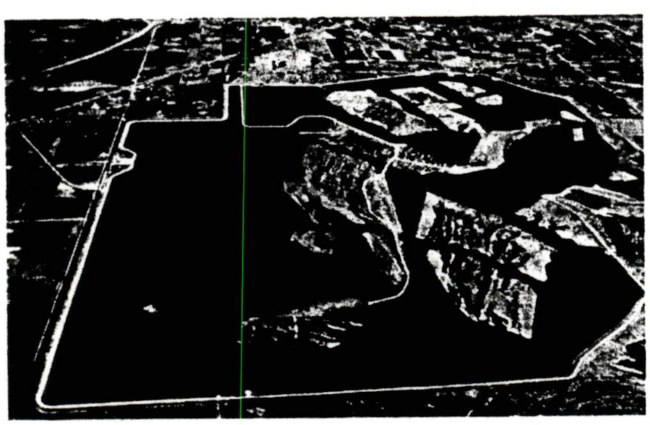

Fig. 3. Aerial view of cooling water reservoir at Braidwood Nuclear Power Station, Ill.

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,

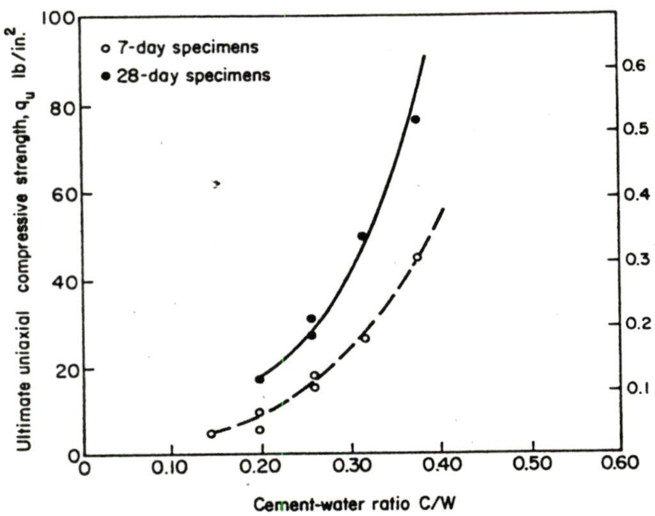

Fig. 4a

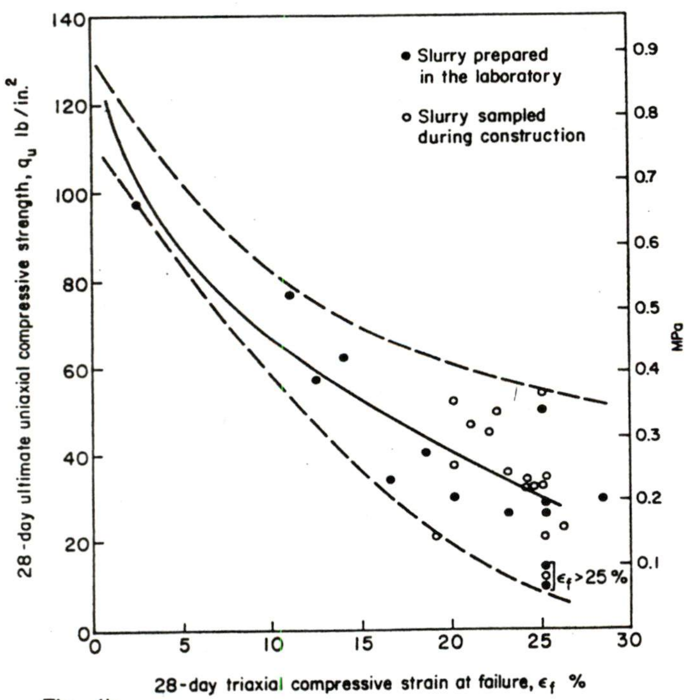

Fig. 4b

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

a slurry trench constructed as a cutoff or seepage barrier beneath a dam must perform for the life of the structure. When constructed with and exposed to clean water, slurry trenches should be considered permanent regardless of the application.

For applications that involve contaminated water or exposure to pollutants, it is important to check the effect the liquid has on the slurry trench. For example, acids will dissolve the cement components of a C-B slurry trench. Sulfates may also be harmful; however, the attack by sulfate soils or wastes may be reduced or prevented by using cement containing a low tricalcium aluminate (C_3A) content. Type II cement with a maximum C_3A content of 8% is used for moderate sulfate exposure (150 to 1500 ppm). Type V with a maximum C_3A content of 5% is for severe sulfate exposure (1500 to 10,000 ppm).

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

Occasionally an instantaneous and significant increase in viscosity will occur following the addition of cement to the bentonite-water slurry. This chemical reaction causes the bentonite to flocculate and thickens the slurry making it difficult to pump. Additives are sometimes used in C-B slurries to prevent premature thickening and to increase workability or delay setting action. In general, the additives are used in a concentration between 0.01 to 0.5% of the weight of cement. Dispersing agents have been used effectively to maintain slurry viscosities within workable limits. Retarding agents, which can delay setting times up to 72 hours, are especially useful for deep trenching where work may continue in the same area for several days. No addivites should be used, however, that will adversely affect the performance of the completed slurry wall. A list of typical additives and their effect on the fluid slurry properties are listed in Table 2. A complete description of many of these

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, magnesium, and iron in hard water.
Sodium carboxymethyl cellulose (SCMC) Pregelatinised starch Industrial gums	Increases bentonite-water viscosity and gelation where salt contamination has inhibited hydration and water absorption. Reduces loss of fluid.
Phosphates	Removes calcium and disperses clay solids. Decreases pH. Reduces viscosity but does not reduce fluid 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 calcium 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.

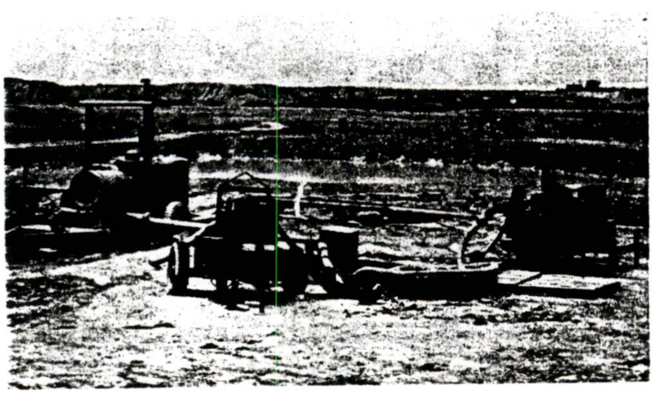

Fig. 5. Flash mixer with circulating pumps. Bentonite slurry holding pond in background.

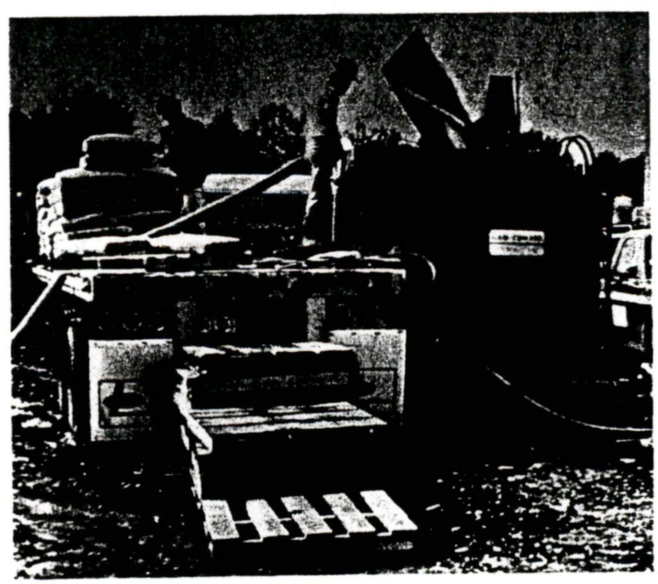

Fig. 6. Five-cu-yd capacity colloidal mixer. Vertical shaft with propellers located in center of tank assists slurry mixing. (Courtesy of Geo-Con Inc., Pittsburgh, Penn.)

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

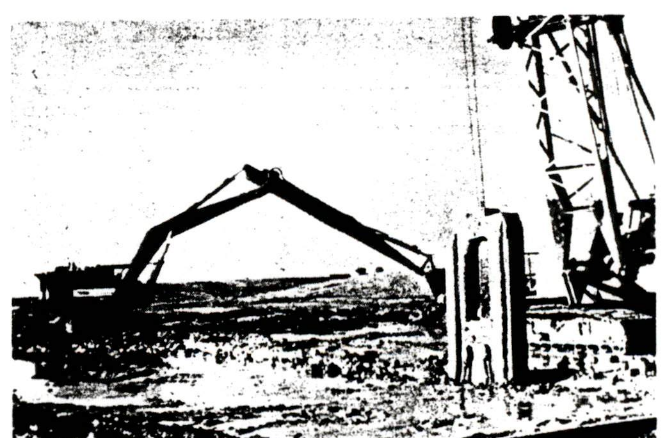

Fig. 9. Equipment used for excavating deep slurry trenches includes a free-hanging clamshell and a modified backhoe capable of excavating to 52 ft. Braidwood Nuclear Power Station, Ill.

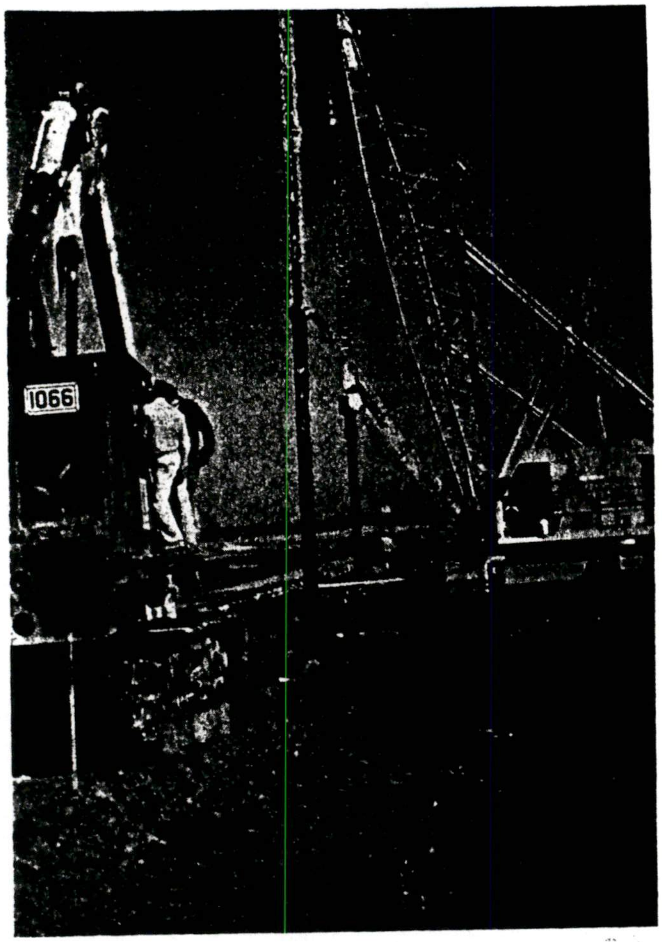

Fig. 10. Two kelly-guided clamshells excavating deep portion of slurry trench. Initial 50-ft depth being excavated with modified backhoe in foreground. Braidwood Power Station, Ill.

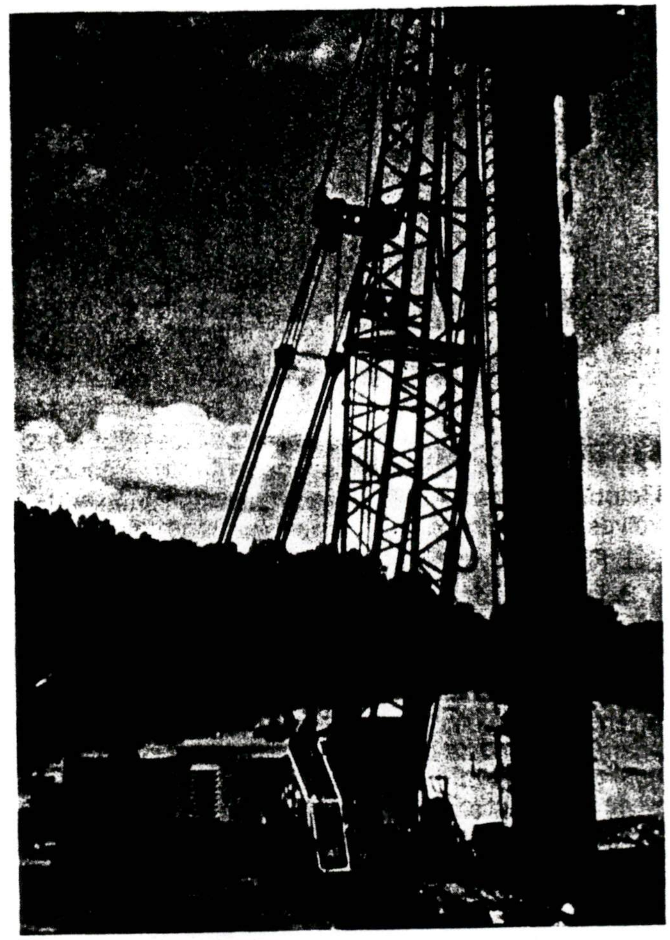

Fig. 12 Vibrating beam technique for installation of cement-bentonite slurry wall. (Courtesy of Slurry Systems, Inc., Gary, Ind.)

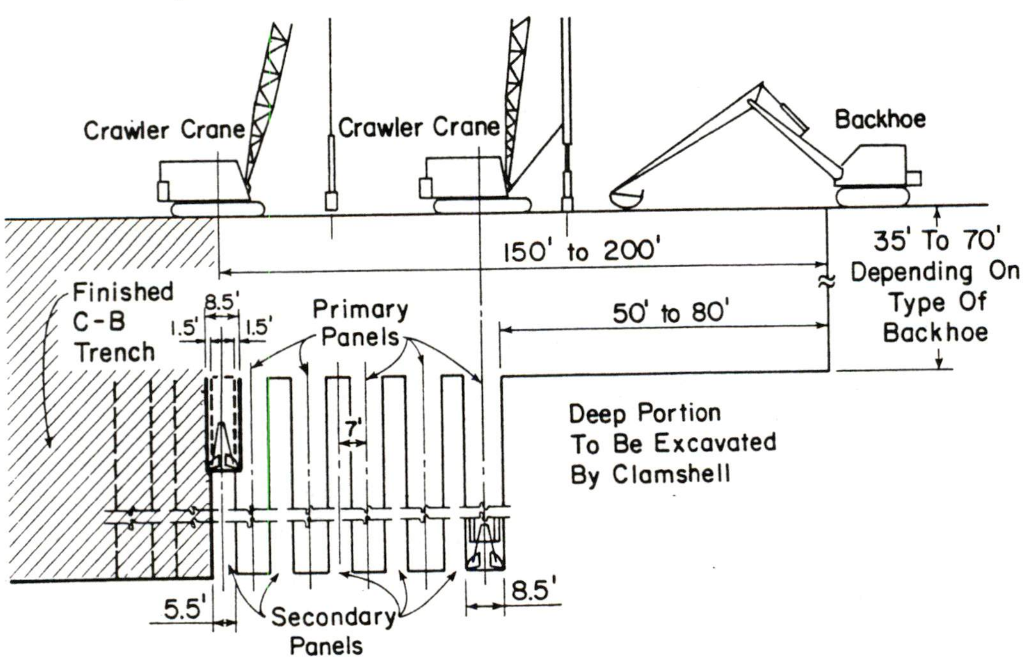

Fig. 11. Typical method of excavating deep slurry trenches.

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/cm³). 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/cm³). A typical 3-sack mix (282 lb cement per cubic yard [167 kg/m³] of water) has a density just over 70 pcf (1.12 gm/cm³).

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.

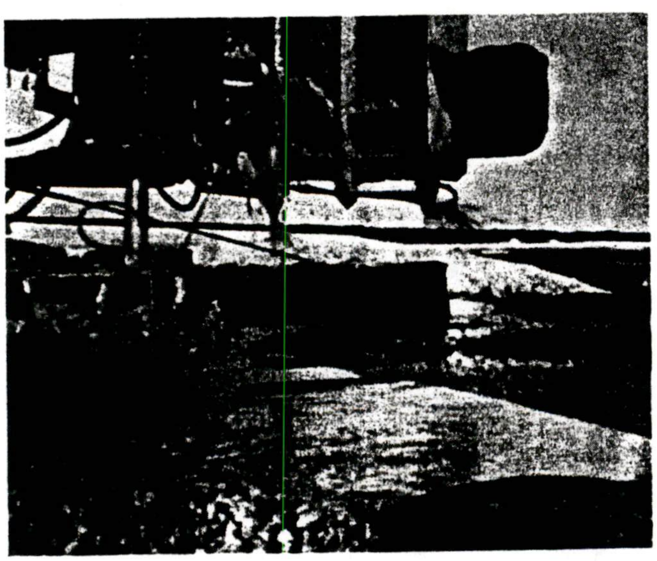

Fig. 13. Spray nozzles and "trailing fin" located at tip of beam. Slurry injected through nozzle at left assists the beam in penetrating the soil. (Courtesy of Slurry Systems, Inc., Gary, Ind.)

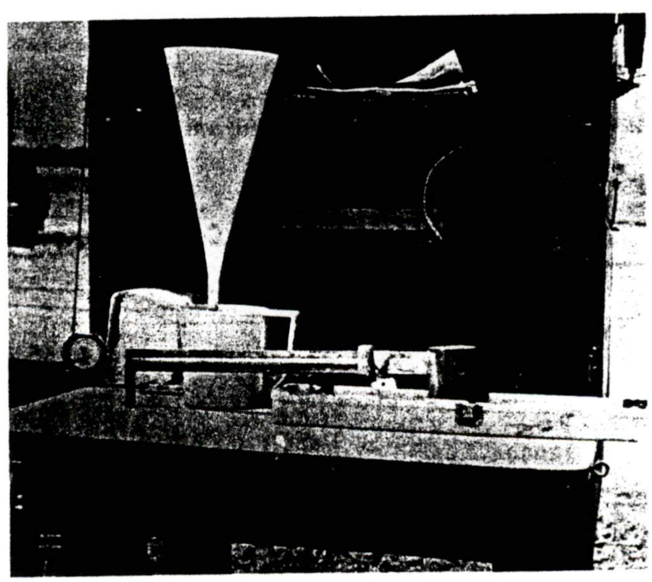

Fig. 14. Standard test equipment used to measure density and viscosity of slurry.

*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 I 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/cm³).

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/cm³).

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/m³) 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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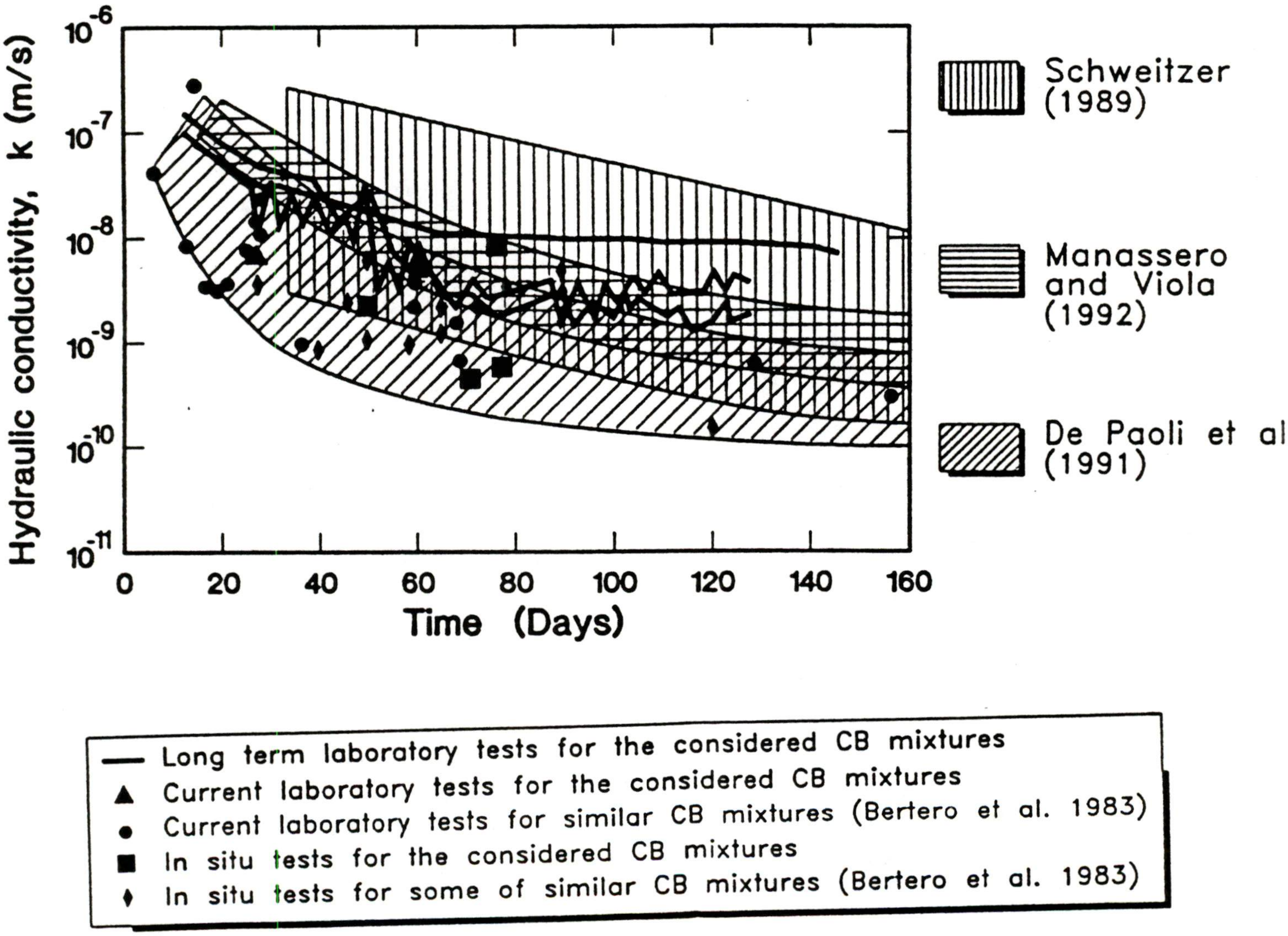
8. *Standard Procedure for Testing Drilling Fluids,* API RP13B, Eighth Edition, April 1980.

Permeability of Cement-Bentonite Mixtures



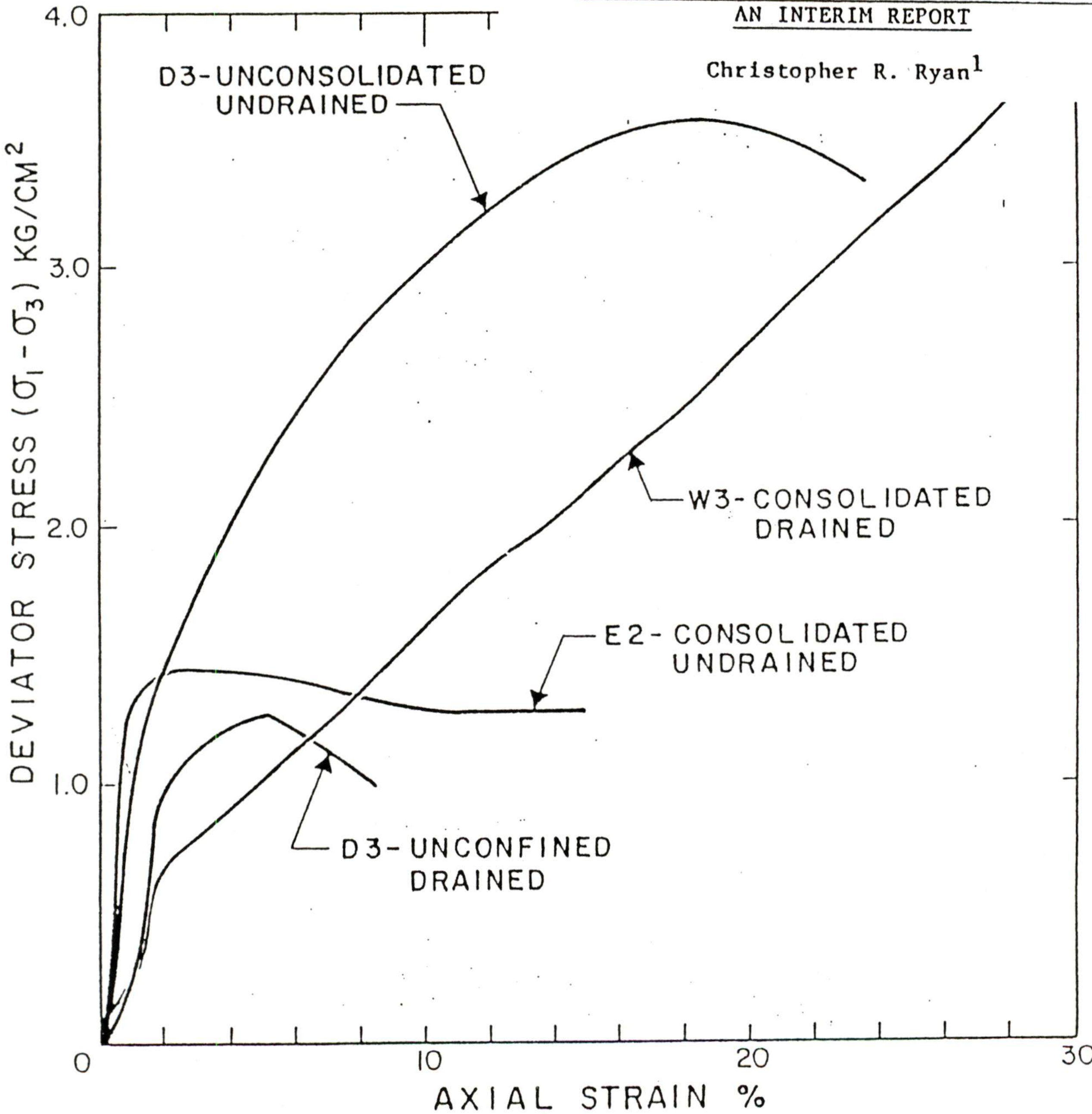
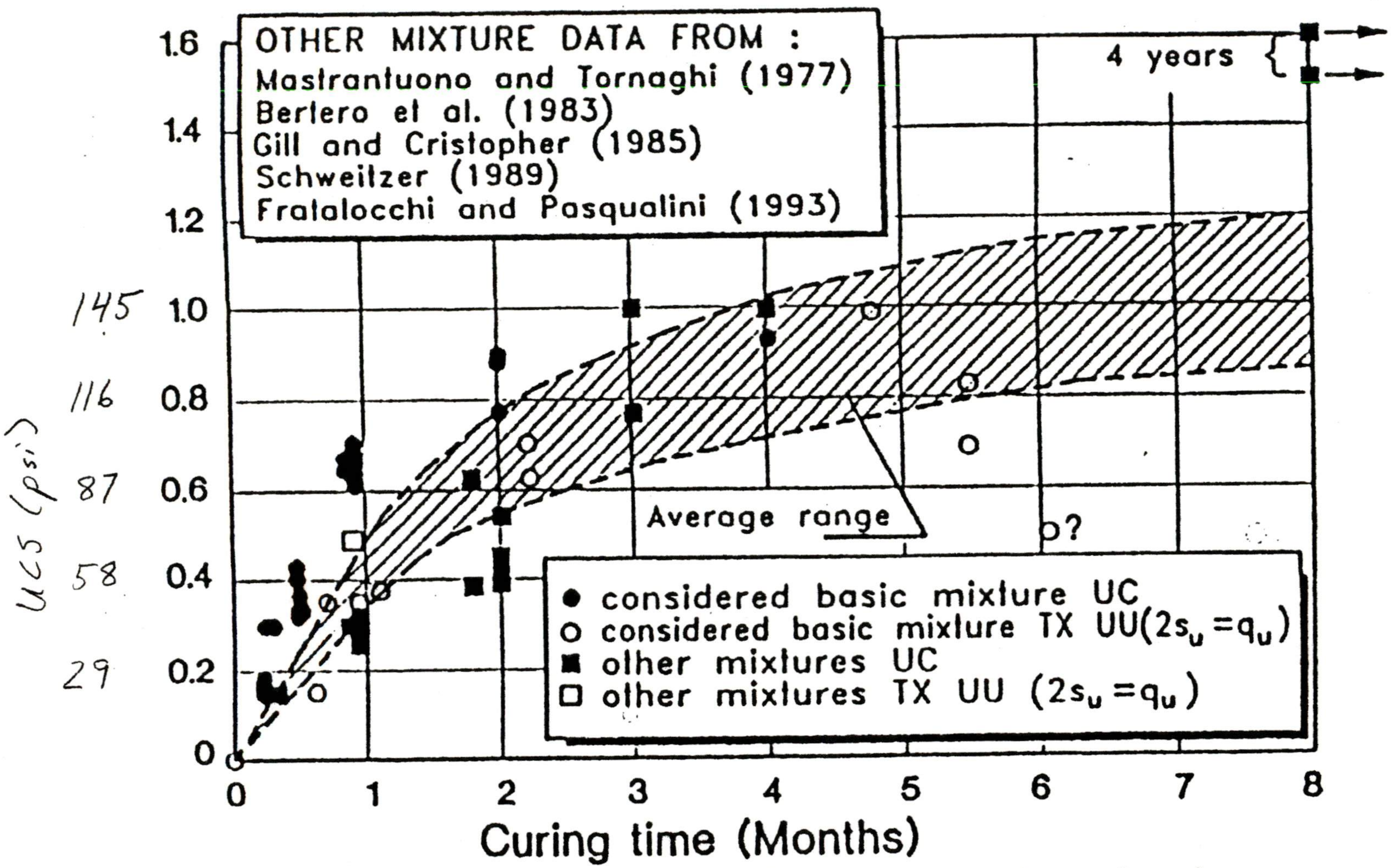


FIGURE 7 TRIAXIAL TESTS ON CEMENT - BENTONITE SLURRY



5: *Unconfined compression strength of typical cement-bentonite mixtures versus curing time*

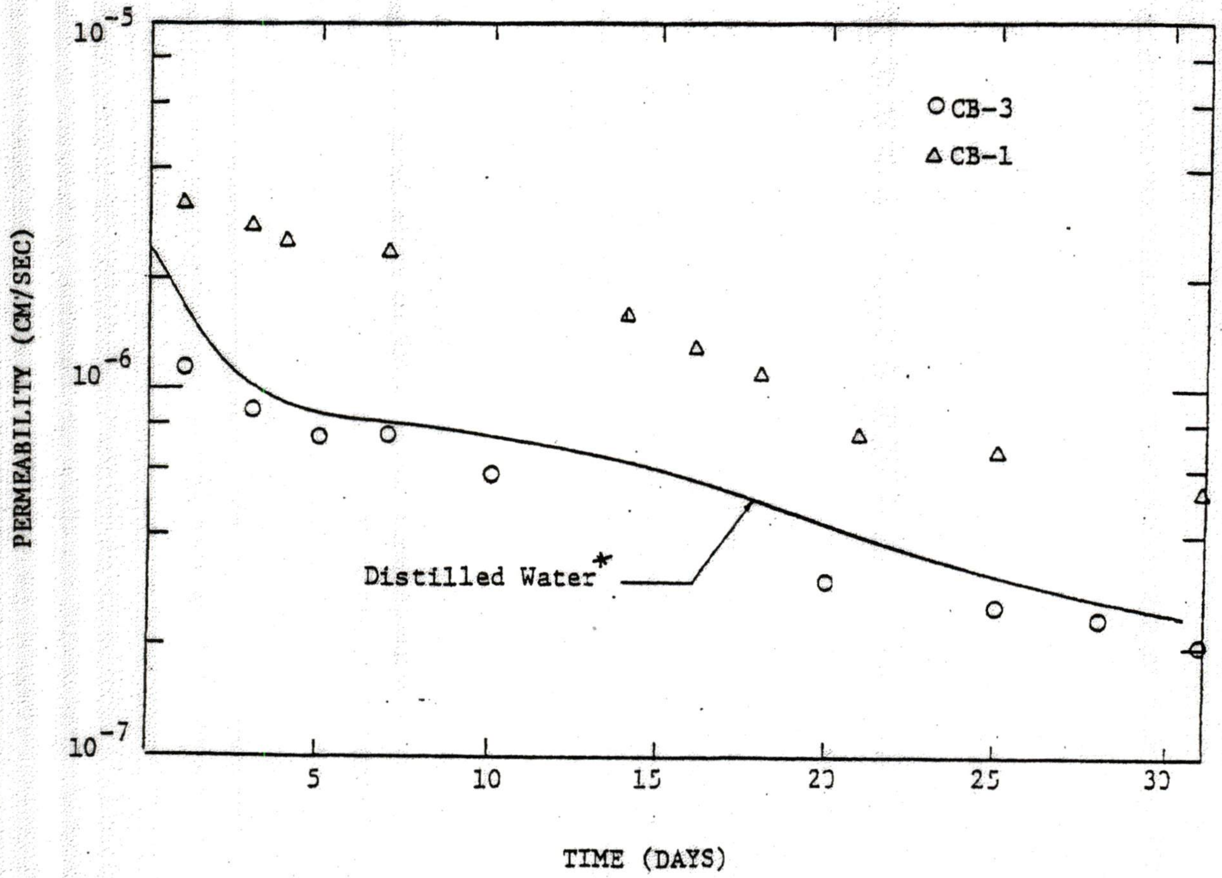
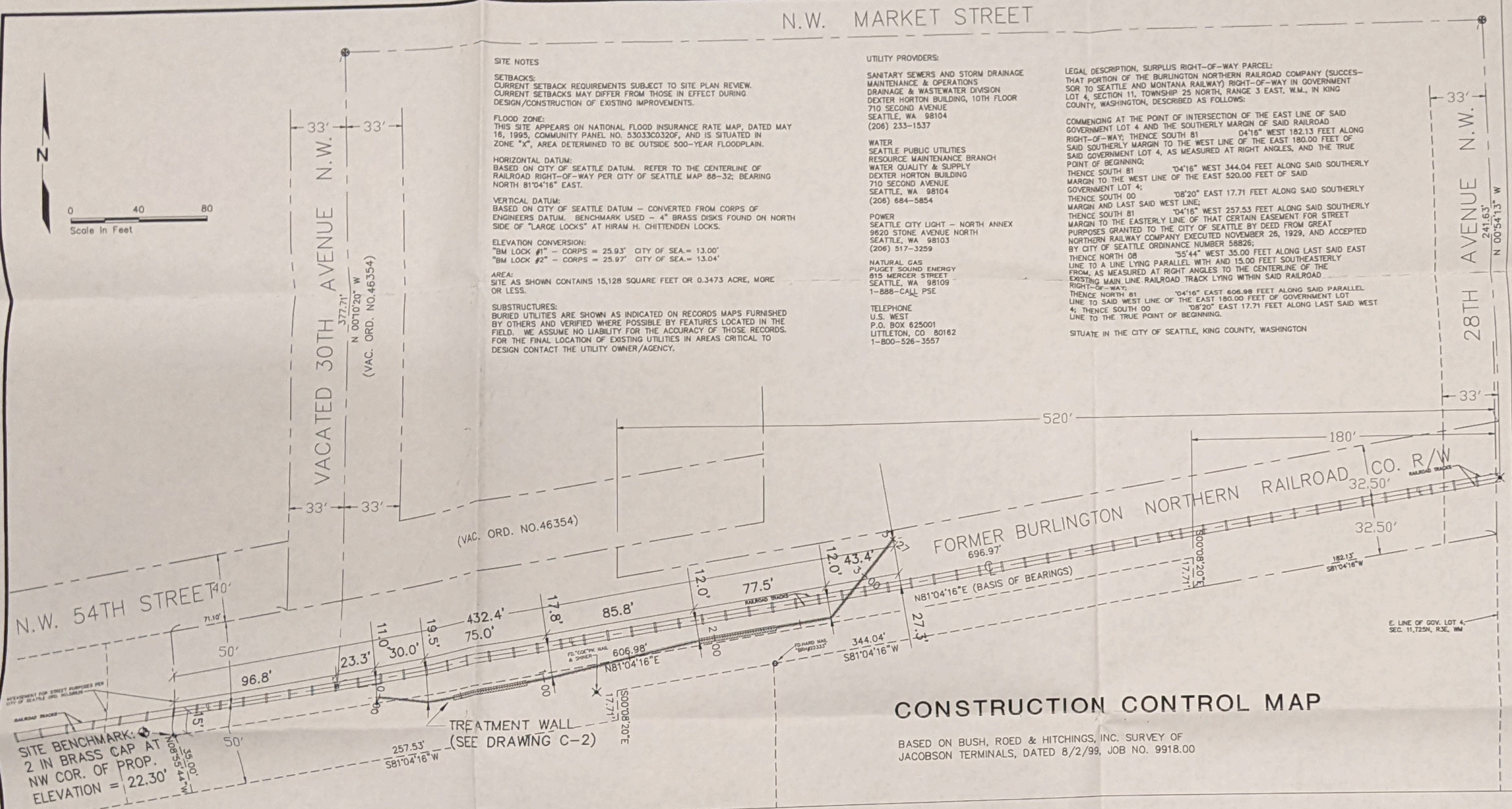


FIG. 2: PERMEABILITY AND TIME FOR TRIAL MIX CB-1 AND CB-3 PERMEATED WITH SITE GROUNDWATER

* AFTER CHAPUIS, R.P., J.J. PARE AND A.A. LOISELL (1984), "LABORATORY TEST RESULTS ON SELF-HARDENING GROUTS FOR FLEXIBLE CUTOFFS", <u>CAN. GEOTECH. JOURNAL</u>, VOL. 21, PP. 185-191



SITE NOTES

SETBACKS:
CURRENT SETBACK REQUIREMENTS SUBJECT TO SITE PLAN REVIEW. CURRENT SETBACKS MAY DIFFER FROM THOSE IN EFFECT DURING DESIGN/CONSTRUCTION OF EXISTING IMPROVEMENTS.

FLOOD ZONE:
THIS SITE APPEARS ON NATIONAL FLOOD INSURANCE RATE MAP, DATED MAY 16, 1995, COMMUNITY PANEL NO. 53033C0320F, AND IS SITUATED IN ZONE "X", AREA DETERMINED TO BE OUTSIDE 500-YEAR FLOODPLAIN.

HORIZONTAL DATUM:
BASED ON CITY OF SEATTLE DATUM. REFER TO THE CENTERLINE OF RAILROAD RIGHT-OF-WAY PER CITY OF SEATTLE MAP 88-32; BEARING NORTH 81°04'16" EAST.

VERTICAL DATUM:
BASED ON CITY OF SEATTLE DATUM – CONVERTED FROM CORPS OF ENGINEERS DATUM. BENCHMARK USED – 4" BRASS DISKS FOUND ON NORTH SIDE OF "LARGE LOCKS" AT HIRAM H. CHITTENDEN LOCKS.

ELEVATION CONVERSION:
"BM LOCK #1" – CORPS = 25.93' CITY OF SEA.= 13.00'
"BM LOCK #2" – CORPS = 25.97' CITY OF SEA.= 13.04'

AREA:
SITE AS SHOWN CONTAINS 15,128 SQUARE FEET OR 0.3473 ACRE, MORE OR LESS.

SUBSTRUCTURES:
BURIED UTILITIES ARE SHOWN AS INDICATED ON RECORDS MAPS FURNISHED BY OTHERS AND VERIFIED WHERE POSSIBLE BY FEATURES LOCATED IN THE FIELD. WE ASSUME NO LIABILITY FOR THE ACCURACY OF THOSE RECORDS. FOR THE FINAL LOCATION OF EXISTING UTILITIES IN AREAS CRITICAL TO DESIGN CONTACT THE UTILITY OWNER/AGENCY.

UTILITY PROVIDERS:

SANITARY SEWERS AND STORM DRAINAGE
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DRAINAGE & WASTEWATER DIVISION
DEXTER HORTON BUILDING, 10TH FLOOR
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TELEPHONE
U.S. WEST
P.O. BOX 625001
LITTLETON, CO 80162
1-800-526-3557

LEGAL DESCRIPTION, SURPLUS RIGHT-OF-WAY PARCEL:
THAT PORTION OF THE BURLINGTON NORTHERN RAILROAD COMPANY (SUCCESSOR TO SEATTLE AND MONTANA RAILWAY) RIGHT-OF-WAY IN GOVERNMENT LOT 4, SECTION 11, TOWNSHIP 25 NORTH, RANGE 3 EAST, W.M., IN KING COUNTY, WASHINGTON, DESCRIBED AS FOLLOWS:

COMMENCING AT THE POINT OF INTERSECTION OF THE EAST LINE OF SAID GOVERNMENT LOT 4 AND THE SOUTHERLY MARGIN OF SAID RAILROAD RIGHT-OF-WAY; THENCE SOUTH 81 04'16" WEST 182.13 FEET ALONG SAID SOUTHERLY MARGIN TO THE WEST LINE OF THE EAST 180.00 FEET OF SAID GOVERNMENT LOT 4, AS MEASURED AT RIGHT ANGLES, AND THE TRUE POINT OF BEGINNING;
THENCE SOUTH 81 °04'16" WEST 344.04 FEET ALONG SAID SOUTHERLY MARGIN TO THE WEST LINE OF THE EAST 520.00 FEET OF SAID GOVERNMENT LOT 4;
THENCE SOUTH 00 °08'20" EAST 17.71 FEET ALONG SAID SOUTHERLY MARGIN AND LAST SAID WEST LINE;
THENCE SOUTH 81 °04'16" WEST 257.53 FEET ALONG SAID SOUTHERLY MARGIN TO THE EASTERLY LINE OF THAT CERTAIN EASEMENT FOR STREET PURPOSES GRANTED TO THE CITY OF SEATTLE BY DEED FROM GREAT NORTHERN RAILWAY COMPANY EXECUTED NOVEMBER 26, 1929, AND ACCEPTED BY CITY OF SEATTLE ORDINANCE NUMBER 58826;
THENCE NORTH 08 °55'44" WEST 35.00 FEET ALONG LAST SAID EAST LINE TO A LINE LYING PARALLEL WITH AND 15.00 FEET SOUTHEASTERLY FROM, AS MEASURED AT RIGHT ANGLES TO THE CENTERLINE OF THE EXISTING MAIN LINE RAILROAD TRACK LYING WITHIN SAID RAILROAD RIGHT-OF-WAY;
THENCE NORTH 81 °04'16" EAST 606.98 FEET ALONG SAID PARALLEL LINE TO SAID WEST LINE OF THE EAST 180.00 FEET OF GOVERNMENT LOT 4; THENCE SOUTH 00 °08'20" EAST 17.71 FEET ALONG LAST SAID WEST LINE TO THE TRUE POINT OF BEGINNING.

SITUATE IN THE CITY OF SEATTLE, KING COUNTY, WASHINGTON

CONSTRUCTION CONTROL MAP

BASED ON BUSH, ROED & HITCHINGS, INC. SURVEY OF JACOBSON TERMINALS, DATED 8/2/99, JOB NO. 9918.00

VICINITY MAP

NOTES:

1. THE MARKET STREET PROPERTY PROJECT, CONSISTING OF INSTALLATION OF A FUNNEL AND GATE, ZERO VALENT IRON TREATMENT/CONTAINMENT WALL, SHALL BE ACCOMPLISHED IN ACCORDANCE WITH THESE PLANS AND THE ASSOCIATED CONSTRUCTION AND SOIL MANAGEMENT PLAN.

2. LOCATIONS OF UNDERGROUND PIPELINES AND OTHER STRUCTURES SHOWN ON THE PLANS ARE BASED ON LIMITED AS-BUILT INFORMATION AND SHOULD BE CONSIDERED APPROXIMATE. CONTRACTOR SHALL FIELD VERIFY THE LOCATIONS OF ALL EXISTING PIPELINES, UTILITIES, AND OTHER STRUCTURES WITHIN THE WALL LOCATION AREA PRIOR TO COMMENCING EARTHWORK.

3. CONTRACTOR SHALL PROTECT ALL EXISTING MONITORING WELLS AT THE SITE, WITH THE EXCEPTION OF JT-1, WHICH SHALL BE REMOVED DURING CONSTRUCTION.

4. PRIOR TO BEGINNING WORK AT THE SITE, THE CONTRACTOR SHALL PROVIDE TEMPORARY EROSION CONTROL TO PREVENT BENTONITE SLURRY AND/OR SEDIMENT-LADEN WATER FROM ENTERING DRAINAGE SYSTEMS, ADJACENT PROPERTIES, THE CITY RIGHT-OF WAY, OR SURFACE WATER BODIES.

5. PRIOR TO BEGINNING EARTHWORK, THE CONTRACTOR SHALL STAKE THE WALL CENTERLINE AND GATE LOCATIONS FOR INSPECTION AND CONFIRMATION BY HART CROWSER FIELD REPRESENTATIVE.

6. THE RAILROAD CONTRACTOR SHALL REMOVE AND REPLACE RAILS AND TIES AS NEEDED TO CONSTRUCT WALL. RAILWAY SHALL BE OUT-OF-SERVICE FOR A MAXIMUM OF 72 HOURS, TO INCLUDE A SATURDAY AND SUNDAY.

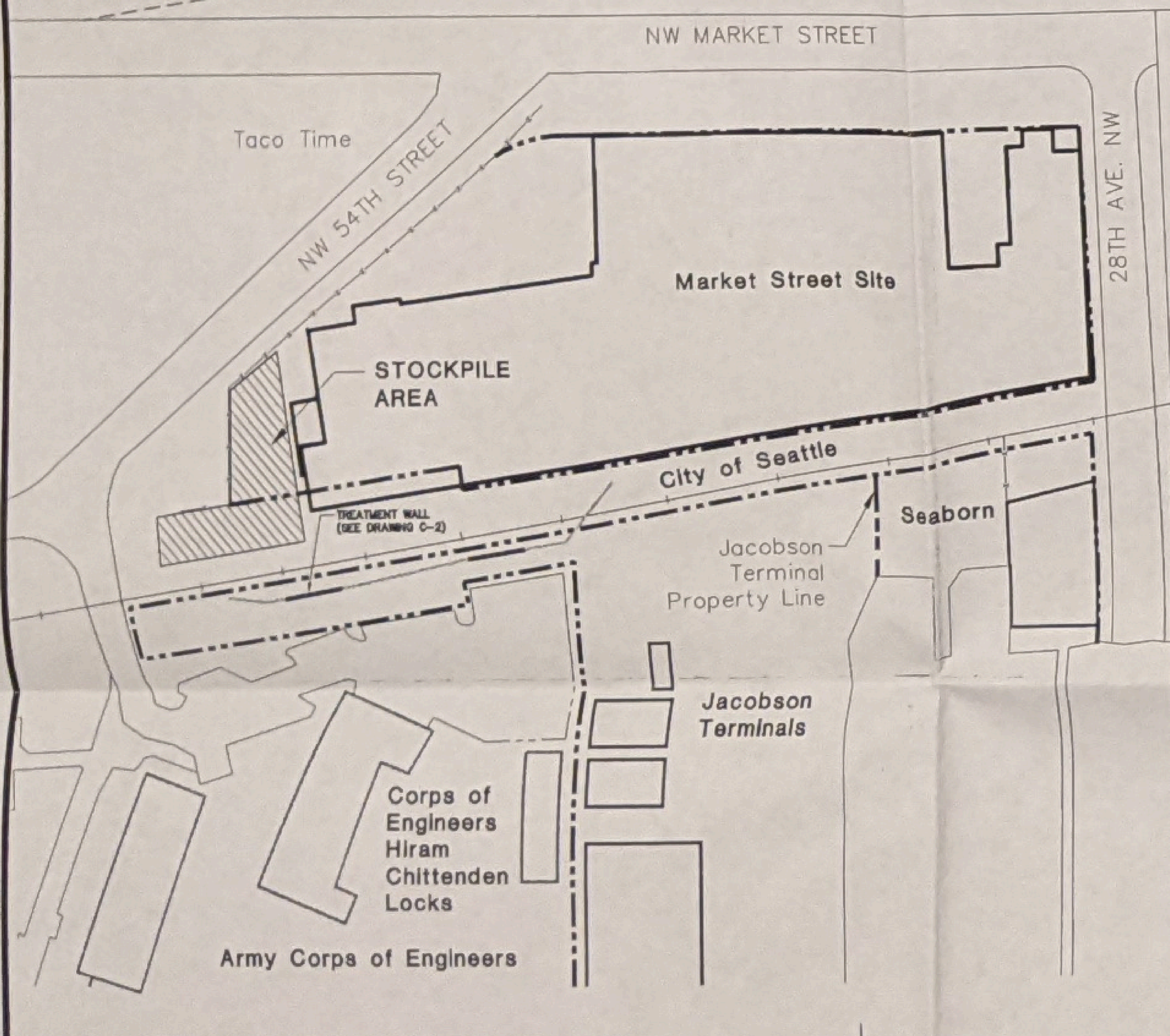
7. CONTRACTOR SHALL REMOVE, RECYCLE, AND CONSTRUCT NEW ASPHALT PAVEMENT TO MATCH EXISTING WITHIN THE FOOTPRINT OF THE WALL.

8. EXCAVATED SOILS WILL BE CLASSIFIED AS ON-SITE BACKFILL OR OFF-SITE DISPOSAL BASED ON FIELD SCREENING AND LABORATORY TESTING BY HART CROWSER. CONTRACTOR SHALL PLACE AND COMPACT BACKFILL SOIL AND STOCKPILE DISPOSAL SOILS AT LOCATIONS SHOWN ON THE DRAWINGS.

9. HYDRAULIC CUTOFF WALL SHALL CONSIST OF CONCRETE BENTONITE. TREATMENT GATES SHALL CONSIST OF IRON/SAND MIXTURE AS SHOWN ON DRAWING C-2, CROSS SECTIONS. BENTONITE CAP OVER TREATMENT GATE SHALL CONSIST OF A SOIL/BENTONITE MIXTURE UTILIZING ON-SITE SOIL, MIXTURE SHALL BE DETERMINED IN THE FIELD BASED ON SOIL CONDITIONS. FINAL DEPTHS OF CUTOFF WALL AND TREATMENT GATES SHALL BE AS SHOWN ON DRAWING C-2 SUBJECT TO CHANGE AS DIRECTED BY THE HART CROWSER FIELD REPRESENITIVE.

10. EXCAVATION ABOVE ELEVATION 10 FEET ASSUMED CLEAN; TEST AND STOCKPILE FOR ON-SITE USE OR APPROPRIATE DISPOSAL.

11. EXCAVATION BELOW ELEVATION 10 FEET POSSIBLY CONTAMINATED; TEST AND STOCKPILE FOR ON-SITE USE OR APPROPRIATE DISPOSAL.

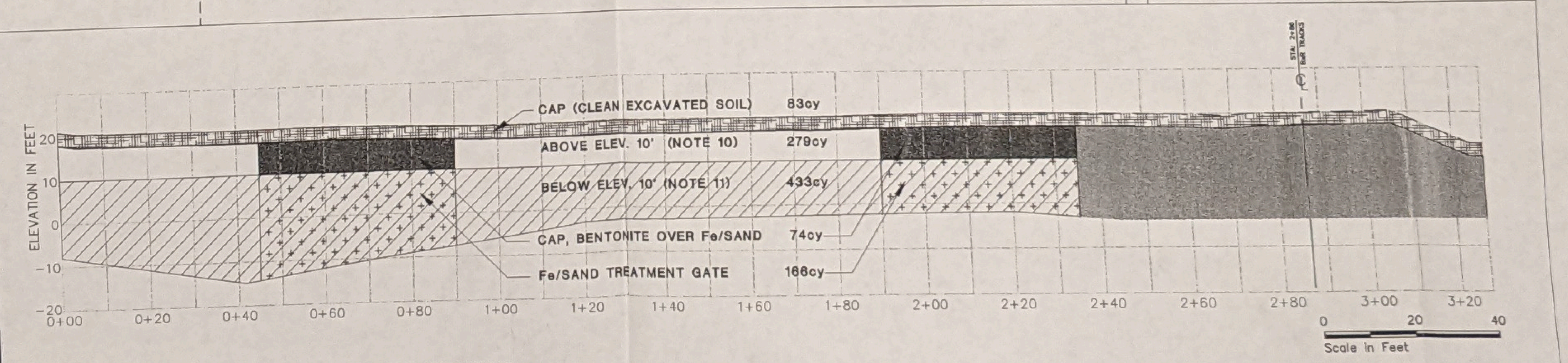


Notes: 1. Base map prepared from 1977 aerial photograph by Walker and Associates and figure prepared by EMCON entitled "Northwest Market Street Site," dated June 1995 and from the Department of the Army entitled "Land Management Map," dated February 18, 1998.

2. Building locations and dimensions are approximate.

3. Property lines are approximate based on record title and do not show adjustments to ownership based on adverse possession, mutual recognition and acquiescence, or similar theories.

AREA MAP



SITE EXCAVATION CALCULATION* PROFILE

TOTAL EXCAVATION		712cy
ABOVE ELEV. 10	(NOTE 10)	279cy
BELOW ELEV. 10	(NOTE 11)	433cy

SITE FILL

CAP (CLEAN EXCAVATED SOIL)	83cy
SITE REGRADE	(TO BE DETERMINED)

IMPORTED WALL MATERIAL

Fe/SAND TREATMENT GATE	166cy
CAP, BENTONITE OVER Fe/SAND	74cy
CUTOFF WALL BENTONITE/CEMENT	389cy

*NEAT LINE CALCULATION

Proj. Mgr.: DLH	Designed By: BLK	Drawn By: HEC
Checked By: JJP		

No.	Date	By	Revision

HARTCROWSER

Hart Crowser, Inc.
1910 Fairview Avenue East
Seattle, Washington 98102-3699
FAX 206.328.5581
206.324.9530

BARRY L. KELLEMS · STATE OF WASHINGTON · 32477 · REGISTERED PROFESSIONAL ENGINEER

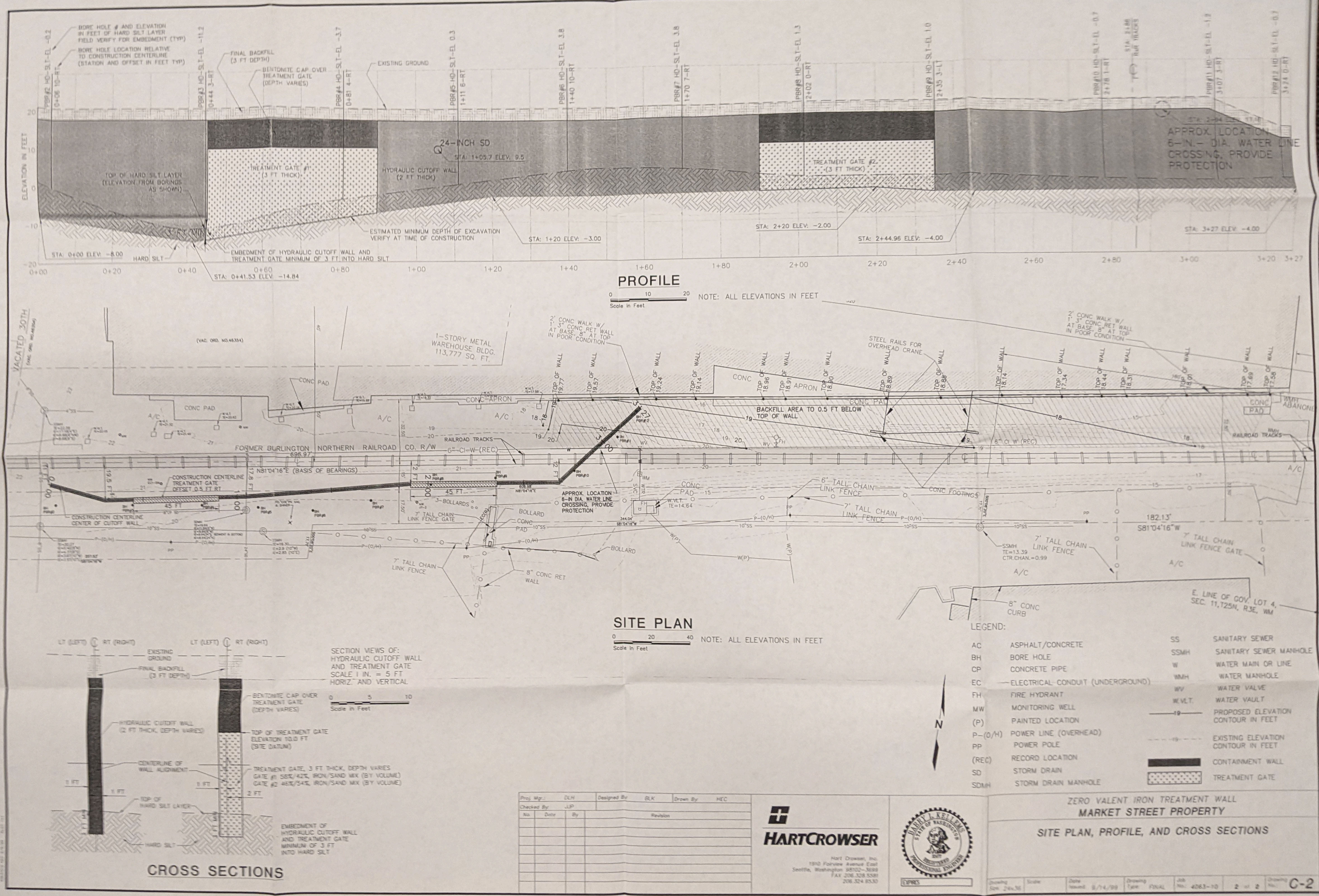
EXPIRES

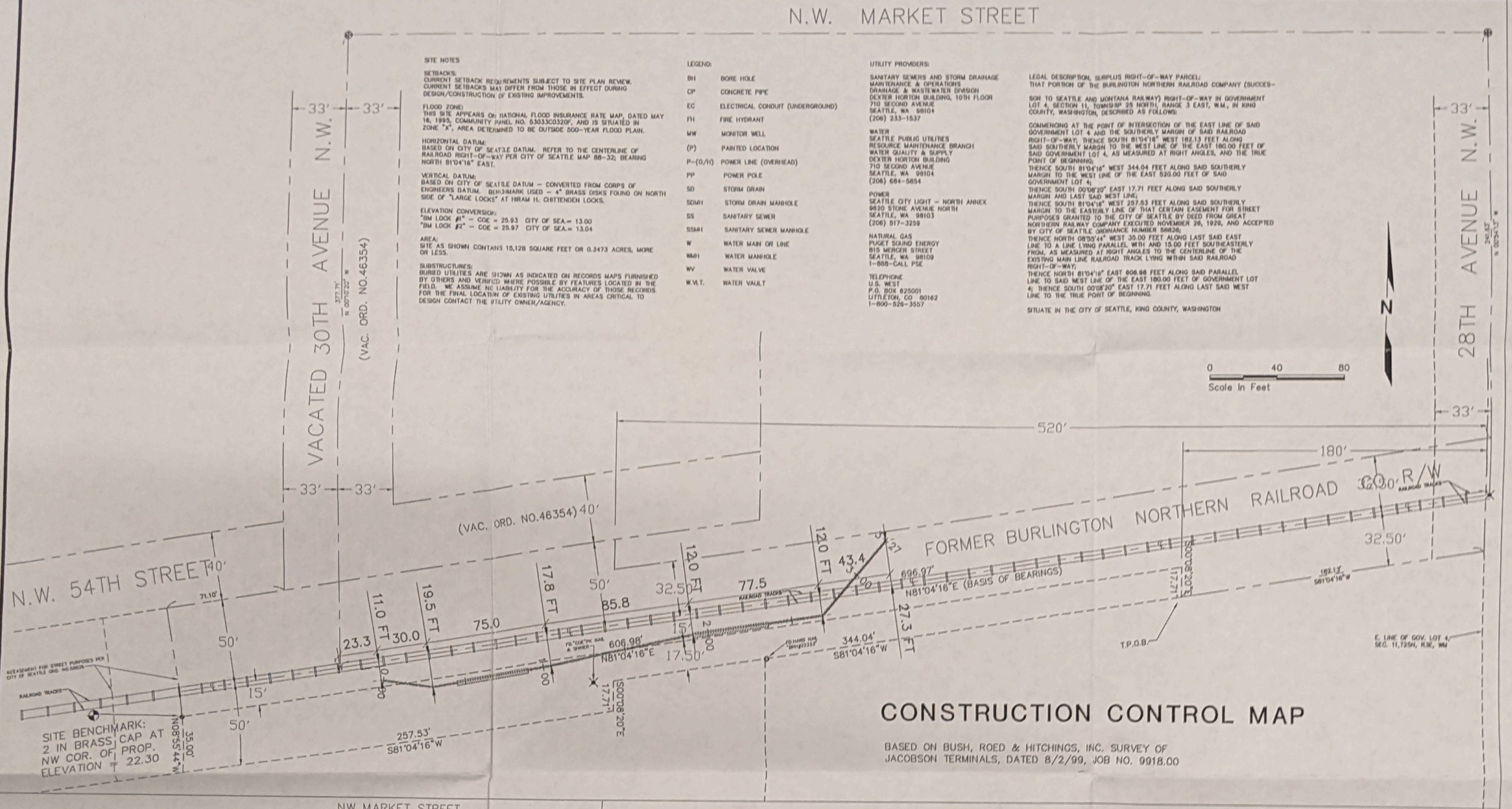
ZERO VALENT IRON TREATMENT WALL
MARKET STREET PROPERTY

CONSTRUCTION CONTROL, AREA, AND VICINITY MAPS AND SITE EXCAVATION PROFILE

Drawing Size: 24x36	Scale: AS SHOWN	Date Issued: 9/14/99	Drawing Type: FINAL	Job No.: 4063-10	1 of 2	Drawing No.: C-1

40631004 CAD 8/12/99 PLOT 1=1


PROFILE
NOTE: ALL ELEVATIONS IN FEET
SITE PLAN
NOTE: ALL ELEVATIONS IN FEET
CROSS SECTIONS
SECTION VIEWS OF: HYDRAULIC CUTOFF WALL AND TREATMENT GATE SCALE 1 IN. = 5 FT HORIZ. AND VERTICAL
LEGEND:
AC ASPHALT/CONCRETE
BH BORE HOLE
CP CONCRETE PIPE
EC ELECTRICAL CONDUIT (UNDERGROUND)
FH FIRE HYDRANT
MW MONITORING WELL
(P) PAINTED LOCATION
P-(O/H) POWER LINE (OVERHEAD)
PP POWER POLE
(REC) RECORD LOCATION
SD STORM DRAIN
SDMH STORM DRAIN MANHOLE
SS SANITARY SEWER
SSMH SANITARY SEWER MANHOLE
W WATER MAIN OR LINE
WMH WATER MANHOLE
WV WATER VALVE
W.VLT. WATER VAULT
PROPOSED ELEVATION CONTOUR IN FEET
EXISTING ELEVATION CONTOUR IN FEET
CONTAINMENT WALL
TREATMENT GATE
HARTCROWSER
Hart Crowser, Inc.
ZERO VALENT IRON TREATMENT WALL
MARKET STREET PROPERTY
SITE PLAN, PROFILE, AND CROSS SECTIONS
Date Issued 9/14/99
Drawing Type FINAL
Job No. 4063-10
2 of 2
C-2



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LEGEND:

BH	BORE HOLE
CP	CONCRETE PIPE
EC	ELECTRICAL CONDUIT (UNDERGROUND)
FH	FIRE HYDRANT
MW	MONITOR WELL
(P)	PAINTED LOCATION
P-(O/H)	POWER LINE (OVERHEAD)
PP	POWER POLE
SD	STORM DRAIN
SDMH	STORM DRAIN MANHOLE
SS	SANITARY SEWER
SSMH	SANITARY SEWER MANHOLE
W	WATER MAIN OR LINE
WMH	WATER MANHOLE
WV	WATER VALVE
W.V.T.	WATER VAULT

UTILITY PROVIDERS:

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SITUATE IN THE CITY OF SEATTLE, KING COUNTY, WASHINGTON

CONSTRUCTION CONTROL MAP

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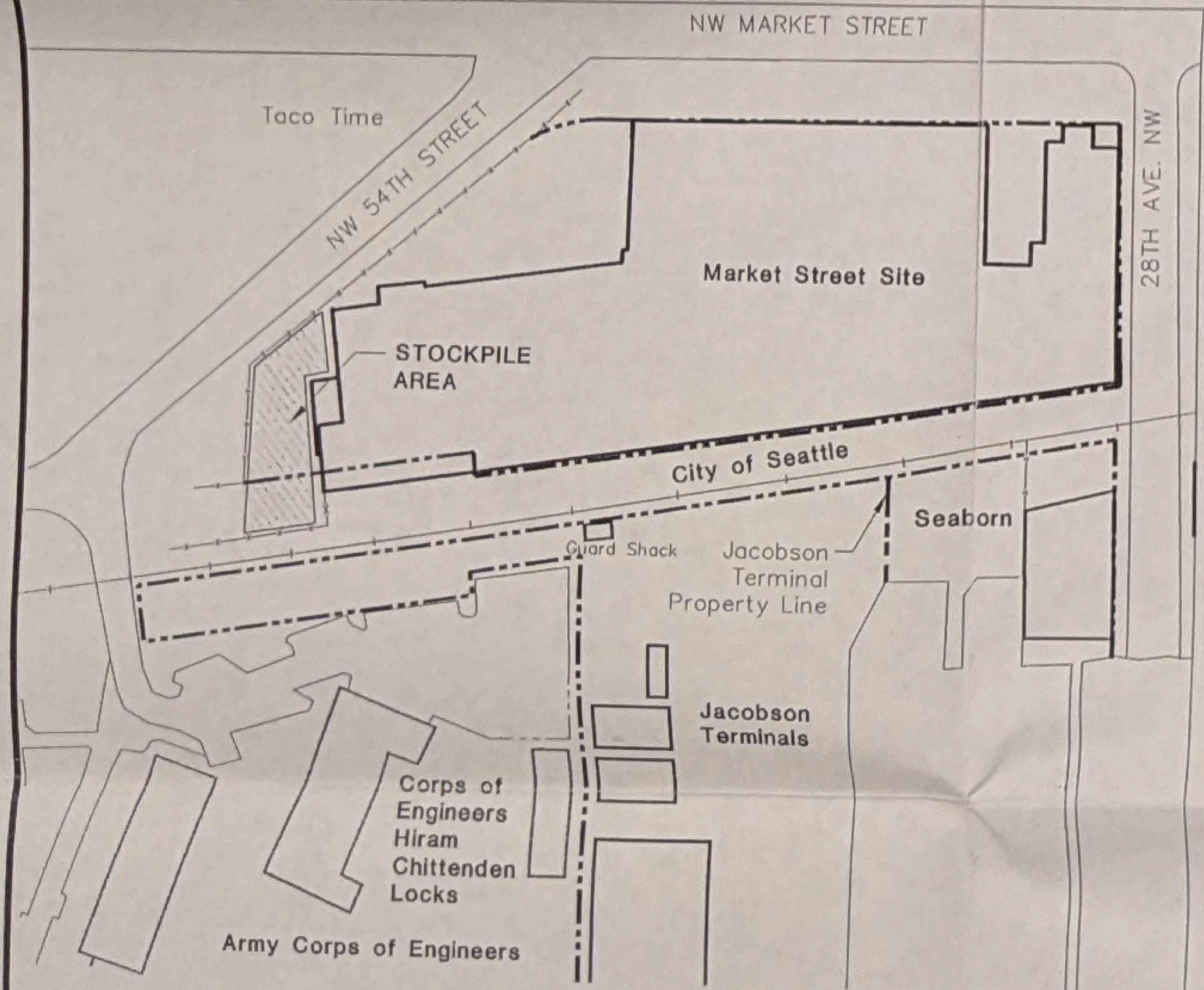

Notes:
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AREA MAP

VICINITY MAP

NOTES:

1. THE MARKET STREET PROPERTY PASSIVE TREATMENT WALL PROJECT, CONSISTING OF INSTALLATION OF A FUNNEL AND GATE, ZERO VALENT IRON TREATMENT WALL, SHALL BE ACCOMPLISHED IN ACCORDANCE WITH THESE PLANS AND THE ASSOCIATED SPECIFICATIONS.

2. LOCATIONS OF UNDERGROUND PIPELINES AND OTHER STRUCTURES SHOWN ON THE PLANS ARE BASED ON LIMITED AS-BUILT INFORMATION AND SHOULD BE CONSIDERED APPROXIMATE. CONTRACTOR SHALL FIELD VERIFY THE LOCATIONS OF ALL EXISTING PIPELINES, UTILITIES AND OTHER STRUCTURES WITHIN THE WALL LOCATION AREA PRIOR TO COMMENCING EARTHWORK.

3. CONTRACTOR SHALL PROTECT ALL EXISTING MONITORING WELLS AT THE SITE, WITH THE EXCEPTION OF JT-1, WHICH SHALL BE REMOVED DURING CONSTRUCTION.

4. PRIOR TO BEGINNING WORK AT THE SITE, THE CONTRACTOR SHALL PROVIDE TEMPORARY EROSION CONTROL TO PREVENT BENTONITE SLURRY AND/OR SEDIMENT LADEN WATER FROM ENTERING DRAINAGE SYSTEMS, ADJACENT PROPERTIES, THE CITY RIGHT-OF WAY, OR SURFACE WATER BODIES.

5. CONTRACTOR SHALL UNCOVER AND PROVIDE A 2'X2' CONCRETE ENCASEMENT OF THE 6-INCH DIA. WATERLINE, TO EXTEND 12-FT EITHER SIDE OF THE CONSTRUCTION CENTERLINE, 10 DAYS PRIOR TO WALL CONSTRUCTION.

6. CONTRACTOR SHALL REMOVE AND REPLACE RAILS AND TIES AS NEEDED TO CONSTRUCT WALL. RAILWAY SHALL BE OUT-OF-SERVICE FOR A MAXIMUM OF 72 HOURS, TO INCLUDE A SATURDAY AND SUNDAY.

7. CONTRACTOR SHALL REMOVE, RECYCLE AND REPLACE ASPHALT PAVEMENT WITHIN THE FOOTPRINT OF THE WALL.

8. EXCAVATED SOILS WILL BE CLASSIFIED AS ON-SITE BACKFILL OR OFF-SITE DISPOSAL BASED ON FIELD SCREENING BY HART CROWSER.
CONTRACTOR SHALL PLACE AND COMPACT BACKFILL SOIL SAND STOCKPILE
DISPOSAL SOILS AT LOCATIONS SHOWN ON THE DRAWINGS.

9. HYDRAULIC CUTOFF WALL SHALL CONSIST OF CONCRETE BENTONITE.

PRELIMINARY DRAWING
NOT FOR CONSTRUCTION

Bench Mark:			
Proj. Mgr.: DLH	Designed By: BLK	Drawn By: HEC	
Checked By:	Approved By:	Date:	
No.	Date	By	Revision

HARTCROWSER

Hart Crowser, Inc.
1910 Fairview Avenue East
Seattle, Washington 98102-3699
FAX 206.328.5581
206.324.9530

CONTAINMENT TREATMENT WALL

CONSTRUCTION CONTROL,
AREA & VICINITY MAP
MARKET STREET PROPERTY

Drawing Size	Scale	Date Issued	Drawing Type	Job No.		Drawing No.
24x36		8/12/99	PRELIM	4063-10	1 of 8	C-1

4063100X CAD 8/12/99 PLOT: 1=1