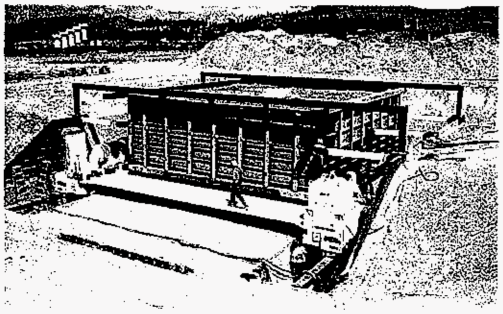
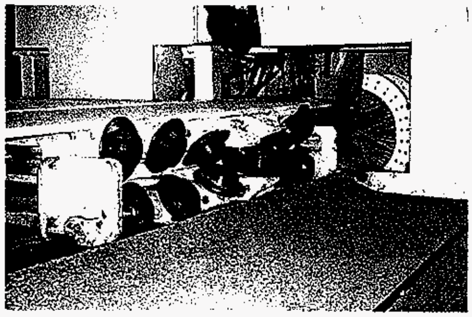
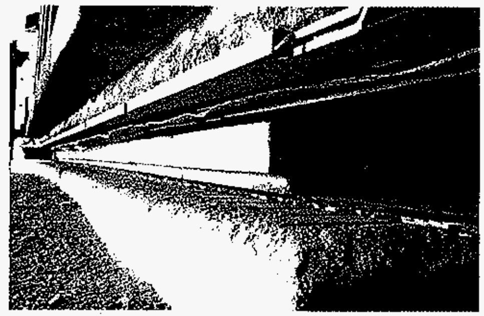
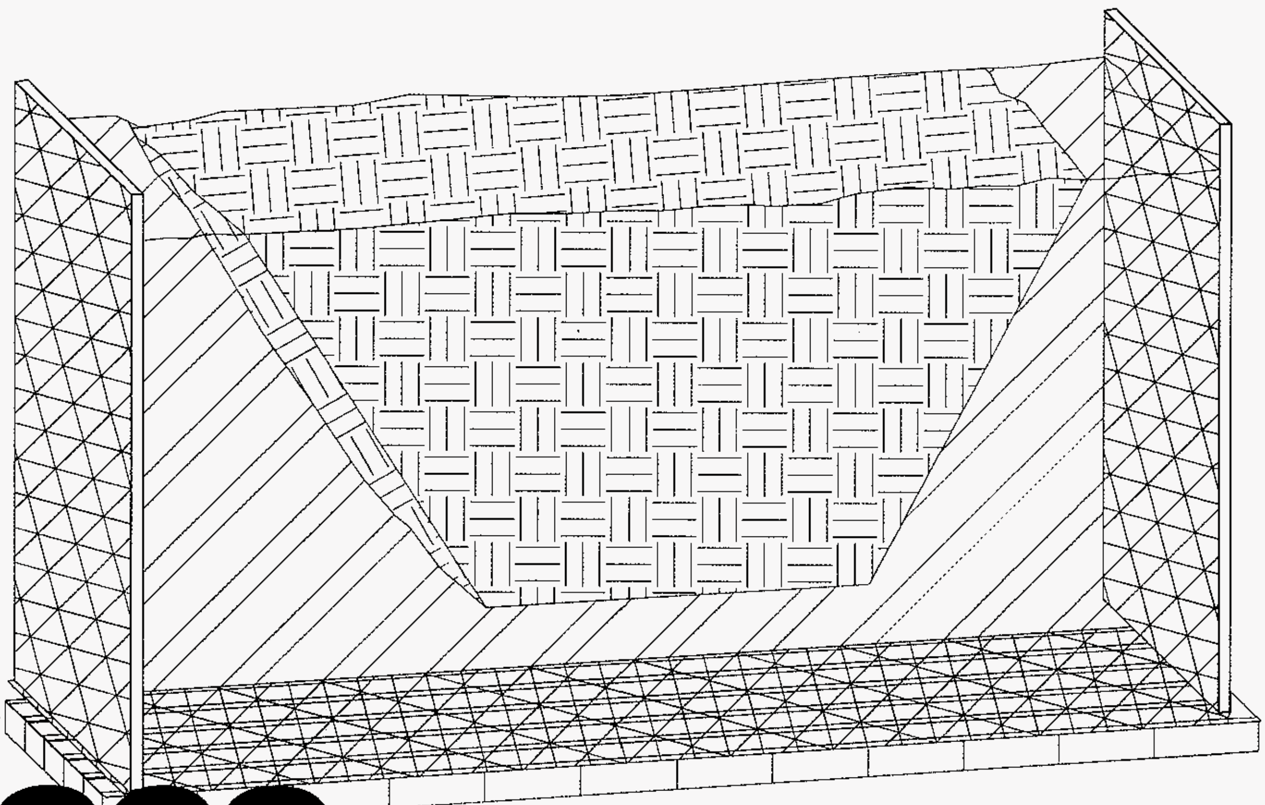
# DEMONSTRATION OF A SUBSURFACE CONTAINMENT SYSTEM FOR INSTALLATION AT DOE WASTE SITES

## U.S. DEPARTMENT OF ENERGY CONTRACT DE-AC26-99FT40363









2003 May

RAHCO International, Inc. • PO Box 7400 • Spokane, WA 99207 • Phone: 509-467-0770 • Fax: 509-466-0212

RAHCO International®

www.rahco.com

# DEMONSTRATION OF A SUBSURFACE CONTAINMENT SYSTEM FOR INSTALLATION AT DOE WASTE SITES

## PHASE I TOPICAL REPORT

## Volume I

**Reporting Period:**

September 1999-May 2003


**Principal Authors:**

Thomas J. Crocker & Verna M. Carpenter

**Submitted by:**

RAHCO International, Inc.
P.O. Box 7400
Spokane, Washington 99207


**21 May 2003**


**U.S. DEPARTMENT OF ENERGY**
**CONTRACT DE-AC26-99FT40363**

# DISCLAIMER

# ABSTRACT

Between 1952 and 1970, DOE buried mixed waste in pits and trenches that now have special cleanup needs. The disposal practices used decades ago left these landfills and other trenches, pits, and disposal sites filled with three million cubic meters of buried waste. This waste is becoming harmful to human safety and health. Today's cleanup and waste removal is time-consuming and expensive with some sites scheduled to complete cleanup by 2006 or later. An interim solution to the DOE buried waste problem is to encapsulate and hydraulically isolate the waste with a geomembrane barrier and monitor the performance of the barrier over its 50-yr lifetime. The installed containment barriers would isolate the buried waste and protect groundwater from pollutants until final remediations are completed.

The DOE has awarded a contract to RAHCO International, Inc.; of Spokane, Washington; to design, develop, and test a novel subsurface barrier installation system, referred to as a Subsurface Containment System (SCS). The installed containment barrier consists of commercially available geomembrane materials that isolates the underground waste, similar to the way a swimming pools hold water, without disrupting hazardous material that was buried decades ago. The barrier protects soil and groundwater from contamination and effectively meets environmental cleanup standards while reducing risks, schedules, and costs.

Constructing the subsurface containment barrier uses a combination of conventional and specialized equipment and a unique continuous construction process. This innovative equipment and construction method can construct a 1000-ft-long X 34-ft-wide X 30-ft-deep barrier at construction rates to 12 ft/day (8 hr/day operation). Life cycle costs including RCRA cover and long-term monitoring range from approximately \$380 to \$590/cu yd of waste contained or \$100 to \$160/sq ft of placed barrier based upon the subsurface geology surrounding the waste.

Project objectives for Phase I were to validate the SCS construction equipment and process, evaluate the system performance, validate the barrier constructability, and assess the barrier effectiveness. The objectives for Phase II, which is a full-scale demonstration at a DOE site, are to perform an extensive characterization of the test site, to demonstrate the equipment and the installation process under site-specific performance and regulatory requirements, to validate the operational performance of the equipment, and to perform long-term verification of the barrier using monitoring wells.

To date, significant progress has been made to establish the technical and economical feasibility of the SCS. This report describes the SCS conventional and specialized equipment, barrier materials, and construction process. It presents results of the specialized equipment Factory Test, the SCS Control Test and the SCS Advance Control Test at the RAHCO facility. Provided herein are the system performance capabilities and an estimated construction cost and schedule for a 1000-ft-long X 34-ft-wide X 29-ft-deep containment barrier at the DOE Oak Ridge Bear Creek Burial Grounds are also provided.

# EXECUTIVE SUMMARY

Several million cubic feet of radioactive and hazardous waste have been buried in shallow pits and trenches throughout the DOE complex. These pits and trenches were constructed similarly to municipal landfills, as illustrated in Figure A, with both stacked and random dump waste forms such as barrels and boxes. Many of the waste containers may be breached, leaking, or even unrecognizable because of deterioration and pose potential health and safety risks to workers and the public.

*Figure A Representative DOE Buried Waste Site*

RAHCO International, under DOE Contract DE-AC26-99FT40363, has developed a buried waste containment system, as illustrated in Figure B, that combines technology previously developed by the DOE[1,2] and the RAHCO-developed subsurface containment system (SCS) to encapsulate and hydraulically isolate the buried waste.

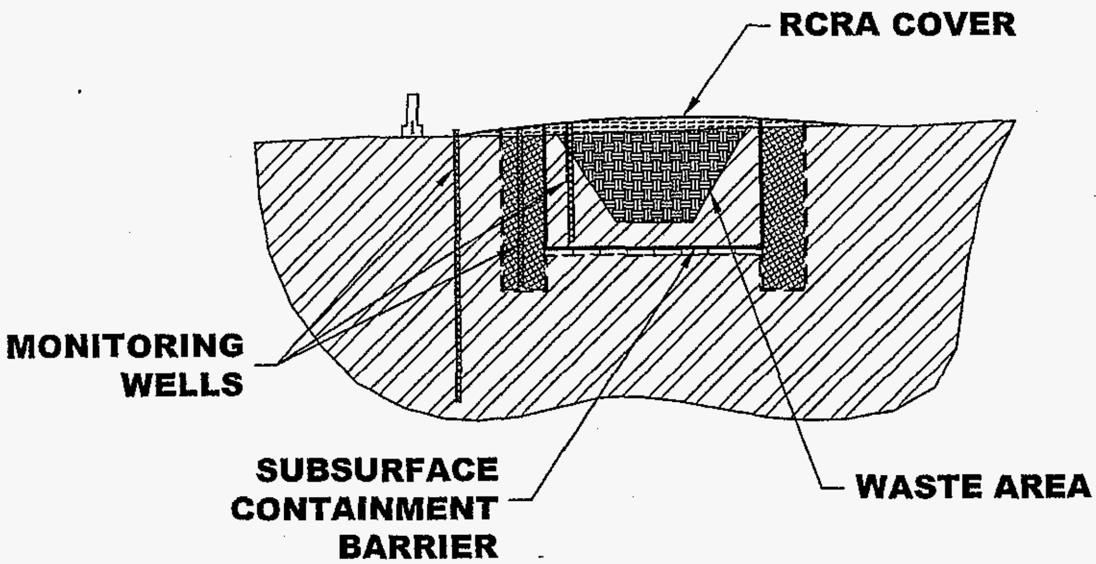



*Figure B Buried Waste Containment System*

[1]Long-Term Capping/Cover System, Sandia National Laboratories

[2]Vadose Zone Monitoring System, BNFL-Savannah River Company

The RAHCO-developed SCS uses conventional and specialized construction equipment, state-of-the-art geomembrane lining materials, and a unique construction method to install the subsurface containment barrier. The SCS uses a commercially available backhoe excavator to dig a 10-ft-wide trench around the perimeter of the waste area to depths of 35 ft and sequentially install 16-ft-long sections of a custom Slide-Rail Shoring System (SRS). This shoring provides personnel and equipment protection; allows access beneath the waste; and acts as a structural foundation for the Slot Construction Unit (SCU). In areas where basalt or hard rocks are found, special hammer equipment called Surestrike hammers can be used to fracture the rock. The specialized SCU then excavates a 12-in.-high, horizontal slot between the side trenches at a depth of 2-4 ft below the waste and installs a geosynthetic clay liner (GCL) supported on interlocking, precast concrete floor blocks. The additional space created by the cut can be filled with a 50% bentonite mix. The SCU is remotely operated from the Power and Control Unit (PCU) which is located on the ground surface. Following construction of the horizontal containment barrier, a mobile crane is used to sequentially install prefabricated, 16-ft-wide X 30-ft-high, interlocking panels of the vertical barrier walls. These panels are also constructed of geomembrane lining materials and horizontal-to-vertical barrier joint. The walls are mechanically attached into the precast concrete floor blocks to provide a continuous containment barrier. Finally, a backhoe excavator is used to backfill and compact the trench and remove the shoring. Construction of the subsurface barrier at rates up to 12 ft/day (8-hr/day operation) are achievable in 15 ksi soil/rock.

Figure C highlights key elements of the SCS at the RAHCO Control Test facility; Spokane, Washington. This photo shows a 16-ft-deep, modular shoring system surrounding a 34-ft-long X 34-ft-wide, engineered test bed. It also shows the SCU positioned on the support rails below the simulated waste area and the PCU connected to the SCU via the cable bundle.

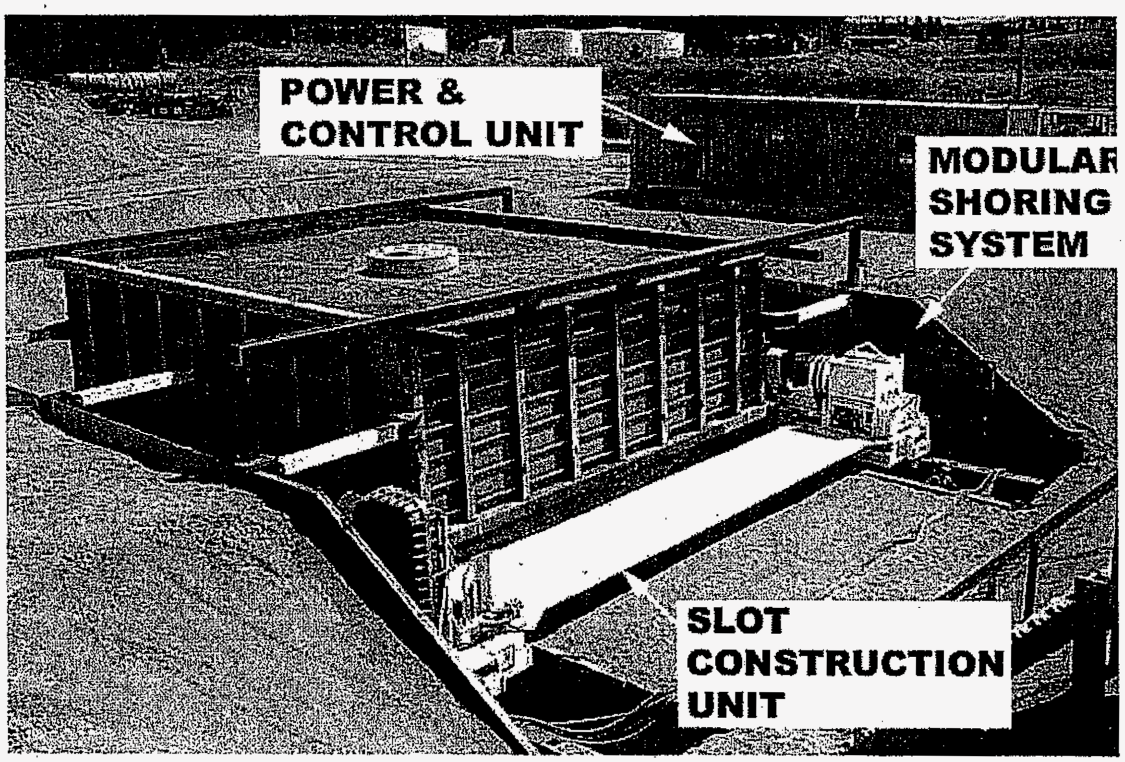



*Figure C Subsurface Containment System*

The RAHCO-developed SCS:

- Can be rapidly mobilized at minimally prepared sites and will not disturb the waste to be contained or adjoining waste areas.
- Is capable of constructing a subsurface containment barrier in varying geological conditions expected at DOE waste sites including hard rock, glacial till, and clay.
- Meets all DOE site health, safety, and environmental requirements and regulations.
- The installed barrier is designed to contain transuranic and hazardous buried waste for a period of 50 yrs with about 1% leakage by Volume with 3' head and limited monitoring requirements.

For a typical buried waste site such as the DOE Oak Ridge, Tennessee, Y-12 Bear Creek Burial Grounds, the SCS is capable of constructing a 1000-ft-long X 35-ft-wide X 30-ft-deep, subsurface containment barrier at an average construction rate of approximately 12 ft/day in an 8-hr/day operation (soil/rock strength of 15 ksi). This results in an 8-mo construction schedule. The estimated life cycle cost including a geomembrane cap and long-term monitoring system is approximately $10 million. This results in an estimated cost of approximately $420/cu yd of waste contained or $110/sq ft of placed containment barrier.

The SCS offers several benefits to the DOE, other governmental agencies, and commercial entities involved in buried waste remediation. Specifically, this system:

- **Provides a minimum interim solution for at least 50 years until treatment options and ultimate disposal issues are resolved.**

  Current buried waste remediation options including retrieve and treat, in situ remediation, and retrieve and dispose are either unproven or prohibitively expensive.
  To date, regulators and stakeholders have raised serious issues and expressed concerns regarding the health and safety risk to workers and the public and/or the long-term effectiveness of these buried waste remediation alternatives. The SCS provides a state-of-the-art, low-cost interim solution that protects worker and public safety while long-term solutions are being investigated and funding secured.

- **Minimizes near-term site reclamation activities.**

  Implementation of current buried waste remediation alternatives require extensive reclamation activities including full-scale characterization of the waste, extensive site preparation, construction of temporary and permanent facilities, and wide-spread construction activities. The SCS requires minimal site characterization and site preparation, needs no permanent structures or facilities, and requires minimal construction activities.

- **Is economically competitive with other remediation methods.**

  Depending on soil/rock strength, life cycle costs range from $380-$530/per cu yd of waste contained, or $100-$140/sq ft of placed barrier. The SCS is economically attractive and is approximately 10 times less expensive than the retrieve-and-treat option.

During Phase I of this contract effort, advanced engineering design identified the conventional and specialized construction equipment, materials, and process used to construct a subsurface containment barrier that meets all DOE performance and ESH requirements.

A Factory Test of the Slot Construction Unit (SCU) was conducted at the RAHCO facility in January and February 2001. This test successfully demonstrated equipment safety features and the capabilities of the SCU to perform its three primary equipment functions: excavate a 12-in., horizontal slot in soil/rock; install the precast concrete floor blocks; and install an 80-mil, geosynthetic clay liner on top of the floor blocks. Several minor design issues were identified and changes implemented. Test results also verified that the SCU has the capability to construct a horizontal containment barrier at rates to 12 ft/day in soft soils.

A Control Test of the SCS was conducted at the RAHCO facility in June and July 2001. This test safely and successfully installed the modular shoring system and constructed a 4-ft-long X 34-ft-wide horizontal containment barrier in an engineered test bed that simulated the subsurface geology at DOE sites. Test results demonstrated that the modular shoring system could be safely and rapidly installed; provided satisfactory ground support; and successfully supported the SCU. Results also confirmed that the remotely operated SCU could successfully excavate a horizontal slot in typical DOE soils and place a horizontal containment barrier. A Visitor's Day was held on 26 July for DOE, EPA, congressional delegation staff, and others to view the Control Test operations.

RAHCO has made significant progress towards establishing both the technical and economic feasibility of the SCS. Specialized construction equipment including the Slide-Rail Shoring System, the Slot Construction Unit, and the Power and Control Unit have been designed, manufactured, and tested. Construction procedures have been defined and two of the four major construction operations have been demonstrated successfully, namely: 1) excavate trench and install shoring and 2) horizontal barrier construction. Preliminary cost and schedule estimates have been developed.

Following Peer and ASME reviews of the system, there was significant interest in this containment technology and a number of candidate waste sites have been identified. However, end users expressed concerns regarding the effectiveness of the containment barrier and requested data substantiating the hydraulic effectiveness of the installed barrier be collected. RAHCO agreed and recommended continued development in FY02 to verify the effectiveness of the installed containment barrier in the following areas: 1) complete construction of the horizontal containment barrier; 2) design, manufacture, and test the vertical barrier and the horizontal-to-vertical joint; 3) verify the hydraulic effectiveness of the containment barrier; and 4) identify a full-scale demonstration site. Considering all four of these areas, RAHCO started an Advance Control Test in July of 2002. This test consisted of three primary parts: vertical-to-horizontal joint bench level tests; construction of the horizontal barrier; and installation of the vertical walls with follow on hydraulic testing.

- **Vertical-to-horizontal Joint Bench Level Tests**

  A series of bench level tests proved a viable configuration of hydrophilic products for the horizontal-vertical joint. This family of hydrophilic products provided effective hydraulic sealing and chemical resistance for the vertical-to-horizontal joint. We then filled the test stand with water and with the combination of all these components we finally did achieve satisfactory results.

- **Finished Construction of the Horizontal Barrier**

  The horizontal slot was cut and horizontal barrier laid by the SCU. (See the CD for actual footage.) Changes made to the SCU included more effective instrumentation controls and a more automated interface. Performance testing of these changes were completed during the actual operation. The SCU consistently performed at 200 fps. The completion of the horizontal barrier was accomplished by late September. The SCU worked very well and RAHCO is satisfied that the machine is ready to complete Phase II at a DOE site.

- **Vertical Walls Installed and Hydraulic Testing**

  The design of the vertical barrier wall frames was essential for handling and installation. They support the existing vertical geomembranes, their vertical joint configuration; and the vertical-to-horizontal joint materials. The frames have a slip-lock design for ease of installation that coincides with the interlocking joints of the vertical geomembrane. The final design provided for the ease of installation and handling.

  After the initial installation, the need for the redesign of the vertical wall slip-lock design to be more tolerant was necessary. When the test bed floor was damaged from people walking on it while wet, a second test bed was built and all the changes identified as a result of the first test were incorporated into this test. This test bed was 16-ft by 26-ft by. Changes made for this test were: more flexible interlocking joints on the vertical frames; two rows of Hydrotite CJ-3030-M for redundancy; Hydrotite caulking in the outermost vertical interlocking joint; and bentontite along the horizontal-vertical joint.

  Once the test area was fully assembled, the test bed was filled with water. The test bed did not need the full 3-days to settle in. Within one day, the products sealed up any construction imperfections and provided the hydraulic isolation necessary to prevent any leaks. Leaks tapered off to about 1% by volume with almost a 3' head. The bentonite used in the full installation plan would eliminate the small leakage noted in testing.

The completion of the Advance Control Test has demonstrated that RAHCO can and has proven their ability to construct a containment barrier that provides the hydraulic isolation necessary to sustain hazardous waste in situ. It is RAHCO's intent to provide DOE end users, federal and state regulators, and local stakeholders with information to evaluate the applicability of this containment technology for specific site remediation actions. We have identified several sites with interested DOE endusers to conduct of a full-scale demonstration as planned in Phase II of this contract effort.

# TABLE OF CONTENTS

VOLUME I -

| Section | Description | Page |
|---|---|---|
| | ABSTRACT | iii |
| | EXECUTIVE SUMMARY | iv |
| | LIST OF FIGURES | xii |
| | LIST OF TABLES | xvi |
| 1.0 | INTRODUCTION | 1 |
| | 1.1 Subsurface Containment System (SCS) | 1 |
| | 1.2 SCU Factory Test | 4 |
| | 1.3 SCS Control Test & Advanced Control Test | 6 |
| | 1.4 SCS Performance Capabilities | 8 |
| | 1.5 Construction Cost & Schedule | 8 |
| 2.0 | RESULTS & DISCUSSION | 11 |
| | 2.1 Equipment Description | 12 |
| | 2.1.1 Conventional Construction Equipment | 12 |
| | 2.1.2 Specialized Construction Equipment | 13 |
| | 2.1.2.1 Slide-Rail Shoring System (SRS) | 13 |
| | 2.1.2.2 Slot Construction Unit | 16 |
| | 2.1.2.3 Power & Control Unit | 24 |
| | 2.2 Barrier Materials | 33 |
| | 2.2.1 Geosynthetic Barrier Materials | 33 |
| | 2.2.2 Precast Concrete Floor Blocks | 36 |
| | 2.3 Construction Process | 37 |
| | 2.3.1 Mobilization | 38 |
| | 2.3.1.1 Prepare Site | 38 |
| | 2.3.1.2 Mobilize Equipment & Materials | 39 |
| | 2.3.2 Construct Subsurface Barrier | 41 |
| | 2.3.2.1 Excavate Trench & Install Shoring | 43 |
| | 2.3.2.2 Construct Horizontal Barrier | 46 |
| | 2.3.2.3 Install Vertical Barrier | 51 |
| | 2.3.2.4 Backfill Trench & Remove Shoring | 52 |
| | 2.3.3 Demobilization | 52 |

## TABLE OF CONTENTS (Continued)

| Section | Description | Page |
|---|---|---|
| 2.4 | Factory Test | 54 |
| 2.4.1 | Test Hardware & Materials | 54 |
| 2.4.2 | Test Results | 55 |
| 2.4.2.1 | . SCU-1: Safety Assessment & Emergency Stop Test | 55 |
| 2.4.2.2 | . SCU-2: Excavation & Steering Test | 57 |
| 2.4.2.3 | . SCU-3: Thrusting & Rail Lock Test | 60 |
| 2.4.2.4 | . SCU-4: Block Insertion & Alignment Test | 61 |
| 2.4.2.5 | . SCU-5: Polyliner Insertion Test | 64 |
| 2.4.2.6 | . SCU-6: System Performance Test #1 | 66 |
| 2.4.3 | Summary & Conclusions | 67 |
| 2.5 | Control Test | 68 |
| 2.5.1 | Scope of Test | 68 |
| 2.5.2 | Test Site Description | 68 |
| 2.5.3 | Engineered Test Bed | 70 |
| 2.5.4 | Test Execution | 71 |
| 2.5.4.1 | . Test CT-1: System Safety & Environmental Assessment | 73 |
| 2.5.4.2 | Test CT-2: Shoring System Functional Tests | 73 |
| 2.5.4.3 | Test CT-3: SCU Performance Tests | 77 |
| 2.6 | Performance Capabilities | 85 |
| 2.6.1 | SCS Construction Rate | 86 |
| 2.6.2 | Excavate & Install Shoring | 87 |
| 2.6.3 | Install Horizontal Barrier | 90 |
| 2.6.4 | Install Vertical Barrier | 93 |
| 2.6.5 | Backfill Trench & Remove Shoring | 94 |
| 2.7 | Construction Cost & Schedule | 95 |
| 2.7.1 | Subsurface Geological Conditions | 95 |
| 2.7.2 | Accessability | 97 |
| 2.7.3 | Construction Assumptions | 97 |
| 2.7.4 | Preliminary Cost Estimate | 97 |
| 2.7.5 | Preliminary Construction Schedule | 97 |
| 2.8 | Advanced Control Test | 99 |
| 2.8.1 | Advanced Control Test Description | 99 |
| 2.8.1.1 | Executive Summary | 99 |
| 2.8.1.2 | Test Location & Schedule | 99 |
| 2.8.1.3 | Advance Control Test Scope | 99 |

## TABLE OF CONTENTS (Continued)

**Section Description** **Page**

2.8.2 Results & Discussion ........ 100

2.8.2.1 Barrier Materials ........ 100

2.8.2.1.1 Horizontal Barrier ........ 100
2.8.2.1.2 Vertical Perimeter Barrier ........ 101
2.8.2.1.3 Horizontal-Vertical Joint ........ 102
2.8.2.1.4 Precast Concrete Floor Blocks ........ 103

2.8.3 Advanced Control Test ........ 103

2.8.3.1 Scope of Tests ........ 103
2.8.3.2 Test Site Description ........ 104
2.8.3.3 Engineered Test Bed ........ 104
2.8.3.4 Test Execution ........ 105

2.8.3.4.1 Test ACT-1: System Safety & Environmental Assessment ........ 106
2.8.3.4.2 Test ACT-2: Vertical Perimeter Barrier Installation Test ........ 106
2.8.3.4.3 Test ACT-3: Passive Hydraulic Test ........ 108

2.8.4 Test Operations ........ 109

2.8.4.1 Mobilize Equipment & Materials ........ 109
2.8.4.2 Demobilize & Restore Site ........ 109

**3.0 CONCLUSIONS ........ 110**

**LIST OF ACRONYMS ........ 112**

**Appendix 1 SCS Performance Analysis ........ 1-1**
**Appendix 2 SCS Cost Analysis ........ 2-1**

**<u>VOLUME II</u> -**

**Appendix 3 Control Test Operational Plan/Work Plan ........ 3-1**
**Appendix 4 Engineering Drawing Package ........ 4-1**
**Appendix 5 Advanced Control Test Operational Plan/Work Plan ........ 5-1**
**Appendix 6 SCU Factory Test Quick-Look Report ........ 6-1**
**Appendix 7 Hydraulic Bench-Level Test Quick-Look Report ........ 7-1**
**Appendix 8 Perimeter Barrier Installation Test Quick-Look Report ........ 8-1**
**Appendix 9 Bench-Level Hydraulic Test with Six-Foot Box Quick-Look Report ........ 9-1**
**Appendix 10 Barrier Validation Hydraulic Test Quick-Look Report ........ 10-1**

# LIST OF FIGURES


| Figure | Description | Page |
|---|---|---|
| A | Representative DOE Buried Waste Site | iv |
| B | Buried Waste Containment System | iv |
| C | Subsurface Containment System | v |
| 1-1 | SCS Specialized Construction Equipment | 2 |
| 1-2 | Subsurface Containment Barrier | 2 |
| 1-3 | Barrier Construction Operations | 3 |
| 1-4 | Slot Construction Unit | 4 |
| 1-5 | Inserted Geosynthetic Clay Liner | 5 |
| 1-6 | Remote Operator Control Station | 5 |
| 1-7 | Engineered Test Bed | 6 |
| 1-8 | Cobbles & Boulders | 6 |
| 1-9 | Side Shoring Installation | 7 |
| 1-10 | Horizontal Containment Barrier Construction | 7 |
| 1-11 | SCS Construction Rate | 8 |
| 1-12 | 50-yr Life Cycle Cost | 9 |
| 1-13 | Cost/Cubic Yard of Waste Contained | 9 |
| 1-14 | Cost/Square Foot of Placed Barrier | 9 |
| 1-15 | Construction Duration | 10 |
| 2.1-1 | Excavator with Bucket End Effector | 12 |
| 2.1-2 | Portable Extrusion Welder | 13 |
| 2.1-3 | Slide-Rail Shoring System | 13 |
| 2.1-4 | Shoring System Components | 14 |
| 2.1-5 | Slide-Rail Panels | 14 |
| 2.1-6 | Linear Slide-Rail | 15 |
| 2.1-7 | Crossbrace Support Layout | 15 |
| 2.1-8 | SCU Layout | 16 |
| 2.1-9 | Slot Construction Unit | 17 |
| 2.1-10 | Beam Structure | 18 |
| 2.1-11 | Cutterhead Assembly | 18 |
| 2.1-12 | Cutterhead Layout | 19 |
| 2.1-13 | Cutterhead Drive Layout | 19 |
| 2.1-14 | Cutterhead Cleaner Layout | 20 |
| 2.1-15 | Thrusting Unit Layout | 20 |
| 2.1-16 | Block Inserter Layout | 21 |
| 2.1-17 | Block Inserter | 21 |
| 2.1-18 | Alignment Jack Layout | 22 |
| 2.1-19 | Polyliner Inserter Layout | 22 |
| 2.1-20 | Polyliner Inserter | 23 |

# LIST OF FIGURES (Continued)


| Figure | Description | Page |
|---|---|---|
| 2.1-21 | SCU Beam Instrumentation Layout | 23 |
| 2.1-22 | Inserter Instrumentation Layout | 24 |
| 2.1-23 | Power & Control Unit Layout | 24 |
| 2.1-24 | Power Distribution | 25 |
| 2.1-25 | Operator Control Station | 25 |
| 2.1-26 | Human-Machine Interface Screen | 26 |
| 2.1-27 | Cutterhead Control Screen | 27 |
| 2.1-28 | Index Control Screen | 28 |
| 2.1-29 | Automated Cut-Index Screen | 28 |
| 2.1-30 | Alignment Jack Control Screen | 29 |
| 2.1-31 | Block Placement Screen | 29 |
| 2.1-32 | Polyliner Placement Screen | 30 |
| 2.1-33 | Maintenance Screen | 30 |
| 2.2-1 | Subsurface Containment Barrier | 33 |
| 2.2-2 | Barrier Joint Detail | 35 |
| 2.2-3 | Precast Concrete Floor Block Layout | 36 |
| 2.3-1 | SCS Construction Flow Diagram | 37 |
| 2.3-2 | Typical Site Mobilization | 40 |
| 2.3-3 | Barrier Construction Operations | 41 |
| 2.3-4 | Detail Construction Flow Diagram | 42 |
| 2.3-5 | Excavate Trench & Install Shoring | 43 |
| 2.3-6 | Typical Shoring System Installation | 44 |
| 2.3-7 | Excavate Pilot Cut & Place Slide Rail | 44 |
| 2.3-8 | Install Panels & Rails | 44 |
| 2.3-9 | Excavate Trench | 45 |
| 2.3-10 | Position Rails & Panels | 45 |
| 2.3-11 | Install Stacker Rails & Panels | 45 |
| 2.3-12 | Excavate & Position Rails & Panels | 45 |
| 2.3-13 | Excavate & Install Components | 45 |
| 2.3-14 | Position Stacking Shoring | 45 |
| 2.3-15 | Construct Horizontal Barrier | 46 |
| 2.3-16 | SCU Installation | 47 |
| 2.3-17 | Stop Block Installation | 47 |
| 2.3-18 | Slot Excavation | 48 |
| 2.3-19 | Position Alignment Beam | 49 |
| 2.3-20 | Insert Floor Blocks | 49 |
| 2.3-21 | Insert GCL | 50 |
| 2.3-22 | Position GCL | 50 |

## LIST OF FIGURES (Continued)


| Figure | Description | Page |
|---|---|---|
| 2.3-23 | Verify GCL Position | 51 |
| 2.3-24 | Install Vertical Barrier | 51 |
| 2.3-25 | Backfill Trench & Remove Shoring | 52 |
| 2.4-1 | Factory Test Equipment | 54 |
| 2.4-2 | SCU & Horizontal Barrier | 55 |
| 2.4-3 | Cutterhead Assembly | 58 |
| 2.4-4 | Blocks & Polyliner Inserted into Beam Structure | 63 |
| 2.4-5 | Inserted Geosynthetic Clay Liner | 67 |
| 2.5-1 | Control Test Site Layout | 69 |
| 2.5-2 | Detailed Test Site Layout | 69 |
| 2.5-3 | Engineered Test Bed Layout | 70 |
| 2.5-4 | Test Bed Construction | 70 |
| 2.5-5 | Test Bed Soils | 71 |
| 2.5-6 | Layout of Horizontal Barrier | 72 |
| 2.5-7 | Installation of Lower Side Shoring | 73 |
| 2.5-8 | Installation of Upper Side Shoring | 74 |
| 2.5-9 | Installation of SCU Support Rails & Inner Shoring System | 74 |
| 2.5-10 | SCU Transport & Placement | 78 |
| 2.5-11 | SCU Checkout | 79 |
| 2.5-12 | Horizontal Slot Excavation | 79 |
| 2.5-13 | Horizontal Barrier Placement | 79 |
| 2.5-14 | Excavation Time | 83 |
| 2.5-15 | Indexing Time | 83 |
| 2.5-16 | SCS Visitor Day | 84 |
| 2.6-1 | Subsurface Containment Barrier Configuration | 85 |
| 2.6-2 | SCS Construction Rate | 86 |
| 2.6-3 | Major Operations Construction Rate | 87 |
| 2.6-4 | Excavate Trench & Install Shoring Construction Rate | 88 |
| 2.6-5 | Bucket Fill Factor | 88 |
| 2.6-6 | Hydraulic Hammer Production Rate | 89 |
| 2.6-7 | Excavator Bucket Fill Time | 89 |
| 2.6-8 | Shoring Penetration Rate | 90 |
| 2.6-9 | Horizontal Barrier Construction Rate | 91 |
| 2.6-10 | Cutterhead Speed Versus Soil/Rock Strength | 91 |
| 2.6-11 | Cutterhead Penetration Versus Soil/Rock Strength | 92 |
| 2.6-12 | SCU Cycle Time Versus Soil/Rock Strength | 93 |

# LIST OF FIGURES (Continued)

| Figure | Description | Page |
|---|---|---|
| 2.6-13 | Install Vertical Barrier Wall Versus Soil/Rock Strength | 93 |
| 2.6-14 | Backfill Trench & Remove Shoring Versus Soil/Rock Strength | 94 |
| 2.7-1 | Bear Creek Valley Burial Grounds | 95 |
| 2.7-2 | Subsurface Geological Conditions | 96 |
| 2.7-3 | Construction Schedule | 98 |
| 2.8-1 | Vertical Wall Frames | 101 |
| 2.8-2 | Hydraulic Joint Construction Details | 103 |
| 2.8-3 | Engineered Test Bed | 105 |

# LIST OF TABLES


| Table | Description | Page |
|---|---|---|
| 2.1-1 | Equipment Description List | 12 |
| 2.1-2 | SCU Operating Functions | 27 |
| 2.1-3 | Alarm Type, Notification, & System Response | 31 |
| 2.2-1 | GCL Specifications | 34 |
| 2.3-1 | Mobilization | 38 |
| 2.3-2 | Construct Subsurface Barrier | 43 |
| 2.3-3 | Demobilization | 52 |
| 2.4-1 | SCU-2 Data Collection Requirements | 57 |
| 2.4-2 | Excavation & Steering Test Checklist | 58 |
| 2.4-3 | Problems & Corrective Action | 59 |
| 2.4-4 | SCU-3 Data Collection Requirements | 60 |
| 2.4-5 | Thrusting & Rail Lock Test Checklist | 61 |
| 2.4-6 | Problems & Corrective Action | 61 |
| 2.4-7 | SCU-4 Data Collection Requirements | 62 |
| 2.4-8 | Block Insertion & Alignment Test Checklist | 63 |
| 2.4-9 | Problems & Corrective Action | 64 |
| 2.4-10 | SCU-5 Data Collection Requirements | 65 |
| 2.4-11 | Polyliner Insertion Test Checklist | 65 |
| 2.4-12 | Problems & Corrective Action | 66 |
| 2.4-13 | SCU-6 Data Collection Requirements | 66 |
| 2.5-1 | Engineered Soils | 71 |
| 2.5-2 | Control Test Matrix | 72 |
| 2.5-3 | Shoring System Checklist | 75 |
| 2.5-4 | Trench Excavation Data | 75 |
| 2.5-5 | Shoring System Installation Timeline Data | 76 |
| 2.5-6 | Calculated Shoring System Installation Time | 77 |
| 2.5-7 | SCU Performance Test Matrix | 78 |
| 2.5-8 | SCU Functional Checklist | 80 |
| 2.5-9 | Problems & Corrective Action | 82 |
| 2.5-10 | SCU Performance Times | 83 |
| 2.6-1 | SCS Construction Rate Assumptions | 85 |
| 2.6-2 | Cutterhead Operating Characteristics | 92 |
| 2.7-1 | Construction Assumptions | 97 |
| 2.7-2 | Oak Ridge Construction & Life Cycle Costs | 97 |

# LIST OF TABLES (Continued)


| Table | Description | Page |
|---|---|---|
| 2.8-1 | Chloroprene Rubber Products | 102 |
| 2.8-2 | Engineered Soils | 104 |
| 2.8-3 | Advance Control Test Matrix | 105 |
| 2.8-4 | Perimeter Barrier Installation Test Checklist | 107 |
| 2.8-5 | Perimeter Barrier Installation | 107 |
| 2.8-6 | SCS Perimeter Barrier Performance Data | 108 |

# SECTION 1.0
# INTRODUCTION

DOE end users consistently identify long-term containment of buried waste as an unaddressed technology need. This technical issue requires the ability to construct a low-cost containment barrier to encapsulate the waste and provide a monitoring system to verify its long-term effectiveness.

Since 1994, RAHCO International, with support from the DOE, has developed a buried waste containment system. RAHCO's current contract, Demonstration of a Subsurface Containment System for Installation at DOE Waste Sites, is funded by DOE Contract DE-AD-26-99FT40363, Phase I is intended to perform advanced engineering design and a Factory/Control Test of the Subsurface Containment System (SCS) at RAHCO's facility in Spokane, Washington. Phase II will conduct a full-scale demonstration at a DOE site. This report describes the results of the Phase I effort.

The buried waste containment system consists of a subsurface containment barrier, a RCRA cover, and a long-term monitoring system. The RAHCO-developed, subsurface containment barrier consists of a high-density polyethylene (HDPE) geomembrane material integrated into a continuous, nearly impermeable barrier that surrounds the buried waste. The resulting subsurface containment barrier can be up to 100-ft wide, of unlimited length, and constructed at depths to 30 ft and has an estimated life expectancy to 50 yrs. Low-cost RCRA covers and the long-term monitoring system have been the subjects of previous DOE development efforts.

RAHCO's approach to constructing the subsurface containment barrier features several innovations that expand upon the capabilities of the current state-of-the-art for trenching, underground mining and tunneling, and placing geosynthetic liners. The following describes the equipment, materials, and process used.

## 1.1 SUBSURFACE CONTAINMENT SYSTEM (SCS)

The SCS uses a combination of conventional and specialized construction equipment; state-of-the-art geomembrane lining materials; and an innovative construction method to construct the subsurface barrier. This system uses conventional construction equipment including a backhoe excavator, front end loader, mobile cranes, and transport trucks. The specialized equipment used consists of the custom Slide-Rail Shoring (SRS) and the RAHCO-developed Slot Construction Unit (SCU) and Power and Control Unit (PCU). The custom, modular shoring (as illustrated in Figure 1-1) allows access beneath the waste area and provides personnel and equipment protection and structural support for the SCU. The remotely operated SCU spans between the two side trenches and travels along rails attached to the shoring system. This unit excavates a 12-in.-high, horizontal slot beneath the waste area; discharges the spoils into the side trenches; and installs a geomembrane liner supported by precast concrete blocks in the excavated slot. The PCU distributes electrical power and houses the SCU operator control station.

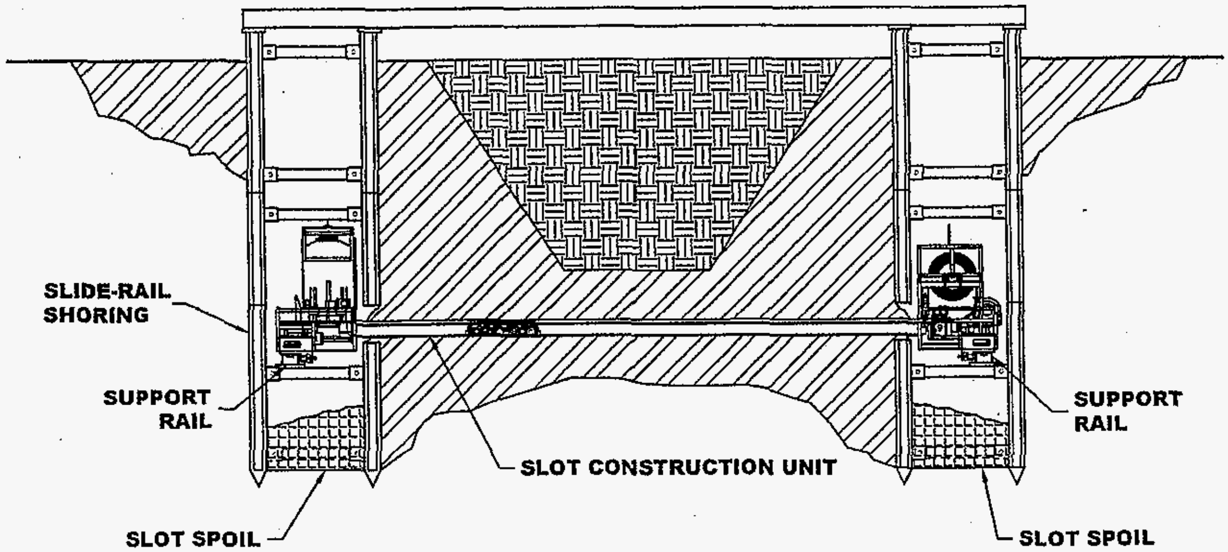



*Figure 1-1 SCS Specialized Construction Equipment*

The subsurface containment barrier, as illustrated in Figure 1-2, consists of a horizontal and a vertical barrier and the horizontal-vertical joint. The horizontal barrier is an 80-mil, geosynthetic clay liner (GCL) placed in 30-in.-wide strips with a 6-in.-wide overlap that spans the width of the barrier. The 6-in. overlap, combined with the bentonite clay which swells with moisture, provides the horizontal joint seal. The vertical barrier is constructed of 100-mil, high-density polyethylene (HDPE) fabricated into 16-ft-wide panels and joined together by standard geosynthetic interlocks. Joining of the horizontal and vertical barriers relies on a special joint design.

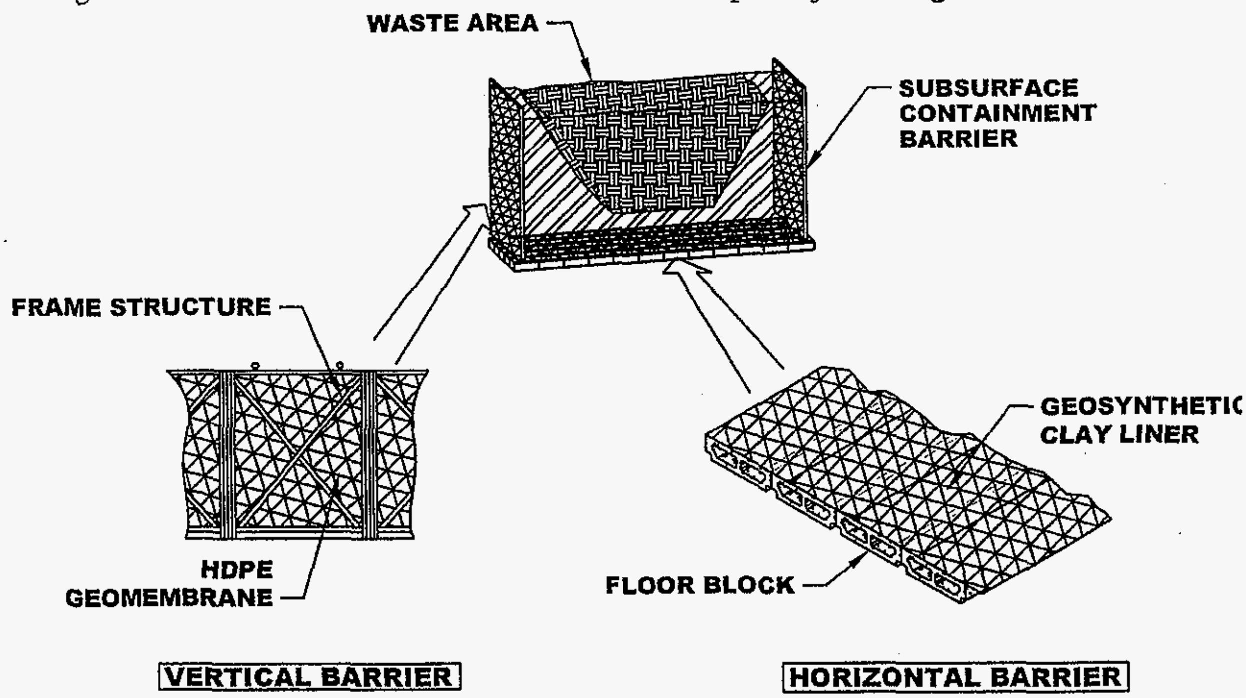



*Figure 1-2 Subsurface Containment Barrier*

Construction of the subsurface containment barrier relies upon the execution of four construction operations. These four operations are:

1. Excavate Trench & Install Shoring
2. Construct Horizontal Barrier
3. Install Vertical Barrier
4. Backfill Trench & Remove Shoring

Figure 1-3 highlights these operations.

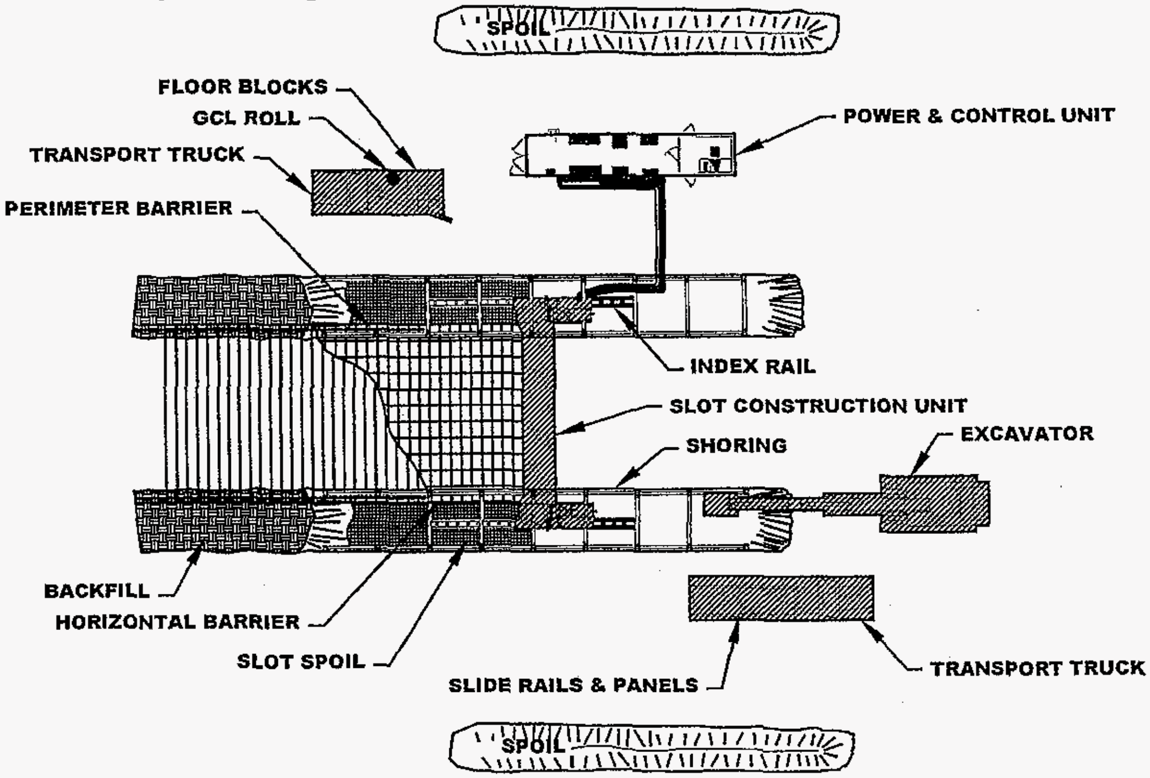



*Figure 1-3 Barrier Construction Operations*

For trenching and shoring installation, a backhoe excavator with end effectors is used to excavate a 10-ft-wide and up to 35-ft-deep trench around the waste area and a front end loader is used to stockpile the excavated materials. This excavator is also used to install and position the modular shoring and indexing rail which is integral to the lower cross members. For horizontal barrier installation, two 200-ton cranes are used to place the SCU in the end trench. The Slot Construction Unit supported by the Power and Control Unit installs the GCL horizontal barrier at depths to 30 ft below the ground surface. Following this step, a mobile crane is used to install the 16-ft-wide, interlocking, vertical geomembrane panels with the horizontal-vertical joint attached. In the final construction operation, the trench backfill and shoring removal operation, the excavator with end effectors, front end loader, and mobile crane are used to backfill and compact the trench and remove the shoring. This construction process proceeds in a concurrent and continuous manner with the open construction area minimized to 100-ft long X 60-ft wide.

The SCS incorporates safety features including: remote operation of the SCU; below-grade, explosion-proof equipment enclosures; strategically located emergency stops; audio and visual alarm notification; sound levels less than 85 dB; and a positive means to prevent operation during maintenance. The system's environmental features include: minimum use of fluids and greases with accompanying containment and conformation with 10 CFR Part 61. Specifically, the barrier system minimizes the escape of hazardous wastes to the ground or surface waters, or to the atmosphere. It uses materials having appropriate properties to prevent failure due to pressure gradients up to 30 feet deep. The polyliner is inspected during construction for uniformity, damage, and imperfections (holes, cracks, thin spots, foreign materials); and vertical seams and joints are inspected to ensure the absence of tears, punctures, or blisters.

A detailed description of the SCS is provided in Sections 2.1, 2.2, and 2.3 of this report.

## 1.2 SCU FACTORY TEST

Testing of the Slot Construction Unit was conducted at the RAHCO facilities; Spokane, Washington; during the period of 27 February to 8 March 2001. The test objectives were to verify that the SCU and PCU could be safely operated; verify equipment design principles; validate the functional performance of the major subassemblies; and obtain system performance data. The test hardware included the Slot Construction Unit (SCU), as shown in Figure 1-4, and the Power and Control Unit (PCU).

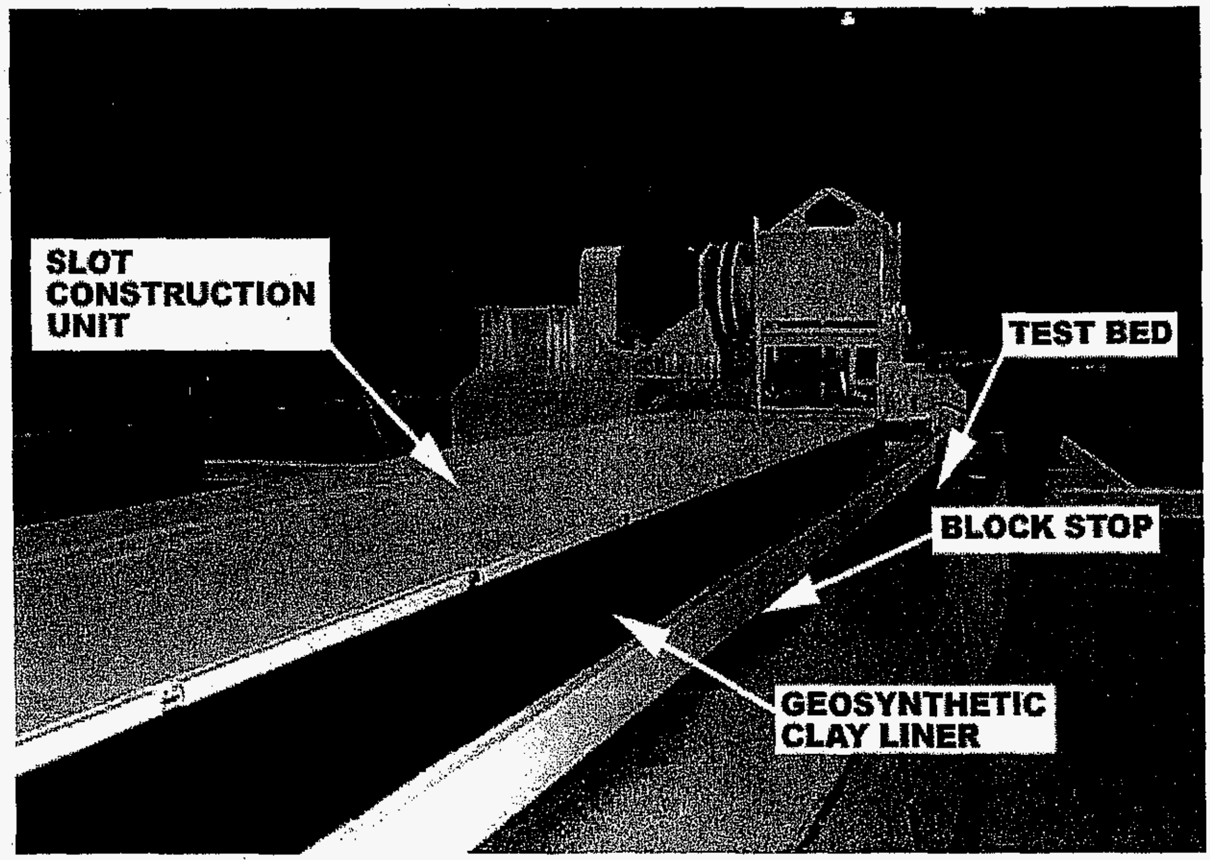



*Figure 1-4 Slot Construction Unit*

The test materials included 150-ft rolls of 30-in.-wide, 80-mil, geosynthetic clay liners (GCL) and 37-in.-long X 24-in.-wide X 7-in.-high precast concrete floor blocks. Figures 1-5 and 1-6 show the installed floor blocks and liner and the remote operator control station.

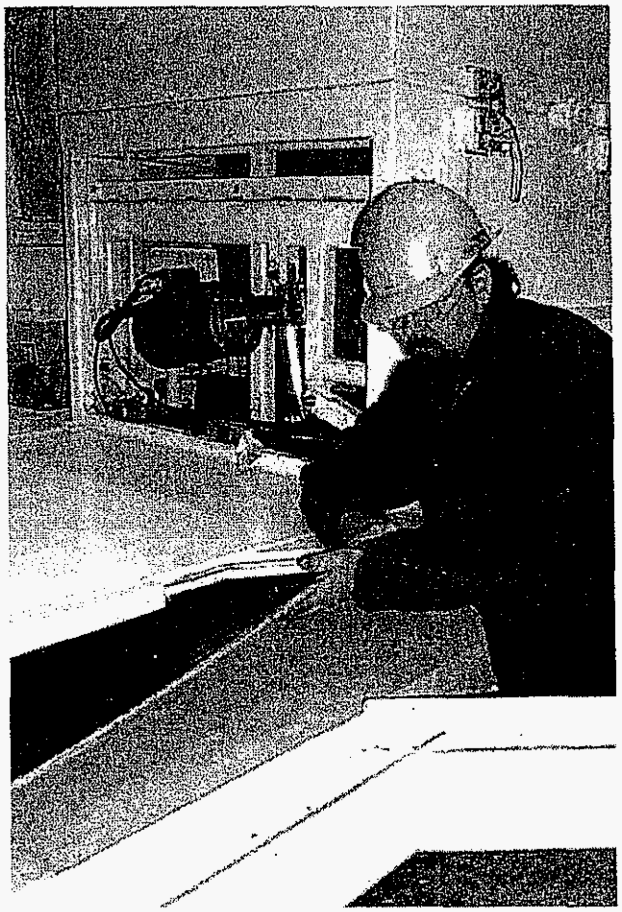


*Figure 1-5 Inserted Geosynthetic Clay Liner*

*Figure 1-6 Remote Operator Control Station*

A total of seven tests were successfully performed. Testing of the SCU and PCU identified several minor design issues that required corrective action and provided SCU system performance data as discussed in Section 2.4. Based upon test results, it was concluded that the upgraded SCU was capable of installing the 35-ft-wide, horizontal containment barrier at rates to 12 ft/day in an 8-hr operating day.

The SCU Factory Test was a success for several reasons:

1. It was conducted safely and met all the stated test objectives.

2. It demonstrated that the SCU subsystems functioned as planned.

3. It verified key SCU design principles; i.e., horsepower and speed.

4. It demonstrated that the SCU could safely and successfully install a horizontal containment barrier within the desired construction tolerances of ±2 in.

A detailed description of the Factory Test is provided in Section 2.4.

## 1.3 SCS CONTROL TEST & ADVANCED CONTROL TEST

The SCS Control Test was performed at the RAHCO facility, Spokane, Washington, during the period of 1 June to 26 July 2001. The objective of this test was to establish the feasibility of the SCS to construct a horizontal containment barrier in a controlled subsurface environment. The specific test objectives were to: 1) verify safe operation, 2) confirm ease of operation, 3) obtain operating performance data, and 4) validate barrier effectiveness.

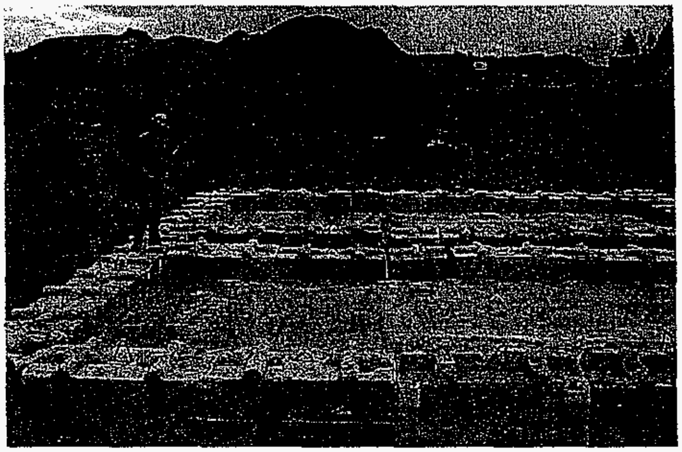


*Figure 1-7 Engineered Test Bed*

The 29-ft-wide X 34-ft-long X 4-ft high, engineered test bed, as shown in Figure 1-7, was constructed into four zones to simulate varying DOE subsurface site conditions. Each zone consisted of varying amounts of sands, crushed aggregate, cobbles, boulders, and cement as shown in Figure 1-8.

*Figure 1-8 Cobbles & Boulders*

The test equipment included conventional construction equipment and the custom Slide-Rail Shoring, the RAHCO-designed and manufactured Slot Construction Unit, and the Power and Control Unit. The construction materials include the GCL and precast concrete floor blocks.

A total of four tests were planned. Test CT-1 was intended to perform a safety and environmental assessment. Test CT-2 was designed to evaluate the shoring equipment and installation process. Test CT-3 was intended to demonstrate the ability of the SCU to install the horizontal containment barrier and Test CT-4 was planned to validate the effectiveness of the GCL barrier. CT-1 and CT-2 were successfully completed. Test CT-3 was partially completed and Test CT-4 was not performed.

Test CT-1 concluded that the equipment could be safely operated and the emergency stop and other safety features were adequate. It also concluded that the operating procedures satisfactorily addressed both safety and environmental issues. A preliminary safety review performed by the International Union of Operating Engineers came to a similar conclusion.

Test CT-2 included the excavation of two side trenches and installation of the custom Slide-Rail Shoring as shown in Figure 1-9.

*Figure 1-9 Side Shoring Installation*

This test demonstrated the ease of installation and the effectiveness of the shoring to provide equipment and personnel safety while simultaneously providing structural support for the SCU. Test data also established that the excavation of trenches and placement of a 16-ft-long X 10-ft-wide X 8-ft-high, modular shoring could be installed in approximately 1-1/2 hr in sandy soils.

Test CT-3 included transport and placement of the SCU and PCU; SCU checkout; excavation of a 12-in.-high, horizontal slot; and construction of the horizontal containment barrier.

Test data substantiated the capability of the SCU to perform successfully in a simulated DOE subsurface environment. The SCU successfully excavated a horizontal slot beneath the waste area and installed a geosynthetic clay liner supported by the concrete floor blocks as shown in Figure 1-10.

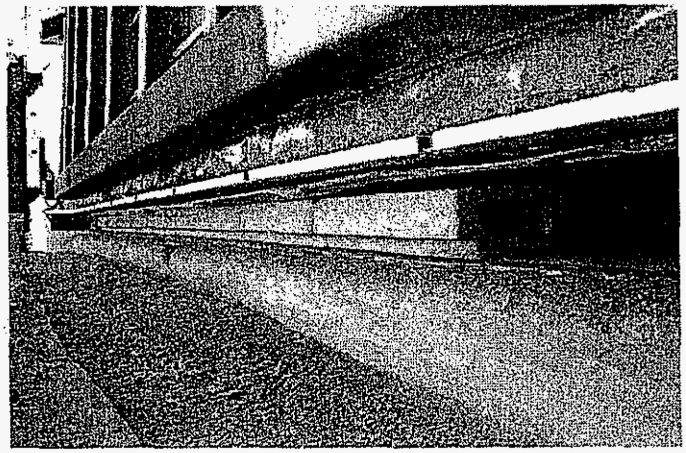


*Figure 1-10*
*Horizontal Containment Barrier Construction*

A detailed description of the Control Test is provided in Section 2.5.

The Advanced Control Test was added to the program to allow further investigation of liner installation and hydraulic testing. The Advanced Control Test consisted of Task 1.6, Horiztonal-to-Vertical Joint Bench-Level Testing and Perimeter Barrier Installation Test and Task 1.7, Hydraulic Testing and Barrier Validation.

The primary goal of the Advanced Control Test was the validation of the hydraulic barrier. Once the barriers are in place, they are effective in providing complete hydraulic isolation. This Hydraulic Testing (see Appendix 5, Advanced Control Test Operational Plan/Work Plan—Hydraulic Test Plan) also collected data to verify the effectiveness of the hydraulic isolation.

The secondary goal of the Advanced Control Test was to validate that the barrier installation system meets all general and site-specific performance requirements (see Appendix 5, Advanced Control Test Operational Plan/Work Plan). The installed barriers were evaluated for construction integrity (materials and structure) and for barrier functional performance using the general and ORR-specific performance criteria provided. The testing collected data to verify the installation system for safety, ease of installation, and speed of installation (see Section 2.8).

## 1.4 SCS PERFORMANCE CAPABILITIES

Using manufacturers' literature combined with the Factory and Control Test results, RAHCO established the overall SCS construction rate and the advance rates for four construction operations. As previously noted, construction rates vary as a function of the site geology and the containment barrier configuration. The following figure, Figure 1-11, summarizes the estimated overall construction rates for varying soil/rock strengths expected at DOE site for a containment barrier configuration of 1000-ft long, 34-ft wide, and 29-ft deep and for operating efficiencies of 75% and 100%.

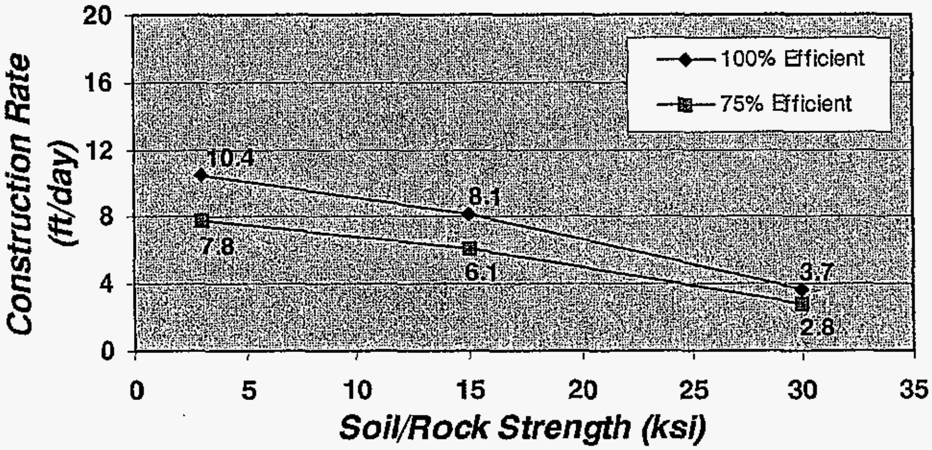



*Figure 1-11 SCS Construction Rate*

As shown, in soft soils including sandy loams, clays, and soft shales having a soil/rock strength of 3 ksi, barrier construction rates ranging from 8 to 10 ft/day are achievable based upon the construction crew operating efficiency. For competent shale and limestone-type materials with a soil/rock strength approaching 15 ksi such as found at the Oak Ridge site, barrier construction rates ranging from 6 to 8 ft/day are achievable. In competent basalt rock-type formations as might be expected at the Idaho site, construction rates as low as 2 to 3 ft/day may be expected.

A more detailed description of the SCS performance capabilities is provided in Section 2.5.

## 1.5 CONSTRUCTION COST & SCHEDULE

Using equipment performance data obtained from equipment vendors and the Factory and Control Tests, RAHCO developed preliminary cost and schedule estimates to construct a subsurface containment barrier at DOE sites. Figure 1-12 highlights the 50-yr life cycle cost including the cost of the RCRA cover and long-term monitoring.

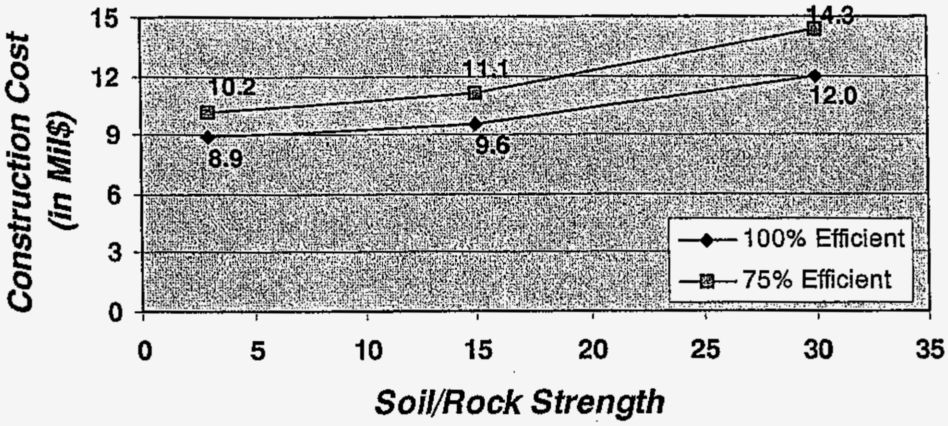



*Figure 1-12 50-yr Life Cycle Cost*

Similarly, Figures 1-13 and 1-14 highlight the range of cost per cubic yard of waste contained and cost per square foot of placed barrier as a function of the soil/bedrock strength.

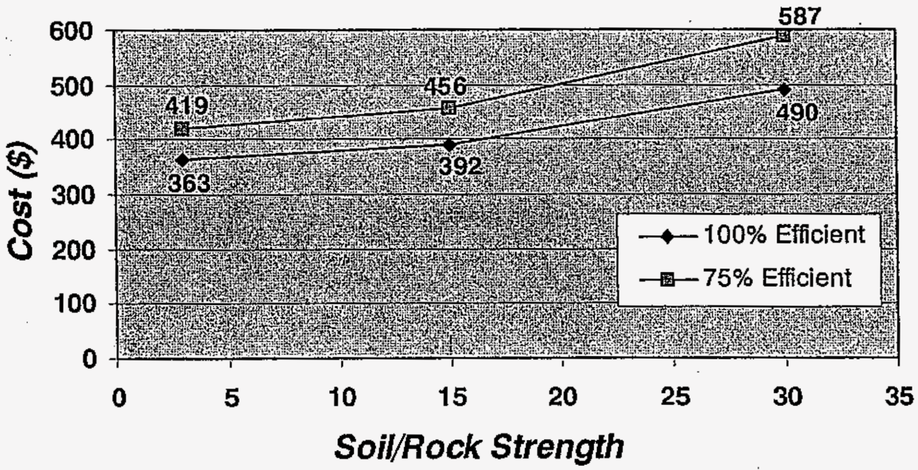



*Figure 1-13 Cost/Cubic Yard of Waste Contained*

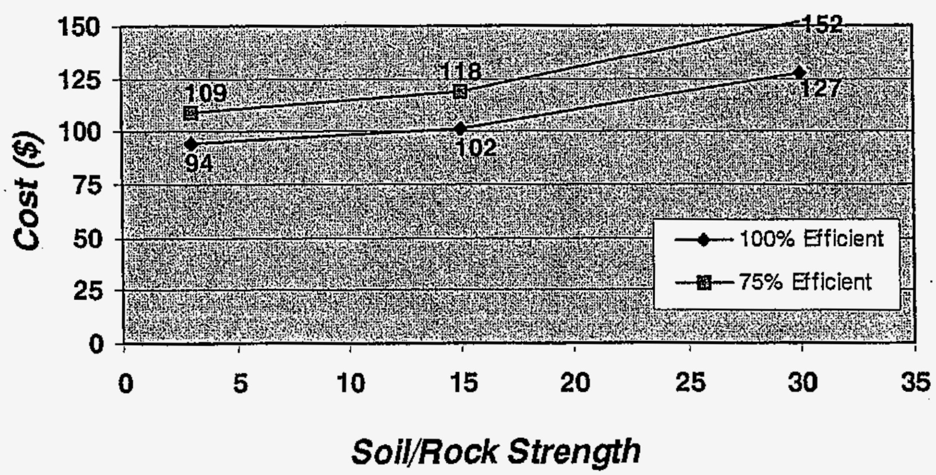



*Figure 1-14 Cost/Square Foot of Placed Barrier*

Details of the construction cost estimates are provided in Appendix 2.

Figure 1-15 shows the construction duration for a typical DOE operation. As shown, a construction schedule can range from 6 to 18 mos based upon an 8 hr/day operation.

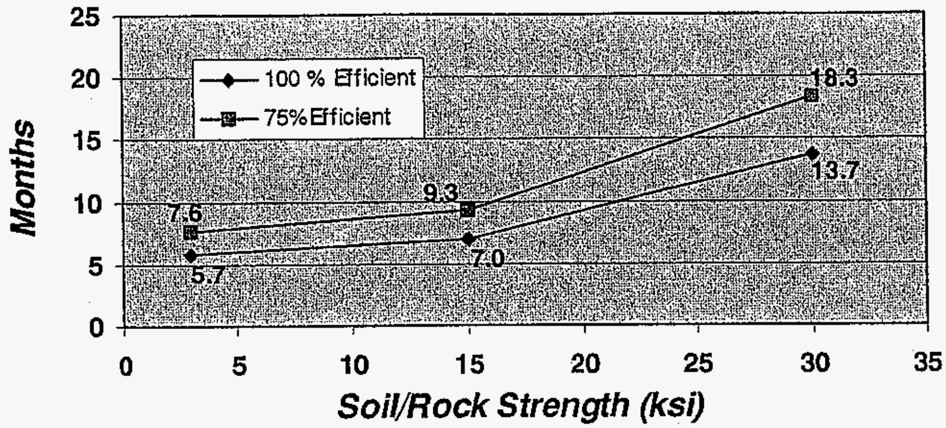



*Figure 1-15 Construction Duration*

For the DOE Oak Ridge Bear Creek Valley site, the construction cost is estimated to be approximately $9 million with the 50-yr life cycle cost estimated to be approximately $10.5 million. The estimated construction duration is approximately 10 mos. Construction costs and schedules are described further in Section 2.7.

Section 2.0 of this report, Results & Discussion, highlights the work completed in Phase I. The results of the advanced engineering design are described by a detailed description of the SCS; the results of the Factory, Control, Advanced Control, and Hydraulic Tests are included and the system performance capabilities and preliminary cost and schedule estimates for a typical DOE waste site are also provided.

Section 3.0 of this report highlights the progress made; identifies the major accomplishments; describes the advantages of the SCS over existing technology, and recommends a path forward. Appendix 1 provides details of the SCS performance analysis; Appendix 2 includes the details of the preliminary cost estimates; Appendix 3 provides the Control Test Operational Plan/Work Plan; and Appendix 4 provides the engineering drawing package; Appendix 5 is the Advanced Control Test Operational Plan/Work Plan; Appendices 6 through 10 are the Quick-Look Reports for following tests, respectively: SCU Factory Test, Hydraulic Bench-Level Test, Perimeter Barrier Installation Test, and Hydraulic Test.

# SECTION 2.0
# RESULTS & DISCUSSION

RAHCO has made significant progress in establishing the technical and economic feasibility of the Subsurface Containment System. Results to date are promising. The use of innovative, specialized construction equipment combined with commercially available geomembrane materials and a unique construction method can successfully construct a continuous subsurface containment barrier. This barrier can protect soil and groundwater from contamination and effectively meet environment cleanup standards while reducing schedules, risk, and cost.

A review of the key DOE requirements and the ability of the SCS to comply with these requirements provides evidence of the technical results achieved.

- **DOE Requirement #1:** "The barrier installation or system shall effectively and efficiently construct a continuous barrier without intrusion or disturbance to the waste requiring containment, and operate with a minimal perimeter so as not to disturb adjacent waste areas."

  The SCS Control Test has demonstrated the capability to install a containment barrier without disturbing either the waste to be contained or the adjacent waste. It has also demonstrated that a perimeter distance of only 15 ft is required.

- **DOE Requirement #2:** "The installed, containment barrier will be a continuous structure without discontinuities, that is constructed of durable, impermeable material, and serves to hydraulically isolate the waste site."

  The SCS containment barrier design utilizes proven, state-of-the-art geomembrane material and provides a continuous barrier without discontinuities. The hydraulic effectiveness of the containment barrier has not been established.

- **DOE Requirement #3:** Both the barrier installation process and the constructed barrier must meet required technology performance requirements, and must also meet any DOE site-specific and regulatory requirements that exist as a result of this demonstration."

  The SCS equipment and process has been demonstrated in the Factory and Control Tests to meet the DOE technology performance requirements and ESH requirements with the exception of the barrier hydraulic permeability requirement.

The following subsections provide a detailed description of the SCS, describe the Factory and Control Tests, identify the SCU performance capabilities, and provide an estimated construction cost and schedule for a 1000-ft-long, subsurface barrier at the Bear Creek Burial Grounds, Oak Ridge, Tennessee.

## 2.1 EQUIPMENT DESCRIPTION

The SCS uses both conventional and specialized equipment to install the subsurface containment barrier. The following table highlights the equipment used.

| TABLE 2.1-1 EQUIPMENT DESCRIPTION LIST | |
|---|---|
| **Conventional** | **Specialized** |
| Backhoe Excavator w/End Effectors | Modular Slide-Rail Shoring System (SRS) |
| Front End Loader | Slot Construction Unit (SCU) |
| 100-ton Crane | Power & Control Unit (PCU) |
| 25-ton Mobile Crane | |
| Flat Bed Truck | |
| Geomembrane Joint Welder | |

### 2.1.1 CONVENTIONAL CONSTRUCTION EQUIPMENT

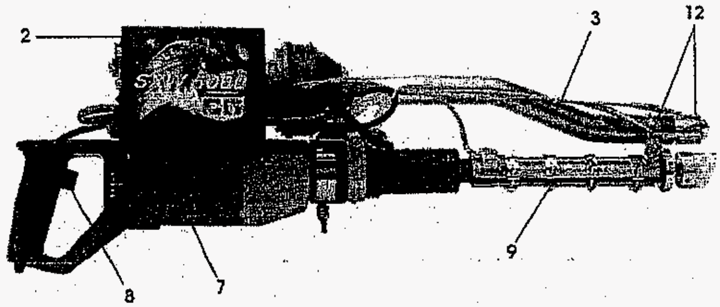
The conventional equipment required to construct the subsurface containment barrier, as shown in Table 2.1-1 is similar to construction equipment used in civil projects, with the exception of the geomembrane joint welder. This unit is a standard device used in the geomembrane industry. A brief description of the backhoe excavator and joint welder are provided because of the unique requirements of this project. Figure 2.1-1 shows the required excavator and provides the specifications.

**SPECIFICATIONS**

| | |
|---|---|
| • Engine | Caterpillar 3406 |
| • Horsepower | 428 hp |
| • Drawbar Pull | 122,800 lbs |
| • Travel Speed | 2.8 mph |
| • Track Width | 30 in. |
| • Track Length | 20 ft-10 in. |
| • Dig Depth | 34 ft-9 in. |

***Figure 2.1-1 Excavator with Bucket End Effector***

The end effectors required include: a minimum 3-cu yd bucket, hydraulic rock hammer, and soil compactor. The geomembrane joint welder is a commercially available unit as shown in Figure 2.1-2.




**SPECIFICATIONS**

- **Weight** **16.6 lbs**
- **Power** **Electric, 240 VAC**
- **Output** **15.8 lbs/hr**

*Figure 2.1-2 Portable Extrusion Welder*

## 2.1.2 SPECIALIZED CONSTRUCTION EQUIPMENT

The specialized equipment includes: Slide-Rail Shoring System (SRS), Slot Construction Unit (SCU), and Power and Control Unit (PCU).

### 2.1.2.1 Slide-Rail Shoring System (SRS)

The custom Slide-Rail Shoring System is a modular, high-capacity shoring system that provides shoring protection for personnel and equipment during the construction operation. It also provides a structural foundation for the Slot Construction Unit as it advances. The double-walled steel panels slide into tracked rails as earth is excavated as illustrated in Figure 2.1-3, virtually eliminating soil movement and providing a vertical trench at the ends and along the sides of the waste area.

*Figure 2.1-3 Slide-Rail Shoring System*

The Slide-Rail Shoring System has seven basic components (panels, corner slide-rails, linear slide-rails, crossbraces, cross beams, wall beams, and post connectors) that are combined to accommodate a variety of trench configurations necessary to install the subsurface containment barrier. The modular components support a continuous construction process and allow lighter equipment to handle the system in tight working conditions as is expected at DOE sites.

Various combinations of corner and linear rails; combined with high-strength panels, beams, and post connectors; allow for shoring of excavations of up to 35-ft deep and allow the excavation of a horizontal slot under the waste area. A typical layout using the basic shoring system components is shown in Figure 2.1-4. The following provides a brief description of the shoring system components.

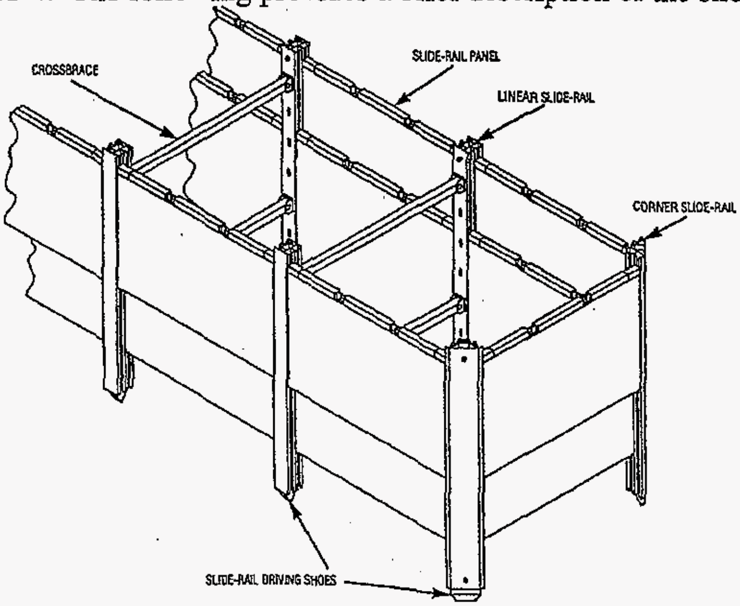



*Figure 2.1-4 Shoring System Components*

**Slide-Rail Panels** as shown in Figure 2.1-5 are either 4 ft or 8 ft in height and in lengths from 8 ft to 20 ft. Driving panels include a reinforced knife-edge bottom to shave the trench face as the panels are pushed into place. The panels are stacked for deeper applications.

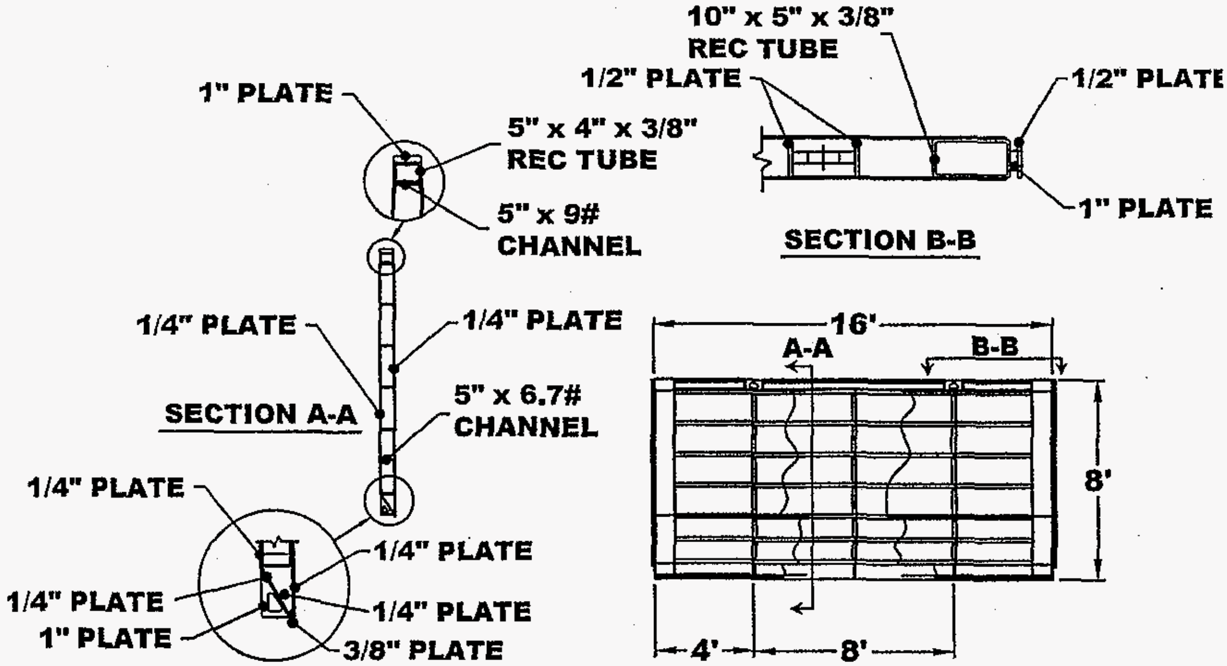



*Figure 2.1-5 Slide-Rail Panels*

**Corner and Linear Slide-Rails** range in heights from 8 ft to 24 ft as shown in Figure 2.1-6. Rails that are 8 ft, 12 ft, and 16 ft in height are generally stacked in combination to facilitate most trench depths and conditions. Specially designed driving caps prevent damages to the slide-rails during installation and removal.

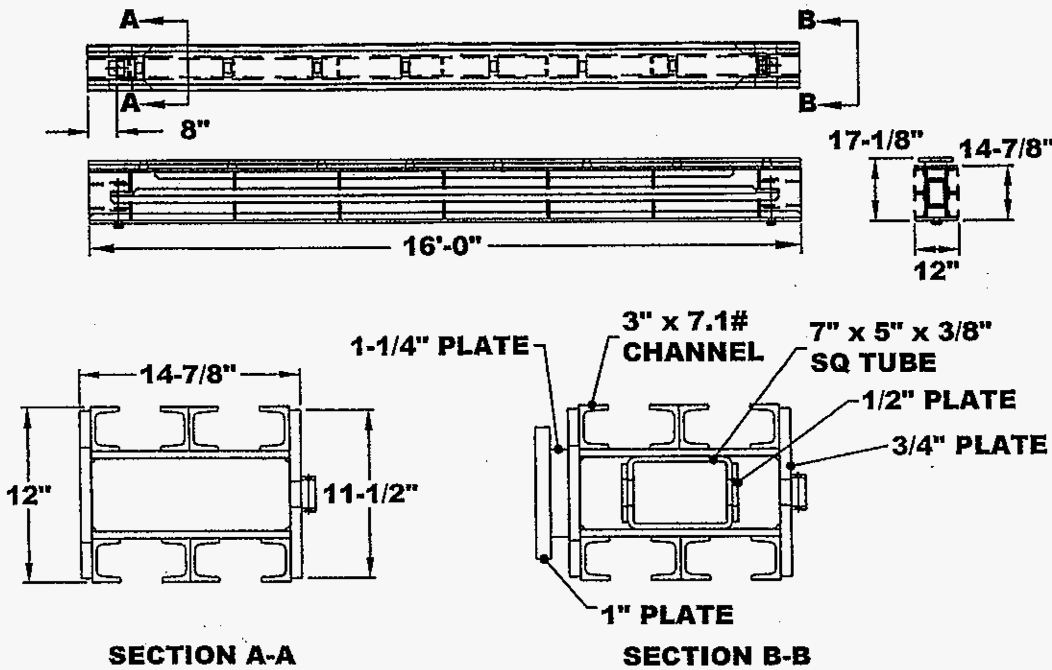



*Figure 2.1-6 Linear Slide-Rail*

**Crossbrace Support** as shown in Figure 2.1-7 is a specialized structural member that interlocks the slide-rails and provides a structural foundation for the SCU support rail.

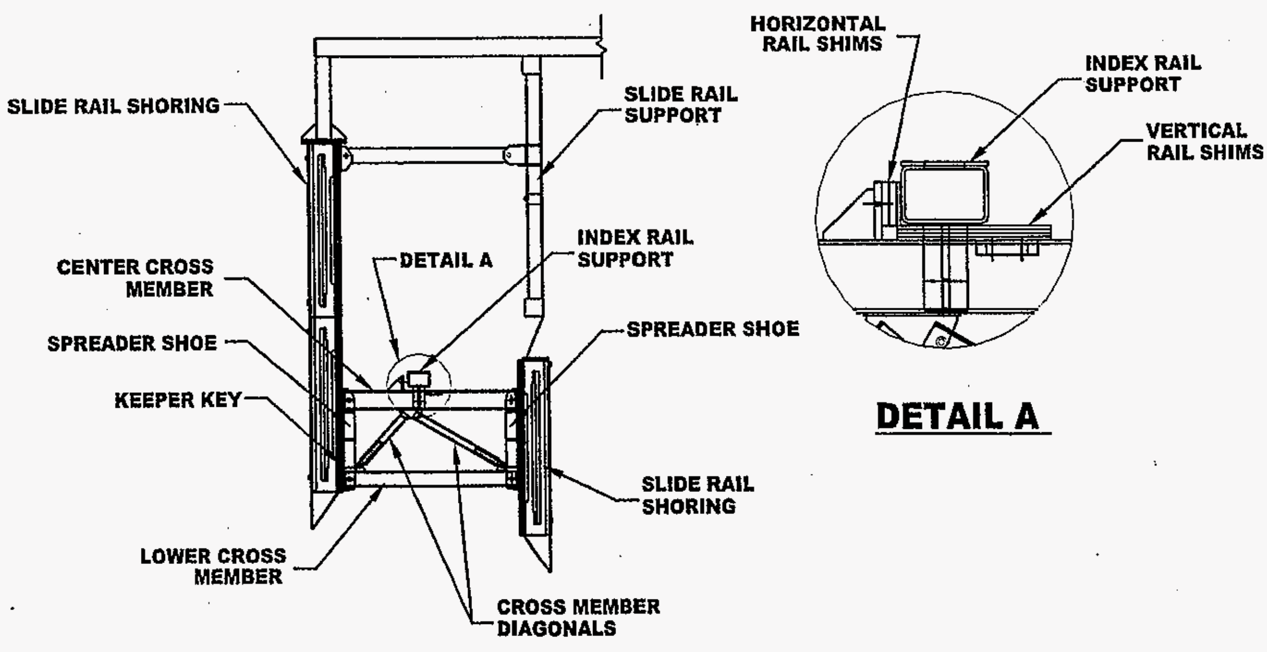



*Figure 2.1-7 Crossbrace Support Layout*

**Crossbraces** are in a variety of widths and utilize a unique keyway shoe system to interlock the slide-rails. The keyway system allows for rapid field adjustment of spreader height to accommodate various trench widths and soil conditions.

**Cross Beams** of H-beam structural shape span the width of the shoring system at slide-rail locations to provide support for the upper inner wall as the SCU excavates a horizontal slot under the waste area.

**Wall Beams** of H-beam structural shape provide support for the upper panels and posts when the upper cross members are removed to accommodate the placement of the SCU in the end trench.

**Post Connectors** are specialized structural shapes that are used to connect the inner upper and lower posts during installation, but are easily removed to allow the SCU to advance.

### 2.1.2.2 Slot Construction Unit

The Slot Construction Unit as shown in Figure 2.1-8 is an innovative, specialized construction machine designed to construct up to a 100-ft-wide, horizontal containment barrier 2 to 4 ft beneath the buried waste. It is designed to construct a horizontal containment barrier at rates to 12 ft/day in an 8-hr/day operation. During normal operation, 11 precast concrete blocks and a 150-ft roll of GCL are preloaded above ground into their respective magazines, and the magazines are locked in place on the SCU beam structure. The SCU then excavates a 12-in.-high, horizontal slot from one side trench to the other and installs a horizontal containment barrier consisting of 80-mil, GCL supported by rows of precast concrete blocks. The unit is operated remotely by a single operator located in the Power and Control Unit located above ground.

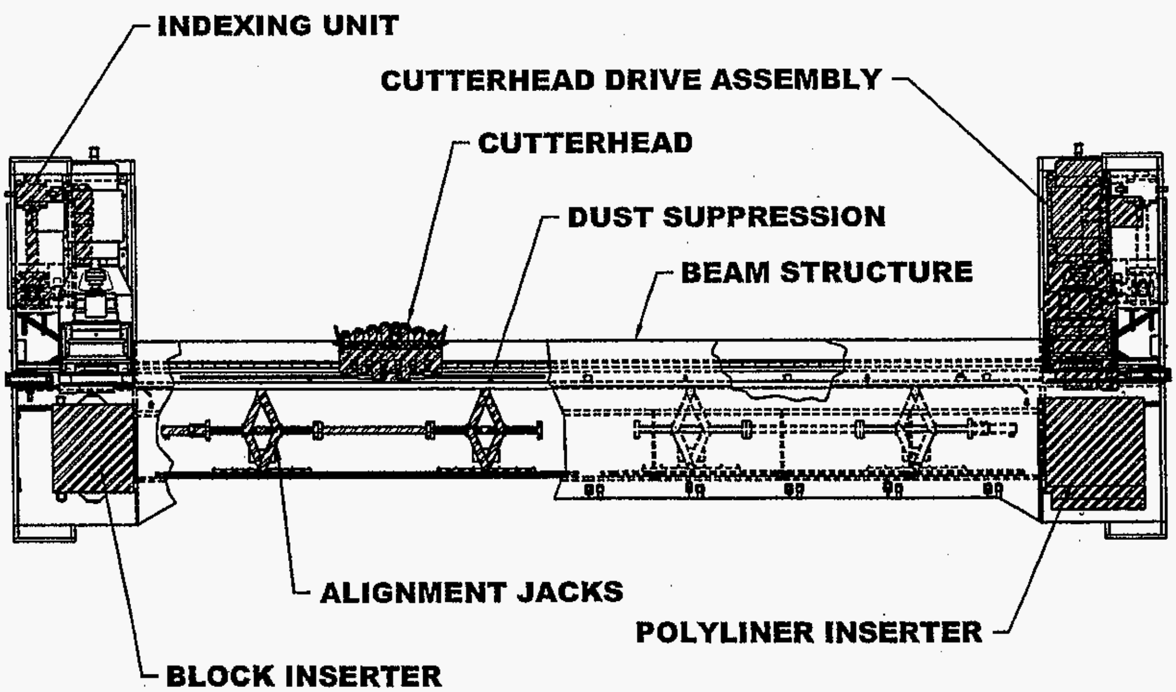



*Figure 2.1-8 SCU Layout*

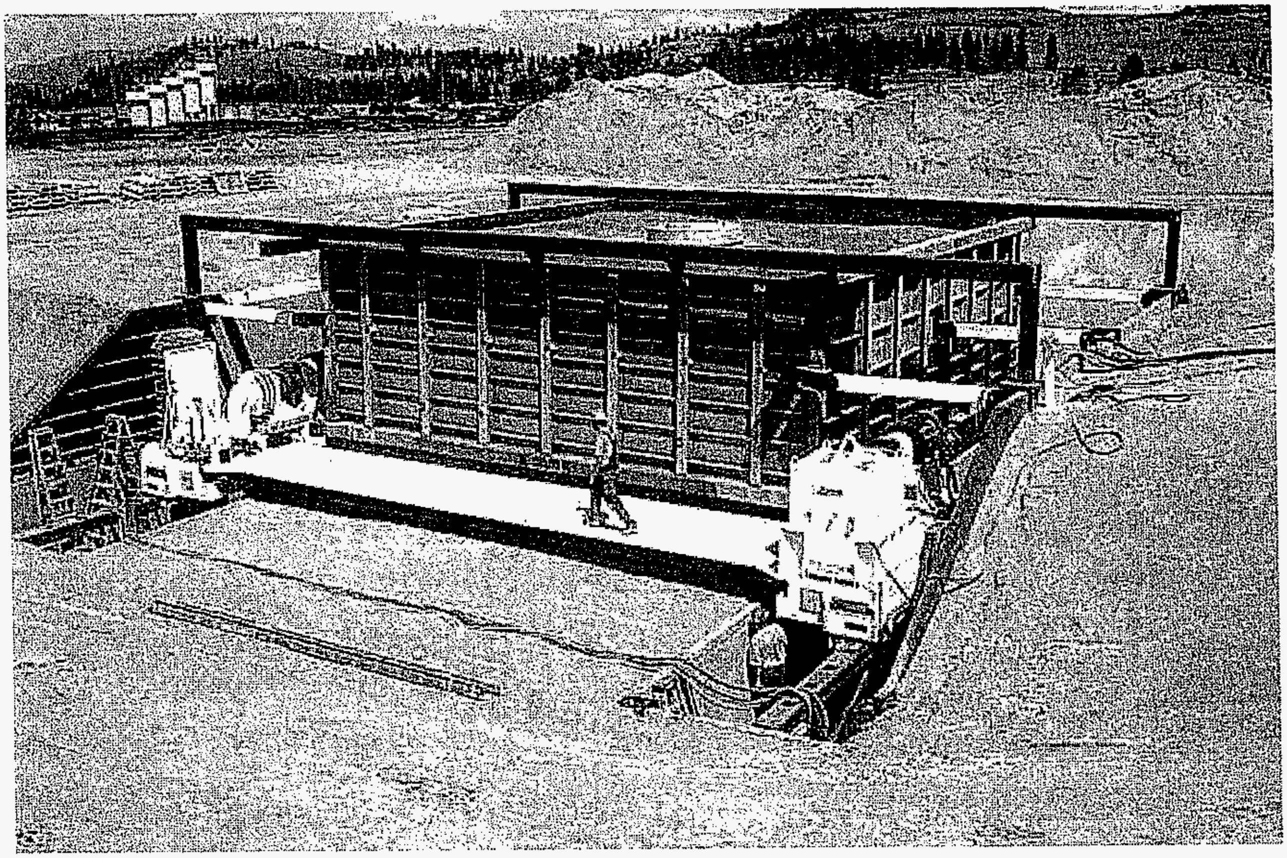


*Figure 2.1-9 Slot Construction Unit*

Key features of the SCU are:

- It is capable of excavating a horizontal slot up to 100 ft in width in a variety of geological conditions.
- It is remotely operated with a minimum operating crew, and easily maintained.
- It is capable of constructing the horizontal barrier at rates to 12 ft/day and placing the barrier within the construction tolerance of ±2 in. of vertical and horizontal centerlines.
- It meets all DOE ESH requirements.

The SCU is similar in design to a long-wall mining machine and consists of seven major sub-assemblies: beam structure, cutterhead assembly, steering system, thrusting unit, block inserter, polyliner inserter, and instrumentation. The following provides a brief description of each.

**Beam Structure:** The beam structure is a structural weldment approximately 15-ft long by 45-ft wide and 10-ft high and weighing approximately 90,000 lbs that provides a foundation for the other mechanical devices and acts as a ground shield for the installation of the precast concrete blocks and GCL. A photograph of the beam structure with the cutterhead mounted to the face of the structure is shown in Figure 2.1-10.

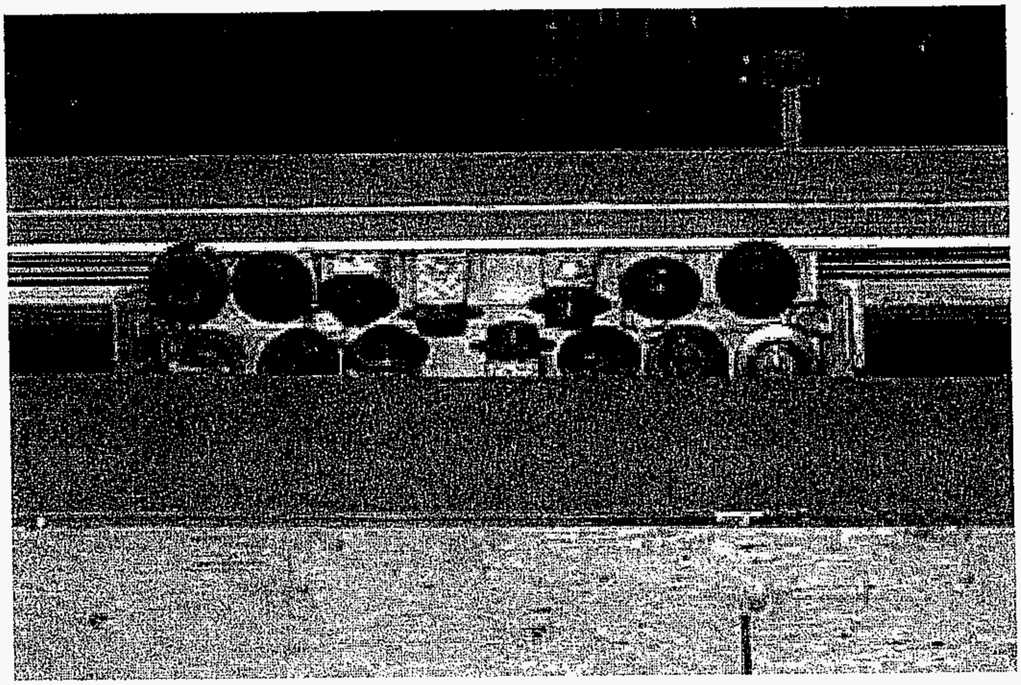


*Figure 2.1-10 Beam Structure*

**Cutterhead Assembly:** The cutterhead assembly, as shown in Figure 2.1-11, is used to excavate a 1-ft-high, horizontal slot beneath the waste area and remove the muck. A cutterhead cleaner is used to remove excavated materials from the cutters. The cutterhead assembly consists of a cutterhead; cutterhead drive unit, and cutterhead cleaning device.

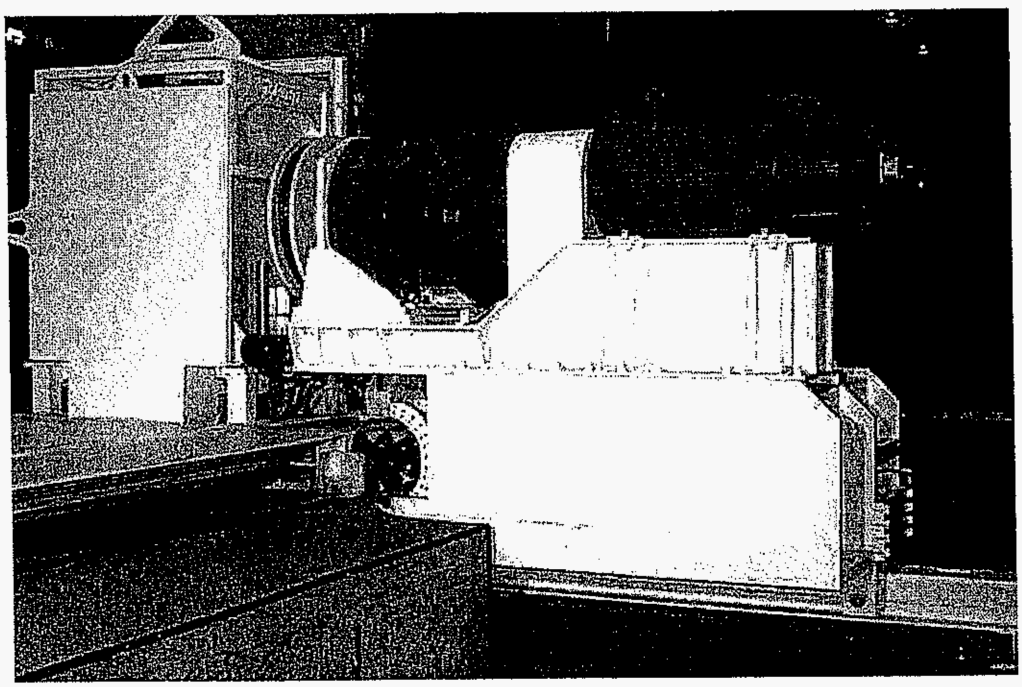


*Figure 2.1-11 Cutterhead Assembly*

**Cutterhead:** As shown in Figure 2.1-12, the 4-ft-long X 1-ft-high cutterhead structure weighs approximately 1200 lbs and employs 14, 6-in. roller disc-type cutter to excavate the soil/rock. The cutterhead is designed to penetrate the soil/rock up to 0.50 in. per pass and provides a maximum of 150,000 lbs of cutting force at travel speeds to 200 fpm. Muck is removed by two plows mounted on each end of the cutterhead with the cutterhead having a muck handling capability of 1.97 cu ft.

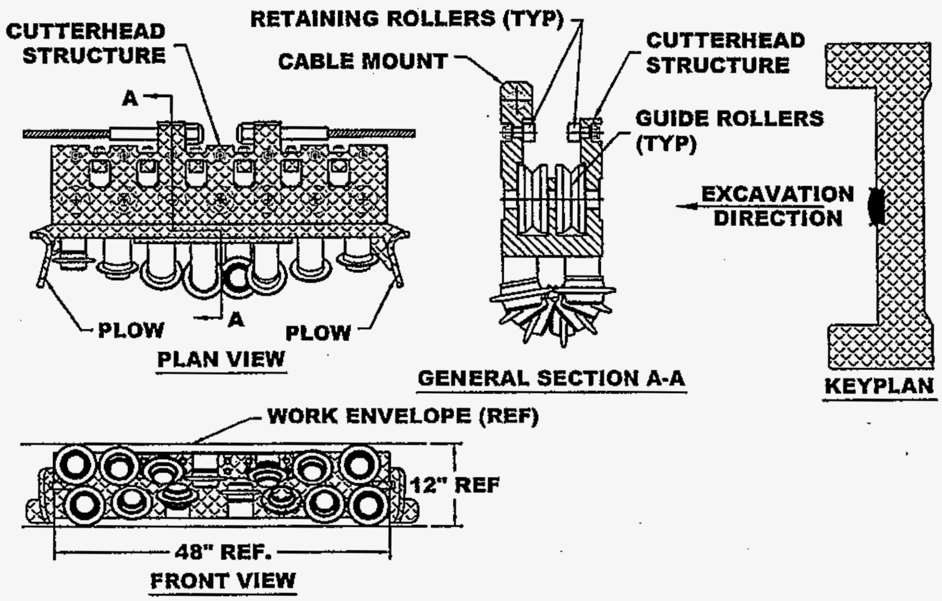



*Figure 2.1-12 Cutterhead Layout*

**Cutterhead Drive:** This unit, as shown in Figure 2.1-13, consists to two 200-hp, variable frequency drive, 480-VAC electric motors; two 24-in-diameter, 4-wrap winches with gearboxes; two 26-in.-diameter idler sheaves; and a 1-in.-diameter wire rope. The unit has the capacity of providing 140,000 lbs of cuterhead pull at travel speeds to 200 fpm.

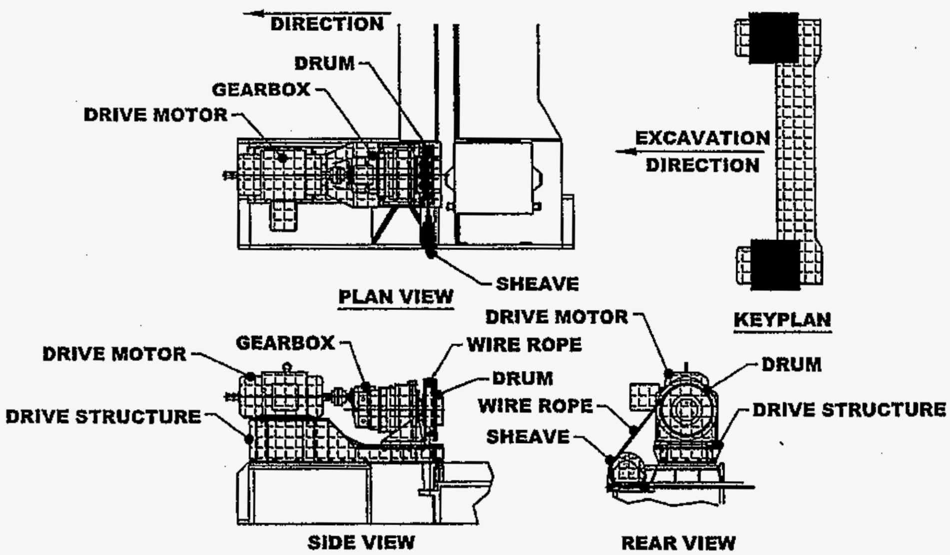



*Figure 2.1-13 Cutterhead Drive Layout*

**Cutterhead Cleaner:** The cleaner, as shown in Figure 2.1-14, is designed to remove any entrapped cuttings from the cutterhead as it exits the slot. The cleaner consists of six individually mounted structures onto which a row of approximately 30, 10-in.-long X 1/4-in.-diameter, nylon rods each have been attached.

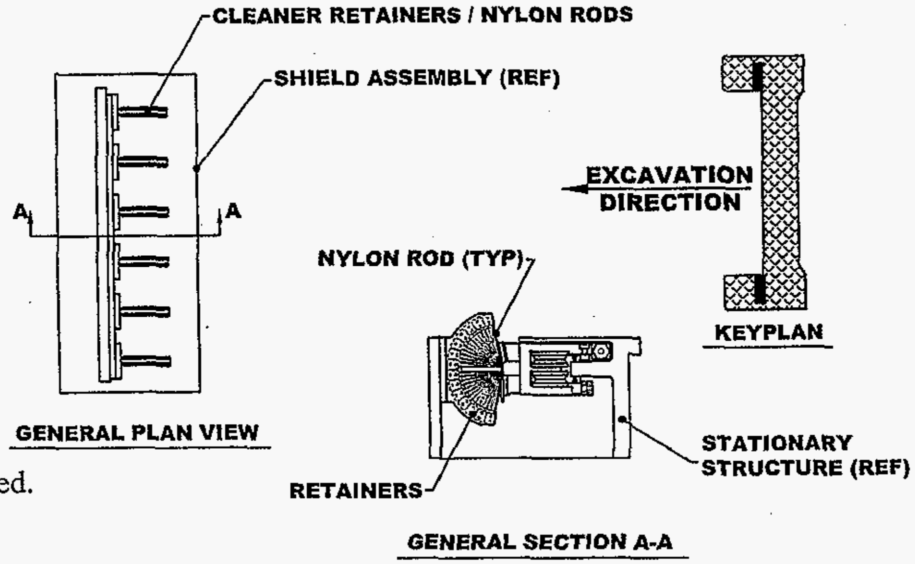



*Figure 2.1-14 Cutterhead Cleaner Layout*

**Steering System:** A combination of sensors and mechanical devices located on the beam structure and cutterhead that allow the SCU to position the barrier ±2 in. of desired grade and centerline. Four inclinometers, located on the beam structure, are used to measure the pitch of the SCU. If required to change alignment of the SCU, shims are manually inserted or removed from the cutterhead to over or undercut the beam structure. This action will cause the SCU to change alignment.

**Thrusting Unit:** Mechanical devices and drives located in the ends of the beam structure as shown in Figure 2.1-15; used to advance the SCU and provide reactive thrust as the cutterhead travels back and forth across the cutting face.

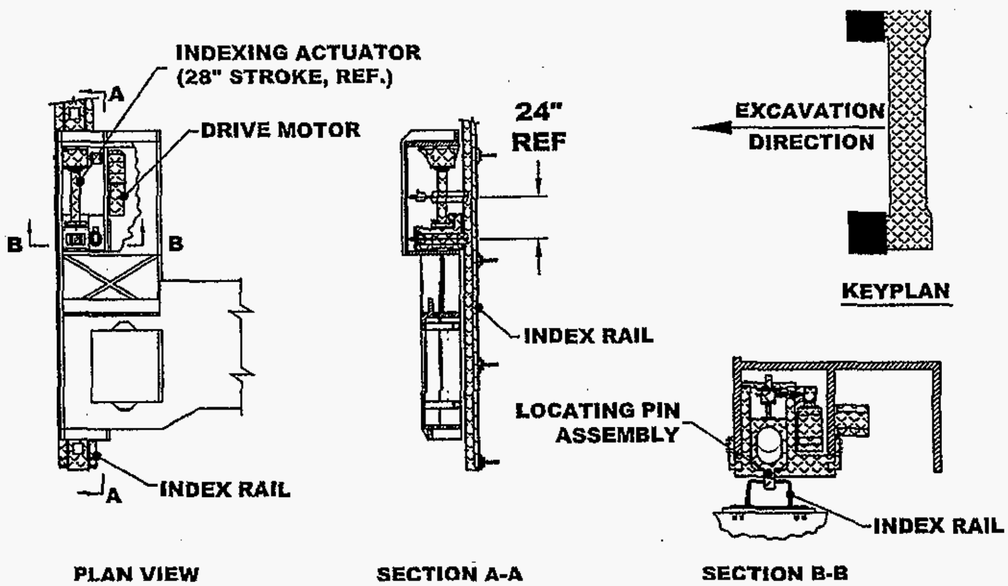



*Figure 2.1-15 Thrusting Unit Layout*

The two thrust jacks, each consisting of a mechanical screw actuator and gear reducer powered by an 18-hp electric motor, provide a total of 280,000 lbs of thrust to the beam structure. The two locating pin assemblies raise and lower a 4-in., square, solid pin to engage the SCU support rail and transfer the thrust loads to the support rails and shoring system. The 4-in. pin is driven by a mechanical screw actuator, gear reducer, and a 1.2-hp electric motor.

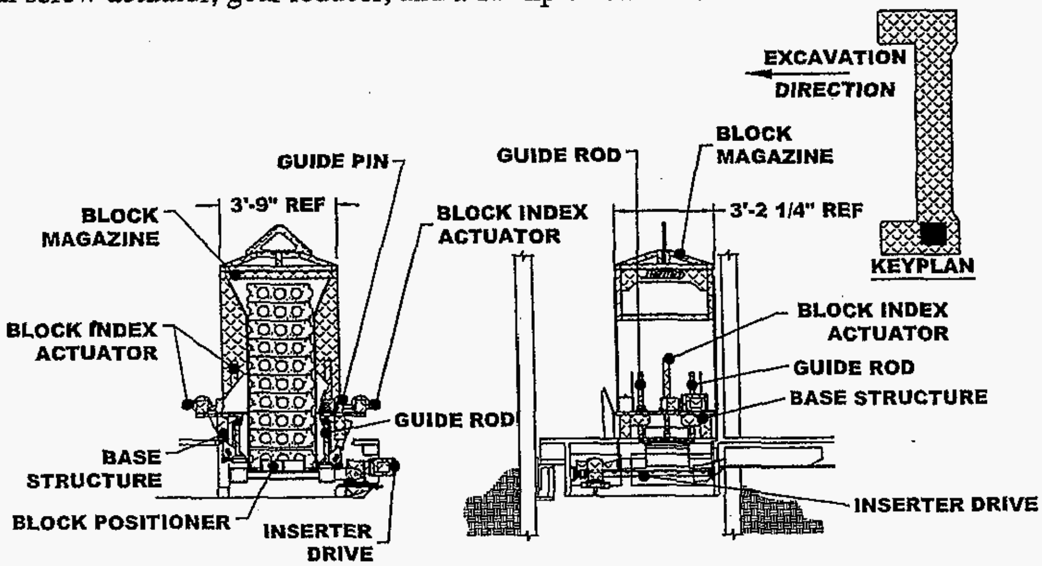



*Figure 2.1-16 Block Inserter Layout*

**Block Inserter:** A combination of structural weldments, mechanical devices, drive motors, and sensors located on the right side of the beam structure as shown in Figures 2.1-16 and 2.1-17; used to store and insert a row of 11 precast concrete blocks within the beam structure.

With 11, 24-in.-wide X 37-in.-long X 7-in.-high floor blocks stacked in the magazine, the block index actuator lifts the top 10 blocks a distance of approximately 1/2 in. and frees the bottom block. The block positioner then pushes the bottom block from the magazine into a 30-in.-wide space within the beam structure—a distance of 38 in. The block positioner is then retracted to allow the block index actuator to lower the 10 blocks to the base of the magazine. The index actuator then lifts 9 of the blocks and the block positioner reactivates to insert the second block into the beam structure. This lift/push process is repeated until all 11 blocks are positioned within the beam structure.

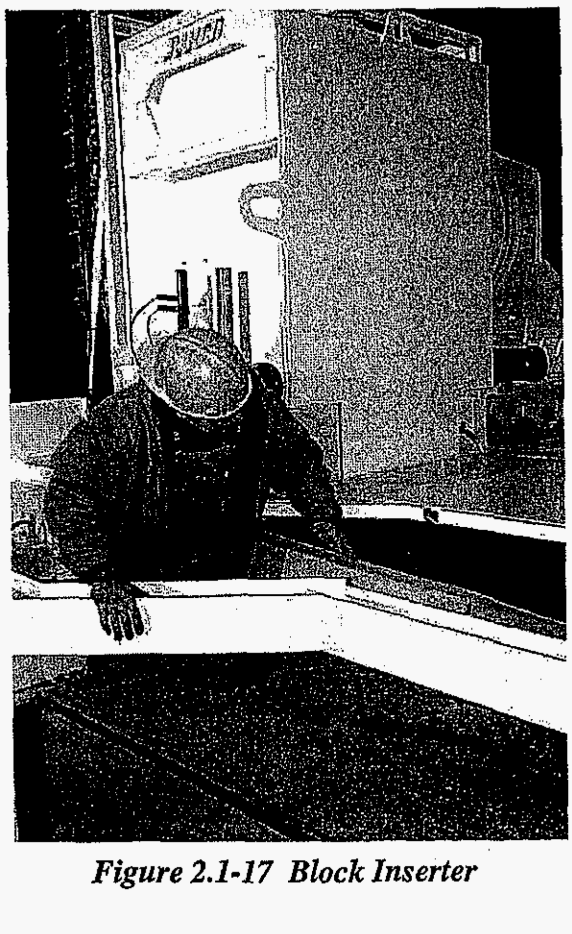


*Figure 2.1-17 Block Inserter*

**Alignment Jacks:** A scissor-type arrangement of mechanical devices, electrical drives, and sensors located within the beam structure as shown in Figure 2.1-18 that positions both the concrete blocks and GCL and maintains a load on the blocks as the cutterhead travels across the cutting face.

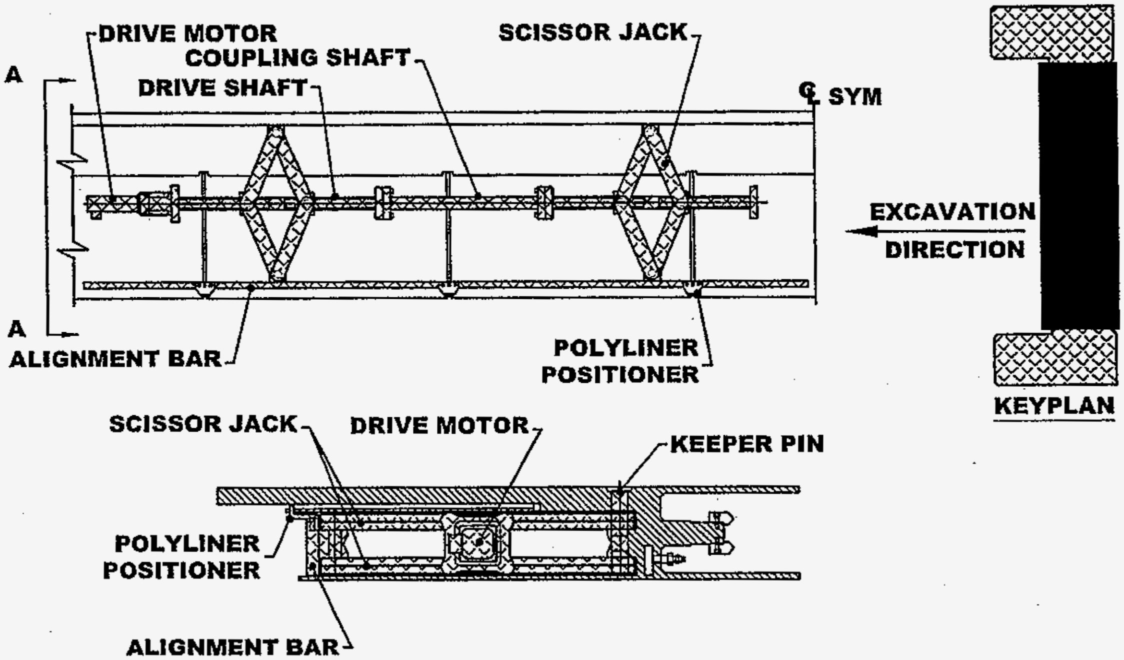



*Figure 2.1-18 Alignment Jack Layout*

**Polyliner Inserter:** A combination of structural weldments, mechanical devices, drive motors, and sensors located on the left side of the SCU as shown in Figures 2.1-19 and 2.1-20; used to store a 150-ft roll of GCL, insert a 30-in.-wide strip into the beam structure, and cut the GCL to the proper length.

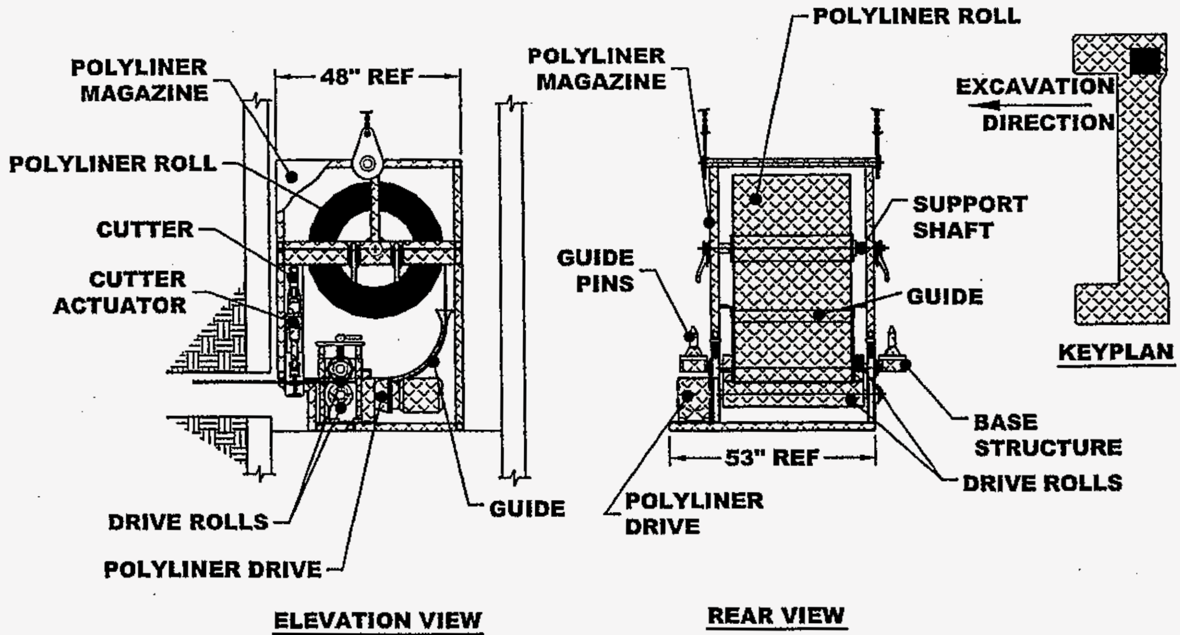



*Figure 2.1-19 Polyliner Inserter Layout*

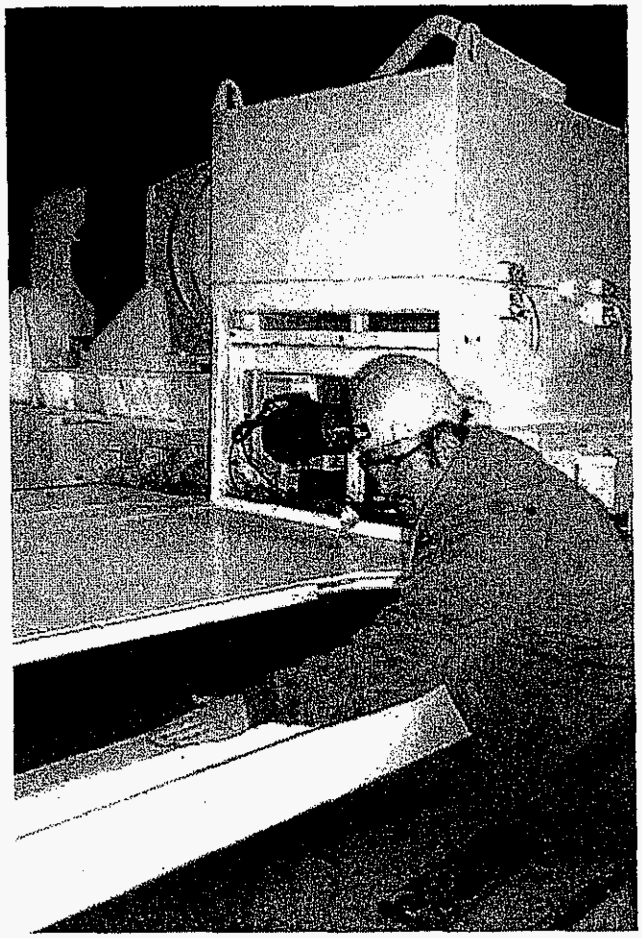


*Figure 2.1-20 Polyliner Inserter*

**Instrumentation:** A combination of sensors and devices used for equipment monitoring and control is shown in Figures 2.1-21 and 2.1-22.

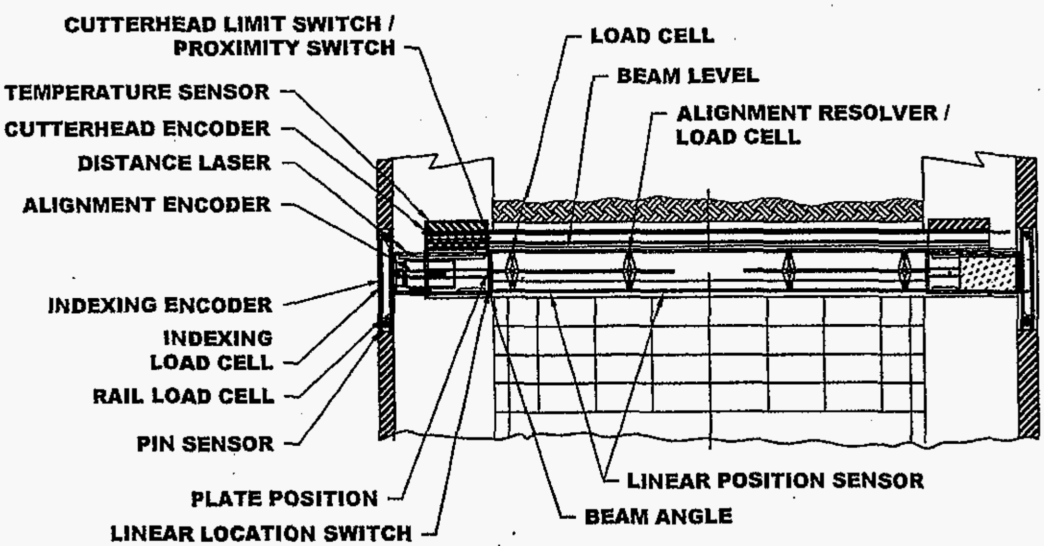



*Figure 2.1-21 SCU Beam Instrumentation Layout*

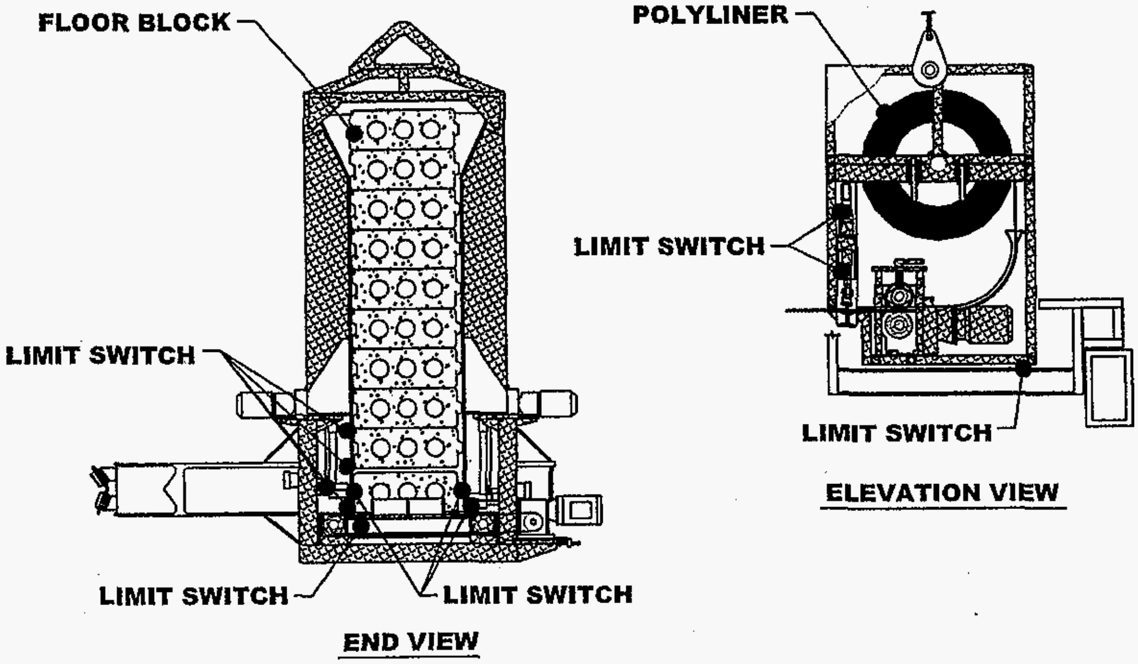



*Figure 2.1-22 Inserter Instrumentation Layout*

#### 2.1.2.3 Power & Control Unit

The SCU is PC-controlled by a single operator located above ground in the Power and Control Unit (PCU). The control system features a data acquisition system that monitors and collects system performance data and is able to generate trend curves for critical operating functions.

The Power and Control Unit (PCU) as shown in Figure 2.1-23 is a 40-ft x 10-ft X 8-ft shipping container that contains electrical power distribution equipment (Figure 2.1-24) to provide power to the SCU and an operator control station (Figure 2.1-25) that allows remote control of the unit by a single operator.

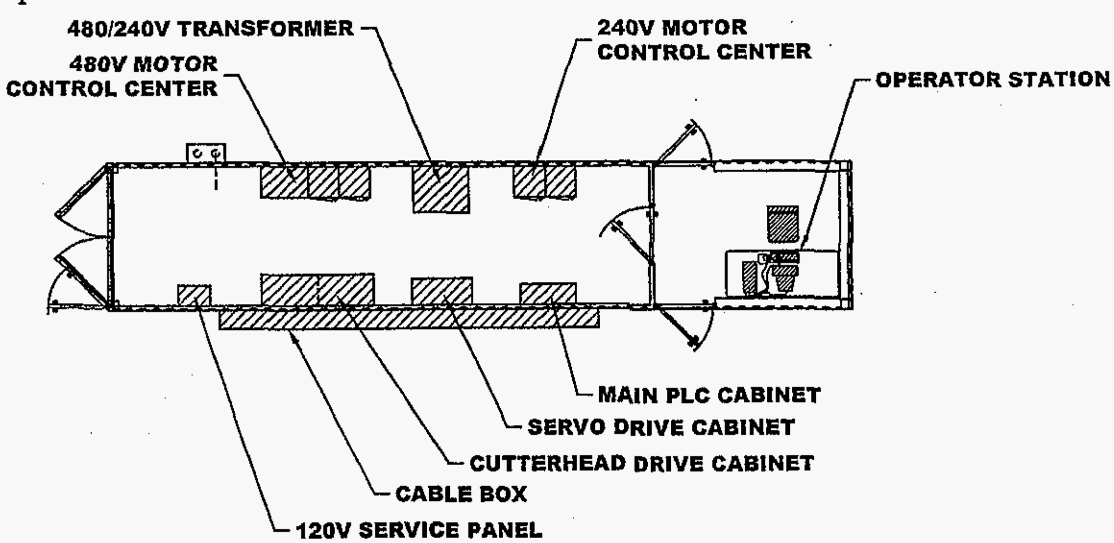



*Figure 2.1-23 Power & Control Unit Layout*

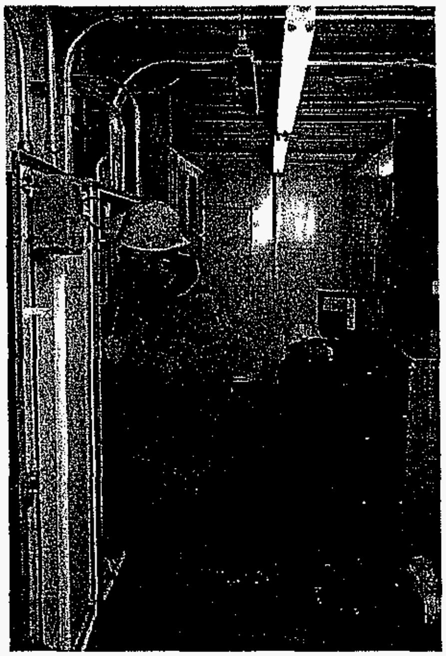


*Figure 2.1-24 Power Distribution*

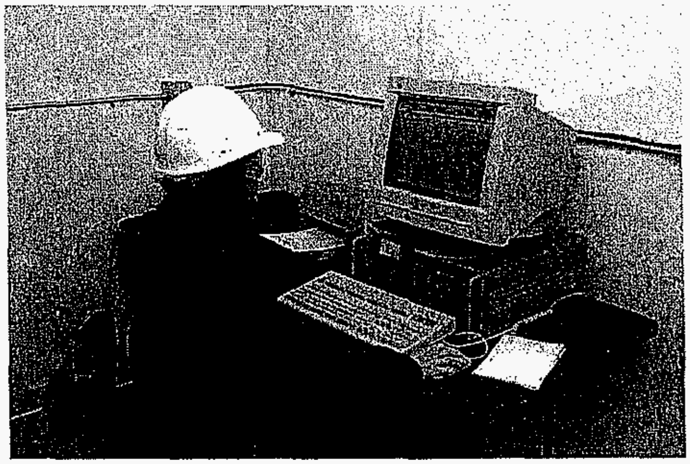


*Figure 2.1-25 Operator Control Station*

The electrical power distribution equipment includes power transformers, miscellaneous electrical equipment, and cables to provide electrical power to the SCU operator's control station and other power needs.

The operator control station includes:

- Operator's Desk & Chair
- Video Monitors & Mounts
- Audio Speaker & Controller
- Communication Equipment
- Lights
- Air Conditioner
- Storage Cabinets

The SCU Control System (CS) consists of both hardware and software to provide PC-based control of the unit during the horizontal barrier construction process. In addition, the CS provides additional operating information, data, and reports to the operator. The CS hardware consists of:

- Modicon Programmable Logic Controller (PLC)
- PLC Input/Output Devices
- Modbus Plus Communication Network
- Personal Computers (2) Including Mouse, Keyboard, Printer, & Monitor
- E-Stop Panel

The PLC is the center of the CS. All controlled devices such as motor starters, valves, solenoids, and indicator lights are controlled through outputs from the PLC. All sensors such as load cells, temperature sensors, limit switches, and proximity switches are connected to inputs to the PLC.

The Modbus Plus communication network is used to connect the PLC with the PCs. Modbus Plus is a high-speed, peer-to-peer network with a communications rate of 1 Mbps. It is connected through a twisted-pair cable and can accommodate up to 32 devices without repeaters over a distance of 1500 ft. For this application, the Modicon PLC will be located less than 20 ft from the operating system PCs.

The software consists of: Concept software, Wonderware Intouch Factory Suite, and RAHCO custom software. The following oprovides a brief description of the software.

The Concept software package is used to configure the Modicon PLC. The package provides an environment for several different real-time control languages including Function Block Diagram, Ladder Diagram, Sequential Function Chart, Structured Text, and Instruction List. Software configured in Concept is "self-documenting," meaning that documentation is automatically generated as the project is configured per the international IEC 1131 standard. Configuration consists of Sequential Function Chart and Ladder Diagram sections that will be sequenced using Concept's sequencing module.

The Wonderware Intouch Factory Suite is a Supervisory Control and Data Acquisition/ Human-Machine Interface (SCADA/HMI) combination. This project will utilize the Data Acquisition functions and will also use the Human-Machine Interface features. The Human-Machine Interface is illustrated in Figure 2.1-26.

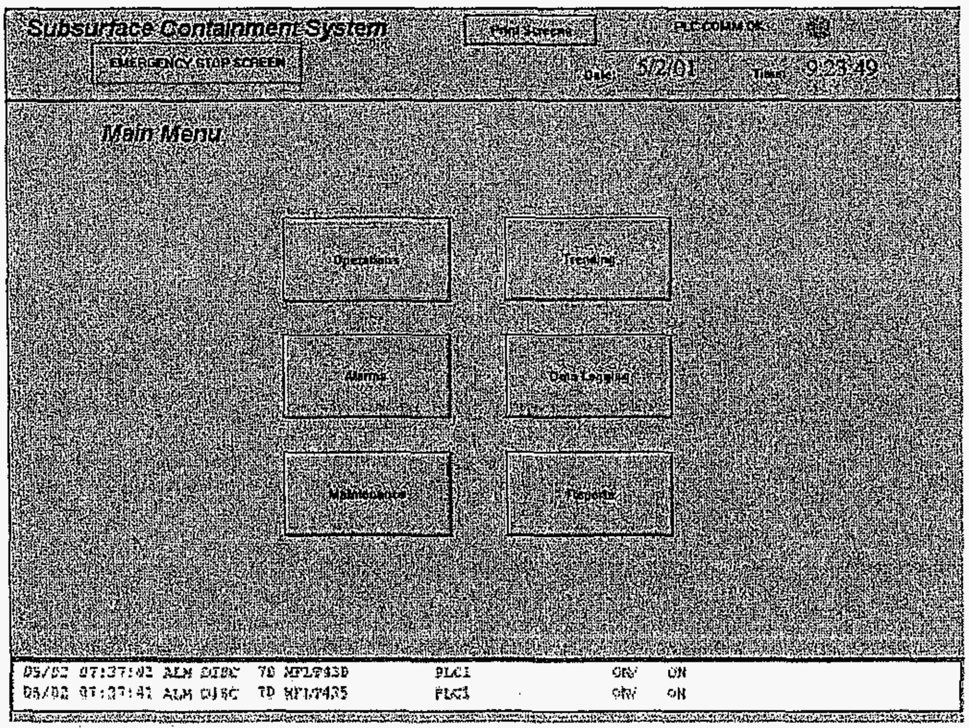


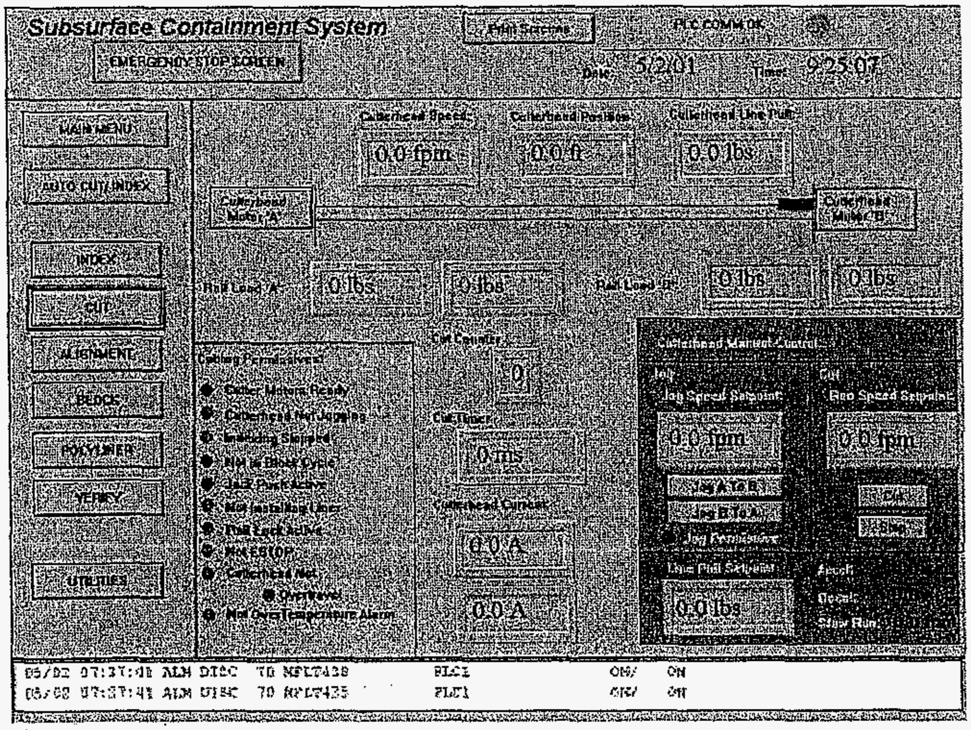

*Figure 2.1-26 Human-Machine Interface Screen*

The following provides a brief description of the Human-Machine Interfaces:

The operations HMI allows the operator to control the following machine functions:

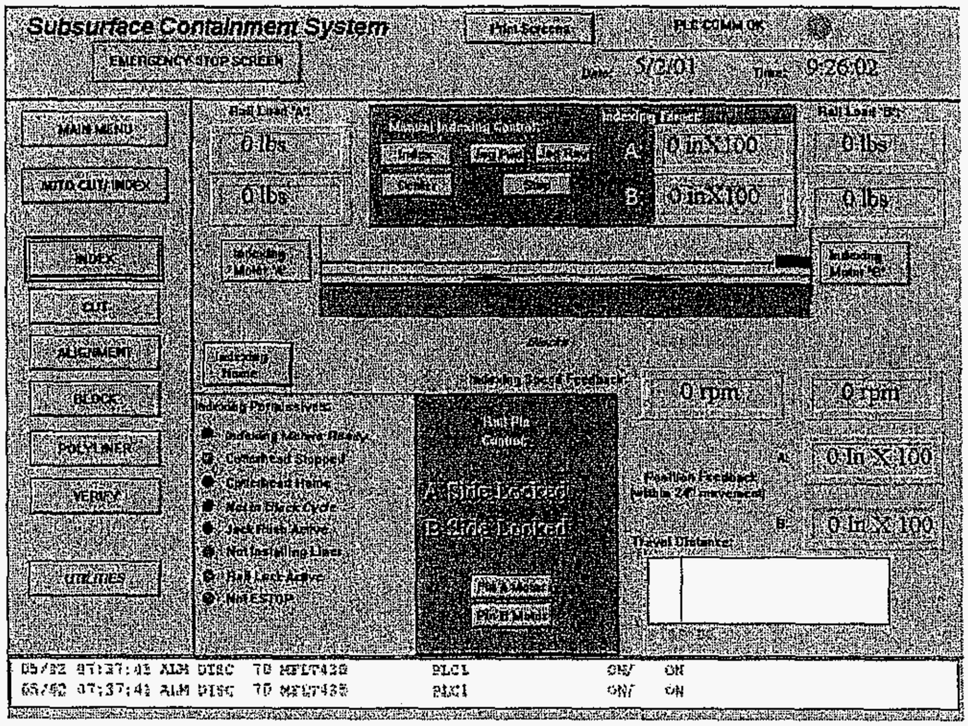
| TABLE 2.1-2 SCU OPERATING FUNCTIONS | |
|---|---|
| **Operating Function** | **Operating Range** |
| Cutterhead Speed | 0-200 fpm |
| Indexing Distance | 0-1 in. |
| Cutterhead Beam Pitch | 1° |
| Cutterhead Beam Yaw | 1° |
| Indexing Lock | On/Off |
| Slot Block Grab/Hoist/Insert | Activate/Deactivate |
| Slot Block Alignment | 1 in. over 15 ft |
| Alignment Jack Loading | 0-1500 lbs |
| Alignment Jack Travel | 0-30 in. |
| Polyliner Insert | Activate/Deactivate |
| Polyliner Shear | Activate/Deactivate |

The following provides a brief description of the HMI to implement the above operating functions:




**Cutterhead Control:** This screen allows the operator to set the run speeds (2-200 fpm) and manually move the cutterhead across the face and observe the cutterhead location, cutterhead motor amps, and indexing rail loading. This screen also identifies the status of the cutter permissives.

*Figure 2.1-27 Cutterhead Control Screen*




**Index Control:** This HMI allows the operator manually to activate the indexing mechanism. This screen provides the operator information regarding the longitudinal position of the index mechanism (distance from start) and the indexing rail loads. It also provides status of the indexing permissives and the status of the rail lock mechanism.

*Figure 2.1-28 Index Control Screen*

**Automated Cut-Index Operation:** This HMI allows the operator to activate the automated cutterhead/indexing operation at a set maximum cutterhead speed (0-200 fpm) and indexing distance (0-1 in.). It provides the operator with data regarding the position of the cutterhead beam-to-block distance and the cutterhead drive motor amps. It also provides the operator with the information on the current machine function and status of run permissives.

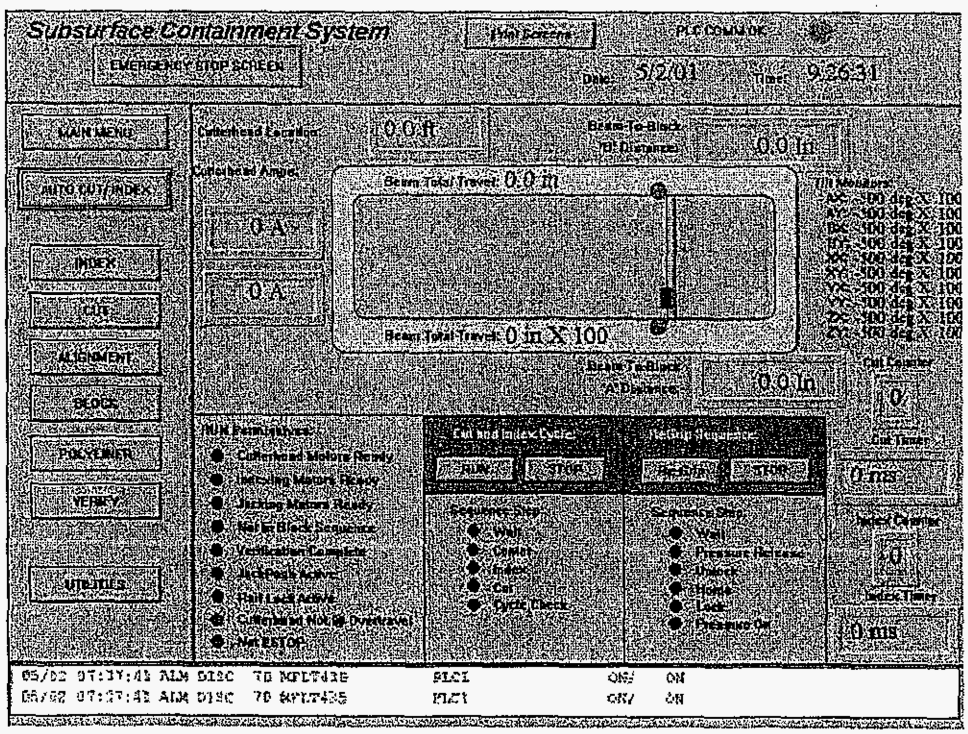



*Figure 2.1-29 Automated Cut-Index Screen*

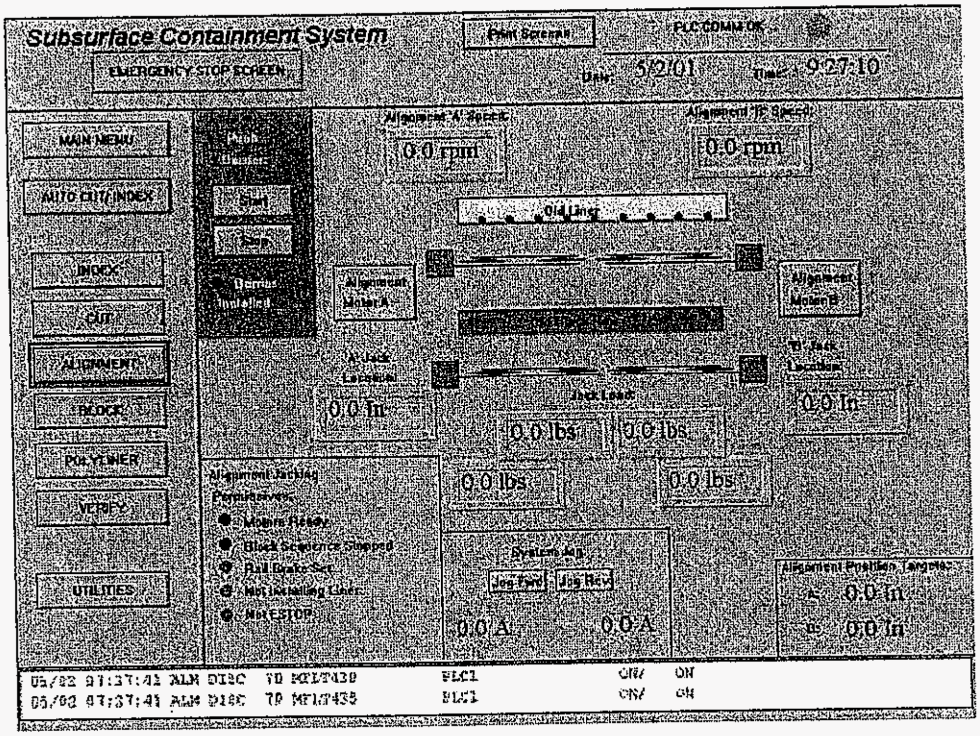



*Figure 2.1-30 Alignment Jack Control Screen*

**Alignment Jack Control:** This HMI allows the operator to perform several functions regarding the alignment jacks.

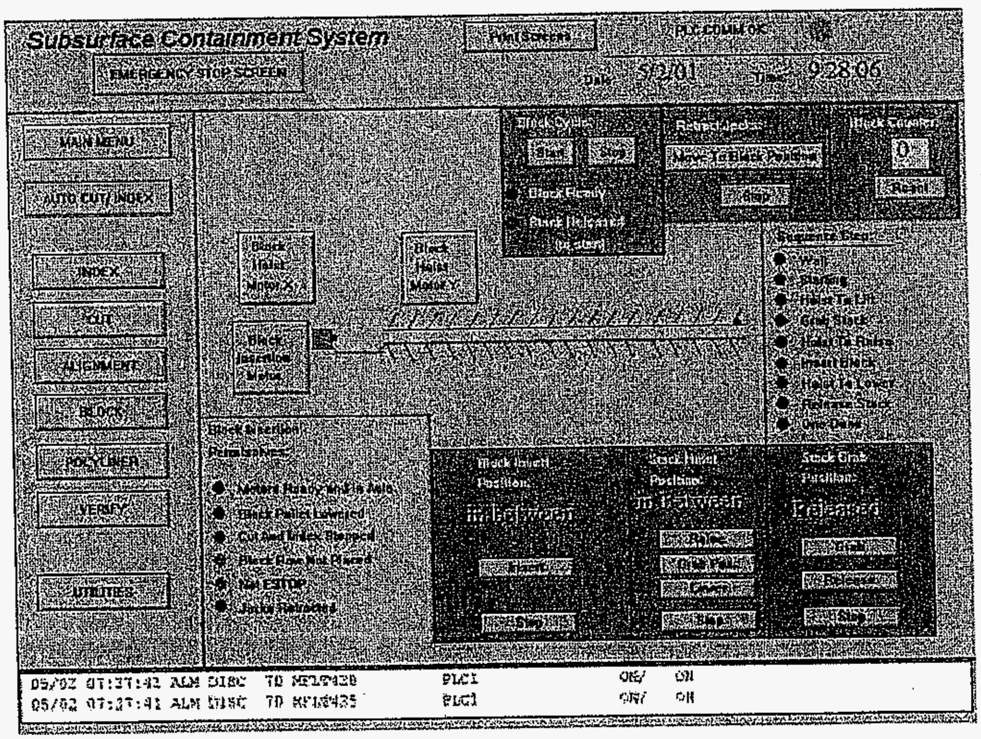



*Figure 2.1-31 Block Placement Screen*

**Block Placement:** This HMI provides the operator with the ability to control and monitor the slot block placement functions.

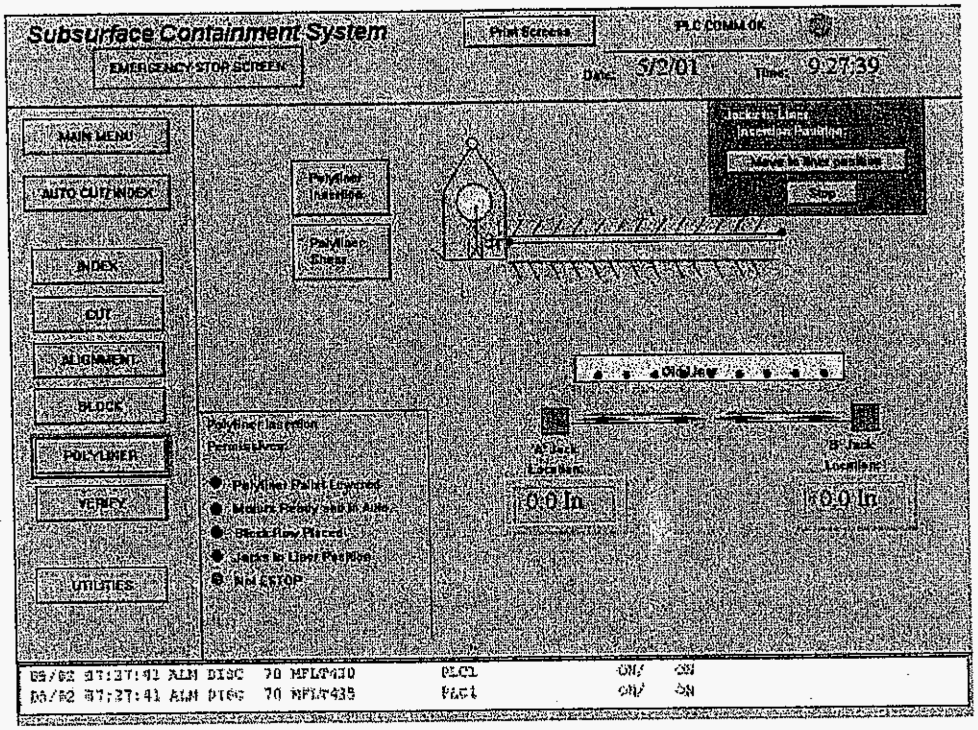



*Figure 2.1-32 Polyliner Placement Screen*

**Polyliner Placement Operations:** This HMI provides the operator with the ability to activate and monitor the polyliner placement operations.

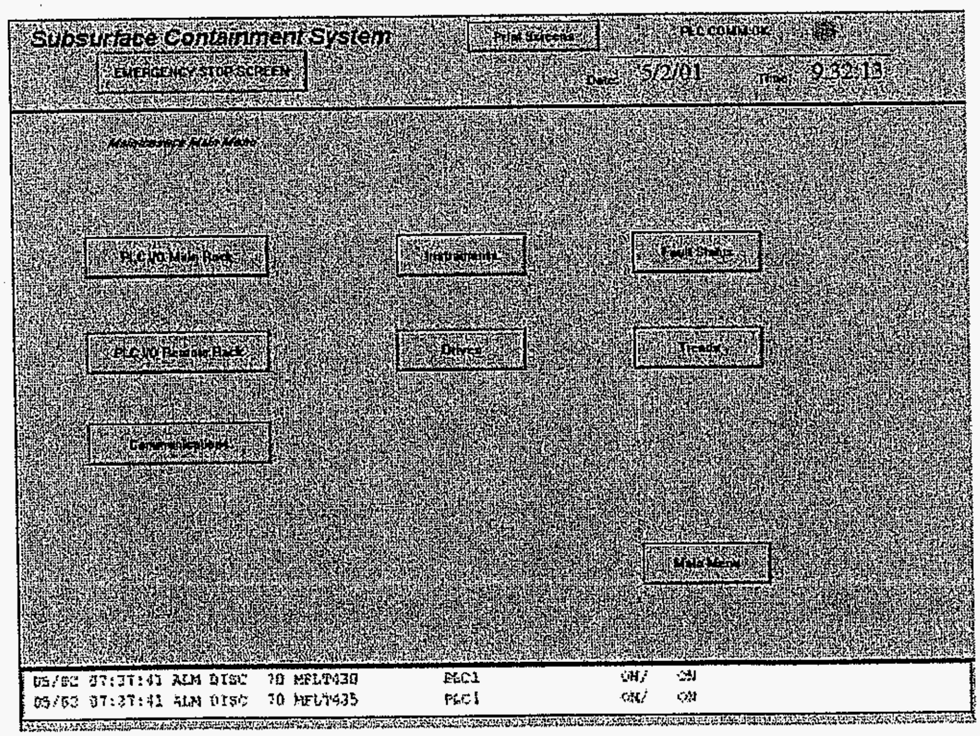



*Figure 2.1-33 Maintenance Screen*

**Maintenance Module:** The SCCS maintenance module provides information and data helpful in determining equipment and component status and assists maintenance personnel in problem troubleshooting. The maintenance module main menu screen is shown in Figure 2.1-33.

The following provides a brief explanation of each of the menu items.

**Trends:** Displays all trends useful for troubleshooting and diagnostic purposes. For example, trends of raw (unfiltered) instrument data or current feedback trends for breakers in the Motor Control Center.

**Alarm Module:** The SCCS alarm module provides both audio and visual notification of an event to the operator and operating crews and activates a system response based on the potential severity of the event. Table 2.1-3 highlights the SCCS alarm types, notification method, and system response.

**TABLE 2.1-3 ALARM TYPE, NOTIFICATION, & SYSTEM RESPONSE**

| Alarm Type | Notification Method | | | System Response | | |
|---|---|---|---|---|---|---|
| | Screen Test | PC Audio | Lights/ Siren | Operational Hold | Operational Stop | Power Shutdown |
| 01— Machine Operating | ✔ | ✔ | | ✔ | ✔ | |
| 02—Health Monitoring | ✔ | ✔ | ✔ | | ✔ | |
| 03—Data Logging | ✔ | | | ✔ | | |
| 03—Safety Devices | ✔ | ✔ | ✔ | | | ✔ |

The following provides a brief explanation of each of the alarm types.

**Machine Operating Alarms:** Occurs when the SCU fails to operate consistent with the set operating parameters [e.g., indexing distance set point (0.5 in.) versus actual distance traveled (0.4 in.)].

**Health Monitoring Alarms:** Occurs when a health monitoring indicator/sensor is activated or exceed set points.

**Data Logging Alarms:** Occurs when a transducer provides information that exceeds expected data ranges (e.g., data indicates cutterhead speed of 220 fpm versus data range of 0-200 fpm).

**Safety Devices Alarms:** Occurs when a safety devices is activated (e.g., explosion sensor, emergency stop). The SCCS has been designed to provide three types of alarm notifications. The following provides a brief description of each of these notification methods.

**Pop-Up Screen Text:** A text notification below the PC screen to notify the operator that an event has occurred.

**PC Audio:** A PC-initiated sound that repeats on a time interval to notify the operator of an event.

**Lights/Siren:** Lights and siren located both inside and outside the operator's control station to notify both the operator and construction crew of an event. Based on the nature of the event, three types of system responses can occur: operational hold, operational stop, and power shutdown.

**Operational Hold:** Allows the SCU to complete the current operational function (e.g., cut the face), but requires the operator to acknowledge the event and to take action before further operating functions can occur.

**Operational Stop:** Initiates immediate stop of the current operation and requires that the operator acknowledge the event and take specific actions as specified in the SCU operating manual before operations can resume.

**Power Shutdown:** Initiates immediate electrical power shutdown from power distribution center. This response to an event requires that the operator acknowledge the event and take appropriate action as defined in the SCU operating manual before operations can resume.

All alarm events and actions taken will be manually recorded by the SCU operator. A time- based electronic file of the alarm events will also be created daily and can be accessed through the report screen. This electronic alarm file will be downloaded daily by the test manager.

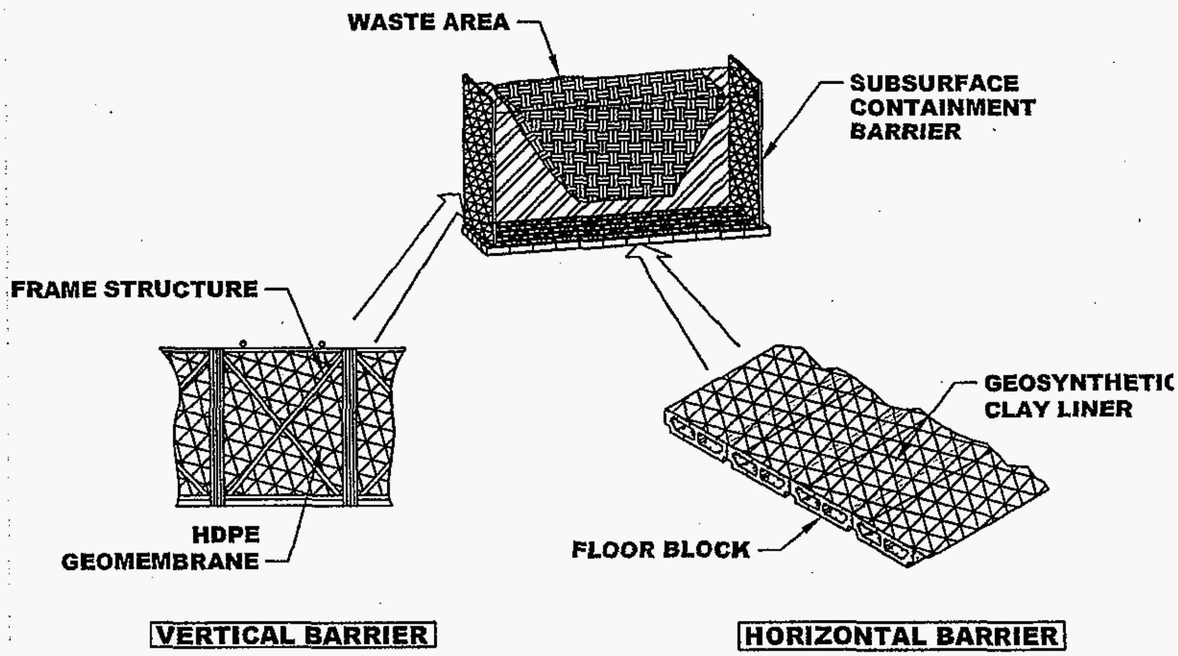
**Trending Module:** The SCCS trending module provides both real-time and historical trending data for operations, health monitoring, and data logging instruments and devices.

## 2.2 BARRIER MATERIALS

This section provides a brief description of the construction materials used to construct the subsurface containment barrier. The materials used include the geosynthetic barrier materials and the precast concrete floor blocks.

### 2.2.1 GEOSYNTHETIC BARRIER MATERIALS

The subsurface containment barrier, as illustrated in Figure 2.2-1, consists of a horizontal barrier, a vertical barrier, and the necessary joints. The bottom horizontal barrier is constructed of 80-mil, geosynthetic clay liner (GCL) supported by custom, precast concrete blocks. The ends and vertical side barriers are constructed of 100-mil, HDPE fabricated into 16-ft-wide panels and joined together by standard geosynthetic joints.




| PROPERTY | VERTICAL BARRIER | HORIZONTAL BARRIER* |
|---|---|---|
| • Thickness | 100 mils | 80 mils |
| • Density | 0.94 g/cc | 0.94 g/cc |
| • Tear Resistance | 84 lbs | 60 lbs |
| • Puncture Resistance | 238 lbs | 105 lbs |
| • Tensile Properties<br>— Yield<br>— Break<br>— Elongation @ Break | <br>259 lbs/in. width<br>486 lbs/in. width<br>700% | <br>173 lbs/in. width<br>324 lbs/in. width<br>560% |
| • Roll Length | 350 ft | 350 ft |
| | | *Bentonite Coating = 1.0 psf<br>*Metallic Strip = 1 in. |

*Figure 2.2-1 Subsurface Containment Barrier*

The 80-mil, geosynthetic clay liner is manufactured by GSE Lining Technologies, Inc. The GCL combines the high swelling and sealing characteristics of bentonite clay with the low permeability of polyethylene geomembrane. Approximately 1.0 psf of high-quality, sodium bentonite is adhered to the membrane. The 80-mil, polyethylene geomembrane has high tensile strength and is puncture resistant. The GCL will be manufactured in a strip 30-in. wide and 150-ft long and rolled onto a 6-in. mandrel to be loaded into the polyliner magazine. The GCL specifications are shown in Table 2.2-1.

**TABLE 2.2-1 GCL SPECIFICATIONS**

| Property | Test Method | Values | | | | |
|---|---|---|---|---|---|---|
| **GCL** | | | | | | |
| Bentonite Coating, minimum, lbs/sq ft (kg/sq m) | GSE QC/QA Procedures | 1.0 (4.9) | | | | |
| Hydraulic Conductivity: GundSeal, maximum, cu m/sq m-sec | ASTM D 5887 | $4 \times 10^{-14}$ | | | | |
| Effective Hydraulic Conductivity: Geomembrane, maximum, m/sec | ASTM E 96 | $7 \times 10^{-13}$ | | | | |
| Hydraulic Flux: Gentonite, maximum, cu m/sq m-sec | ASTM D 5887 at 5 psi (34.5 kPa) | $5 \times 10^{-11}$ | | | | |
| Hydraulic Flux: Overlapped Seam, maximum, cu m/sq m-sec | ASTM D 5887 at 5 psi (34.5 kPa) | $5 \times 10^{-11}$ | | | | |
| Wet/Dry Cycles, maximum, 10 cycles | ASTM D 5887 at 5 psi (34.5 kPa) | No Effect on Permeability | | | | |
| Freeze/Thaw Cycles. maximum, 4 cycles | ASTM D 5887 at 5 psi (34.5 kPa) | No Effect on Permeability | | | | |
| **Polyethylene Geomembrane** | | | | | | |
| | | **Smooth Geomembrane** | | | **Textured Geomembrane** | |
| Thickness, minimum, mils (mm) | ASTM D 751/1593/5199 | 11 (0.28) | 18 (0.46) | 54 (1.35) | 27 (0.68) | 54 (1.35) |
| Density, minimum, g/cu cm | ASTM D 792/1505 | 0.94 | 0.94 | 0.94 | 0.94 | 0.94 |
| Tensile Properties, minimum | ASTM, D 638, Type IV | | | | | |
| Strength at Break, lb/in.-width (N/mm) | Dumbell, 2 ipm | 35 (6) | 58 (10) | 243 (43) | 38 (7) | 75 (13) |
| Strength at Yield, lb/in.-width (N/mm) | | 20 (3.5) | 33 (5.9) | 130 (23) | 65 (11) | 130 (23) |
| Elongation at Break, % | G.L. = 2.5 in. (64 mm) | 400 | 400 | 560 | 120 | 120 |
| Elongation at Yield, % | G.L. = 1.3 in. (33 mm) | 10 | 10 | 13 | 13 | 13 |
| Puncture Resistance, minimum, lb (N) | FTMS 101, Method 2065 | 16 (71) | 26 (115) | 80 (356) | 38 (169) | 80 (356) |

| TABLE 2.2-1 GCL SPECIFICATIONS (Continued) | | |
|---|---|---|
| **Property** | **Test Method** | **Values** |
| **Bentonite** | | |
| Montmorillonite Content, minimum, % | X-Ray Analysis | 90 |
| Fluid Loss, maximum, ml | ASTM D 5891 | 18 |
| Free Swell, minimum, ml | ASTM D 5890 | 24 |

Joining of the horiztonal and vertical barriers is performed in situ and relies on a special joint design and extrusion welding techniques as shown in Figure 2.2-2. The following provides a brief description of the joining methods used.

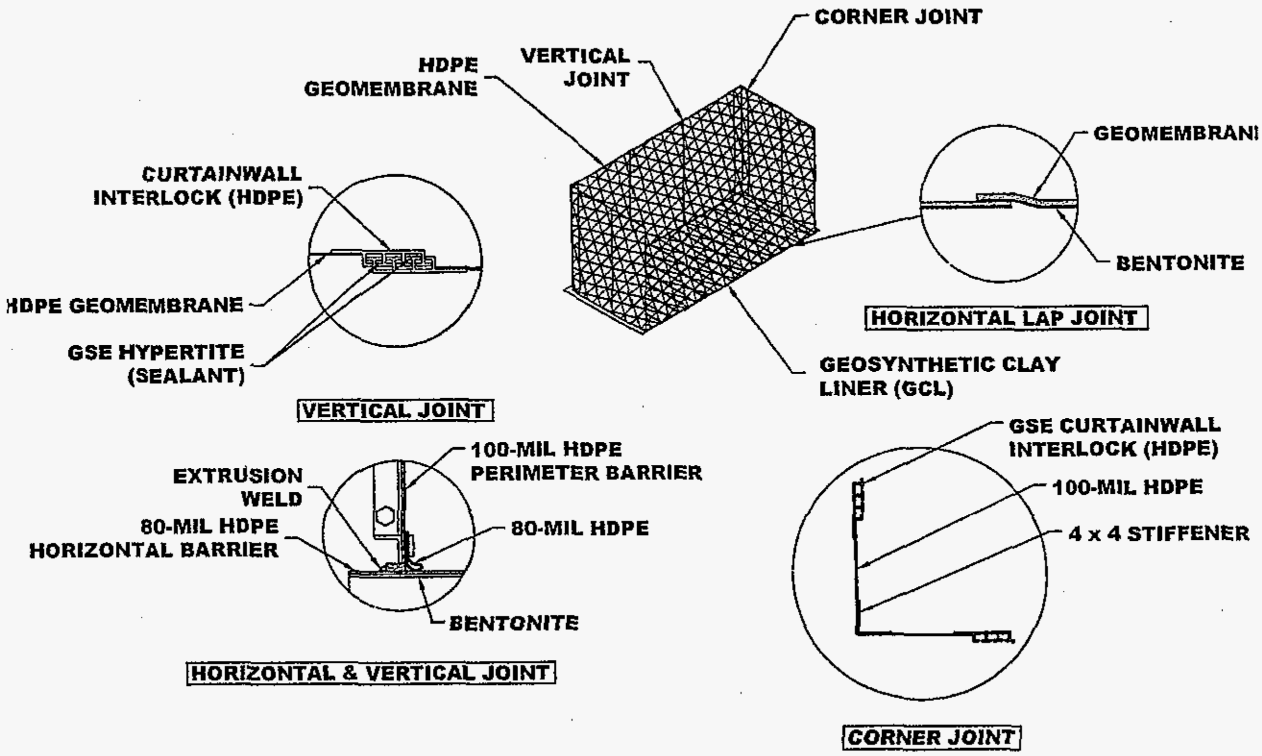



*Figure 2.2-2 Barrier Joint Detail*

**Horizontal Lap Joint:** This joint is achieved by providing a 6-in. overlap of the 30-in.-wide GCL strips. This joint relies upon the ground pressure and the expansive capabilities of the sodium bentonite to provide a joint seal.

**Vertical Interlock Joint:** This joint is a multichannel locking device made of HDPE and requires two pieces to form the joint. Utilizing this component with the HDPE geomembrane forms a panel. The design of the joint allows a vertical slip plane permitting differential vertical movement. Concurrent placement of a hydrophilic rubber sealant (capable of swelling to eight times its size) during installation causes the joint to compress or fit tight.

**Horizontal-Vertical Joint:** This special joint treatment relies upon the extrusion welding of an outer L-shaped flap located at the bottom of a geomembrane panel to the GCL liner and an 80-mil HDPE flap that provides an inner compression seal.

**Corner Joint:** This specially formed HDPE geomembrane panel is stiffened in the corner and includes two interlocking joints.

### 2.2.2 PRECAST CONCRETE FLOOR BLOCKS

The concrete floor blocks as shown in Figure 2.2-3 are 37-in. long, 24-in. wide, and 7-in. high and weigh approximately 4000 lbs. The block is constructed of a standard 3000-psi concrete mix and rebar.

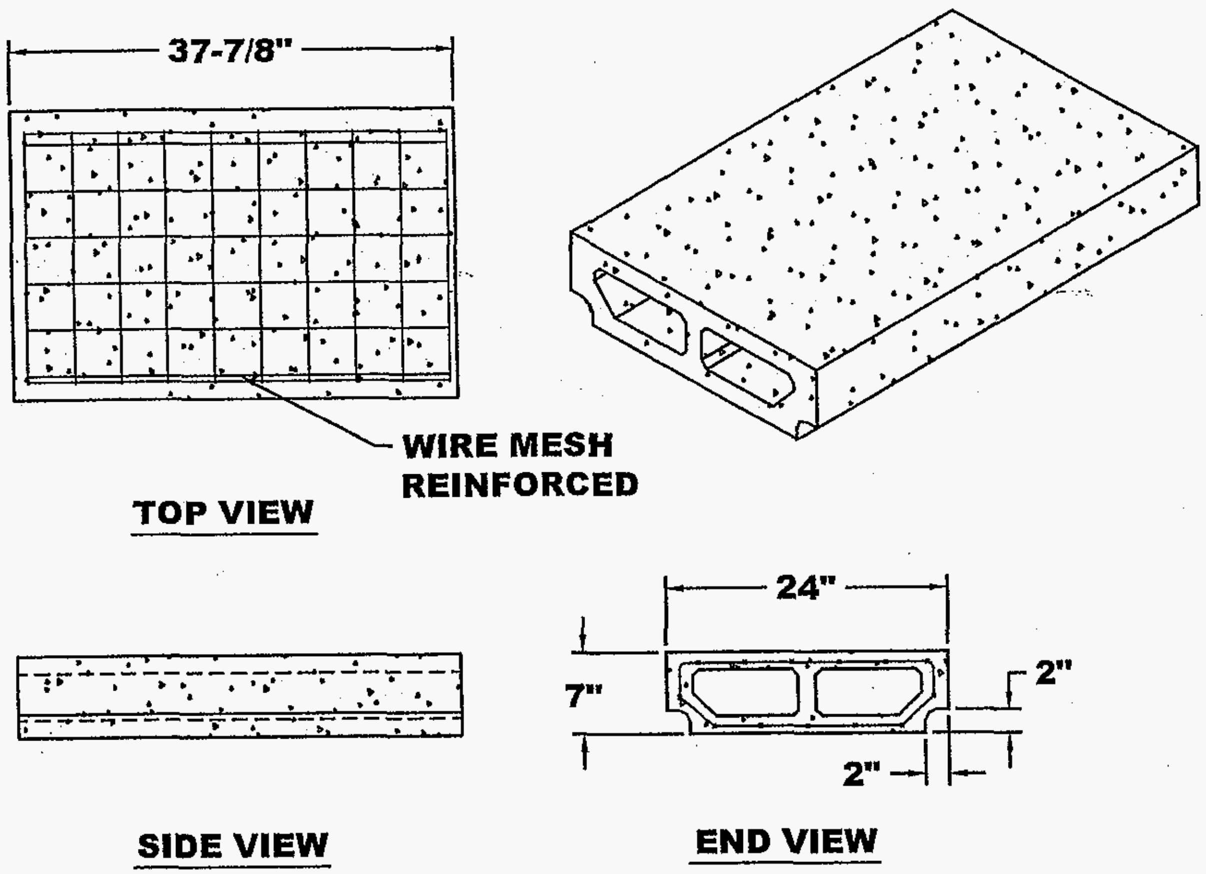



*Figure 2.2-3 Precast Concrete Floor Block Layout*

## 2.3 CONSTRUCTION PROCESS

The SCS is intended to construct the subsurface containment barrier in a safe, environmentally compliant, and cost-effective manner. To achieve this objective, the construction process relies upon minimum equipment, efficient and well-trained labor, and simple operations. The integration of these into a continuous construction process makes the RAHCO-developed SCS construction method unique and cost-effective. A CD-ROM is provided as part of this report to describe the overall construction method.

The SCS construction process consists of a three-stage operation as shown in Figure 2.3-1: mobilization, subsurface barrier construction, and demobilization.

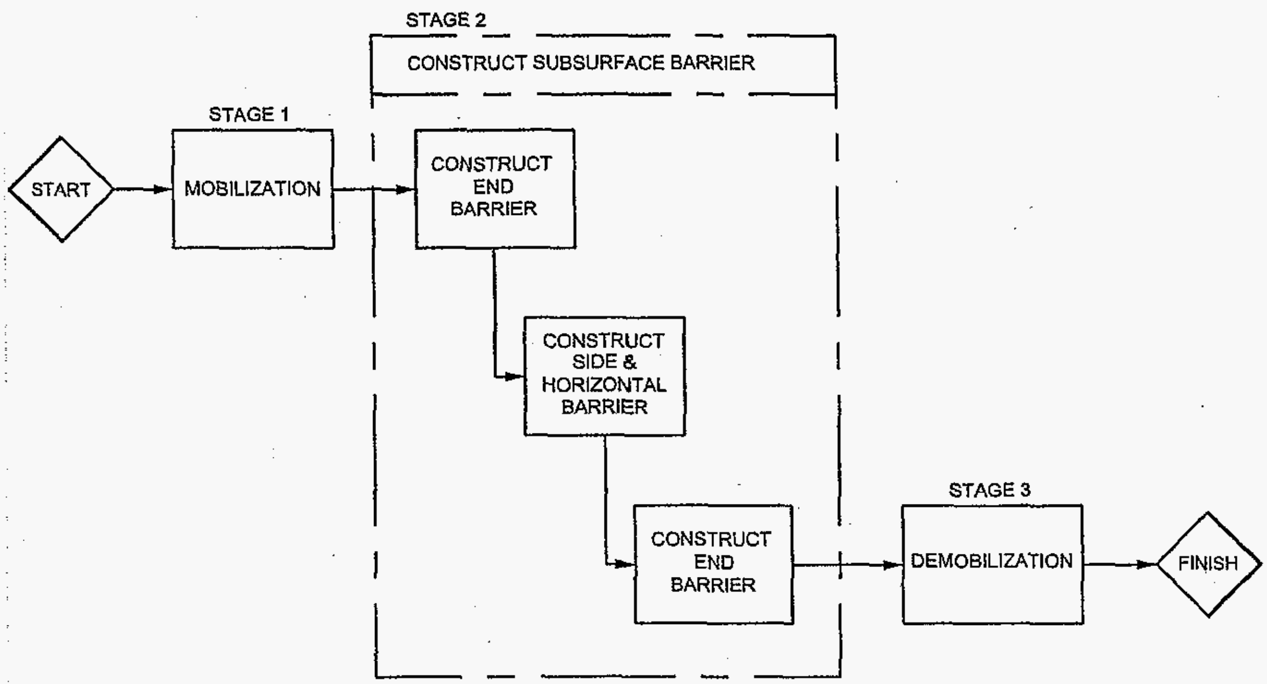



*Figure 2.3-1 SCS Construction Flow Diagram*

All construction operations will be performed in accordance with the established Environmental Safety and Health Plan, Environmental Compliance Plan, and Trench Safety Plan.

- Environmental Safety & Health Plan: This plan establishes the work practices necessary to ensure the protection of the construction personnel and provides a mechanism for the establishment of safe working conditions at the site. The safety organization and environmental safety and health procedures will be established following an analysis of potential hazards at the site. Specific hazard control methodologies will be evaluated and selected in an effort to minimize the potential for accidents or injury. All construction activities will be performed in accordance with the Occupational Safety & Health Administration (OSHA) standards in 29 CFR 1910 and 1926 and identified consensus standards.

- Environmental Compliance Plan: This plan describes the method for complying the applicable Work Smart Standards. It does not address specific sensor or detection technology (radionuclides, etc.) or methods to remediate a hazardous situation. Applicable technology and procedures currently exist within the DOE that can be used.

- Trench Safety Plan: This plan describes the equipment and methods for complying with applicable trench shoring standards and requirements.

The following provides a brief description of the major SCS construction operations and identifies the appropriate construction equipment and labor.

## 2.3.1 MOBILIZATION

The SCS requires minimal site preparation and the equipment and materials are easily and rapidly mobilized. Table 2.3-1 highlights the operations and specific activities to be performed during mobilization.

**TABLE 2.3-1 MOBILIZATION**

| Operation | Activities |
|---|---|
| 1. Prepare Site | Lay out test site, access electrical power, grade and contour site, install silt fences, and construct infiltration/ sedimentation trench. |
| 2. Mobilize Equipment & Materials | Transport SCU and PCU to test site, stage construction materials, and assemble construction equipment. |

### 2.3.1.1 Prepare Site

Site Preparation includes those activities that will be accomplished prior to equipment and material mobilization and includes access road improvement, construction survey, work area delineation, grading, and construction of equipment laydown area. Guidelines will be followed for managing, minimizing, and disposing of wastes as per the approved Environment Compliance Plan and will provide the necessary ESH monitoring as required per the ESH Plan.

- **Access Roadway Improvements & Parking Area Construction:** The existing roadways accessing the DOE buried waste sites are normally of good quality and are minimally compacted, sand roads. Since heavy traffic trucks normally accesses these areas, the load capacity of the road base is considered to be capable of carrying any over-the-road-type tractor-trailers used by the SCS. The width of the road, minimally 10 ft, is limited to one-way traffic for tractor-trailer-type loads, but is adequate for two-way, small pick-up truck or personnel traffic, as one of the vehicles can pull over to the side to allow passage to occur.

- **Construction Survey:** A construction survey of the site will be performed to delineate the construction boundary, excavation boundary, supplement existing topographic information, and confirm locations of existing utilities as revealed at the ground surface. Survey information will be compared with information depicted on existing design drawings. The site land survey will be performed. Land surveying will also be performed to provide "as-built" information.

- **Work Area Delineation:** Orange construction fencing will be used to delineate the work area, except at areas where silt fencing establishes the work area; i.e., no orange construction fending will be used at these locations.

- **Erosion & Storm Water Control Installation (Silt Fence Installation & Diversion Ditches):** Erosion and storm water features will be designed to provide an effective means to control both of these potential problems. A 24-hr, 25-yr storm will be used as the design storm for calculating the size of the sediment pond and diversion trenches. Standard silt fence will be provided along the downstream side of the entire work area.

- **Infiltration/Sedimentation Trench:** An infiltration/sedimentation trench will be constructed to allow for groundwater encountered during trenching and barrier construction activities. Groundwater will be pumped to this basin and be allowed to flow back into the geologic formation.

- **General Grading Preparation for Trench Installation:** General grading will be accomplished prior to trenching operations. Only minor grading is expected. The areas that will be cleared will consist of the trench areas, the stockpile area, and the laydown area.

- **Laydown Area for Equipment Assembly:** A laydown area will be prepared and used for the assembly of the barrier installation equipment. This area will consist of a fairly level area approximately 20 ft X 50 ft.

#### 2.3.1.2 Mobilize Equipment & Materials

Mobilization includes those activities necessary to assemble on site all the construction equipment and materials. Since the site is most likely to be a remote site; i.e., no easily accessible utilities are available and the time period for conducting construction operations is fairly short, no permanent type of utilities will be connected. Therefore, electrical, potable water, other water, sanitary, and phone communications will be provided on a temporary means.

The mobilization activities will include, at a minimum, the following:

**Mobilize SCU & PCU:** These units will be transported to the site using a flat bed tractor-trailer truck. The SCU will be located at the SCU staging area while the PCU will be located as shown in Figure 2.3-2.

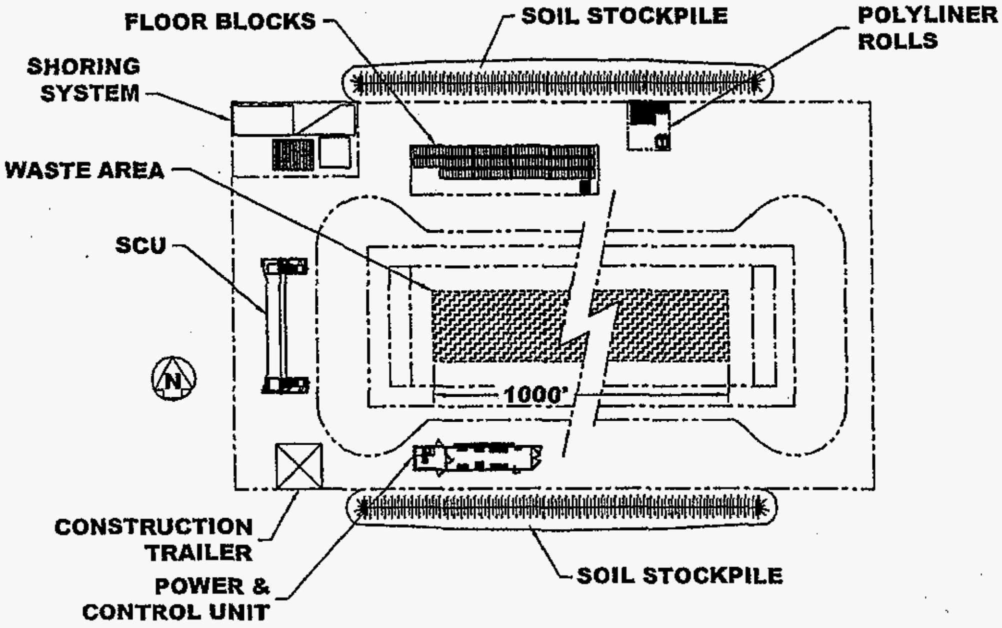



*Figure 2.3-2 Typical Site Mobilization*

**Assemble Barrier Materials:** Precast concrete floor blocks and geosynthetic materials will be delivered to the site on flat bed tractor-trailer trucks, off-loaded using a forklift, and placed in the material staging area.

**Electrical:** Electrical power will be provided by diesel generators.

**Office Trailer Setup & Security Gate Lock Arrangements** If an office trailer is used, the trailer unit will be mounted on wheels and will be supported as required. RAHCO will provide keys to the existing lock at the entrance of the access road. DOE waste sites are currently considered a secured area and thus no site-specific security fencing will be provided.

**Potable Water:** Vendor-supplied, bottled water will be used for potable water.

**Sanitary:** Toilet facilities will be provided by use of portable toilet units. The unit will be serviced by a local provider as required.

**Communication:** Phone communication will be provided by use of cell phones.

**Assemble Construction Support Equipment:** Equipment to the site will be delivered directly into the area using over-the-road equipment. Equipment will be unloaded from the trailers using appropriate lifting equipment; e.g., cranes. Equipment accessing the site will be required to stay on the roadway.

**Fuel Storage Setup:** No gasoline will be stored on site; only diesel-grade fuel will be stored in temporary steel tanks. Tanks will meet the required local regulations for the temporary storage of diesel fuel.

**Personnel Training:** Full-time employees will be required to have current training in accordance with the site training requirements.

**ESH Support:** Full-time ESH representatives and/or technicians will be on site during trenching and barrier construction. At a minimum, the following monitoring will be performed:

- Provide monitoring equipment.
- Conduct required monitoring as per approved ESH and environmental compliance plans.

## 2.3.2 CONSTRUCT SUBSURFACE BARRIER

During barrier construction operations, the SCS equipment operates in a continuous, "inchworm" manner at barrier placement rates to 12 ft/day with only 100 ft of open construction area. This continuous construction process as shown in Figure 2.3-3 reduces the amount of open trench, minimizes environmental impacts, improves construction efficiency, and reduces overall construction cost. Figure 2.3-4 identifies the construction process and the functions to be performed in constructing the subsurface containment barrier.

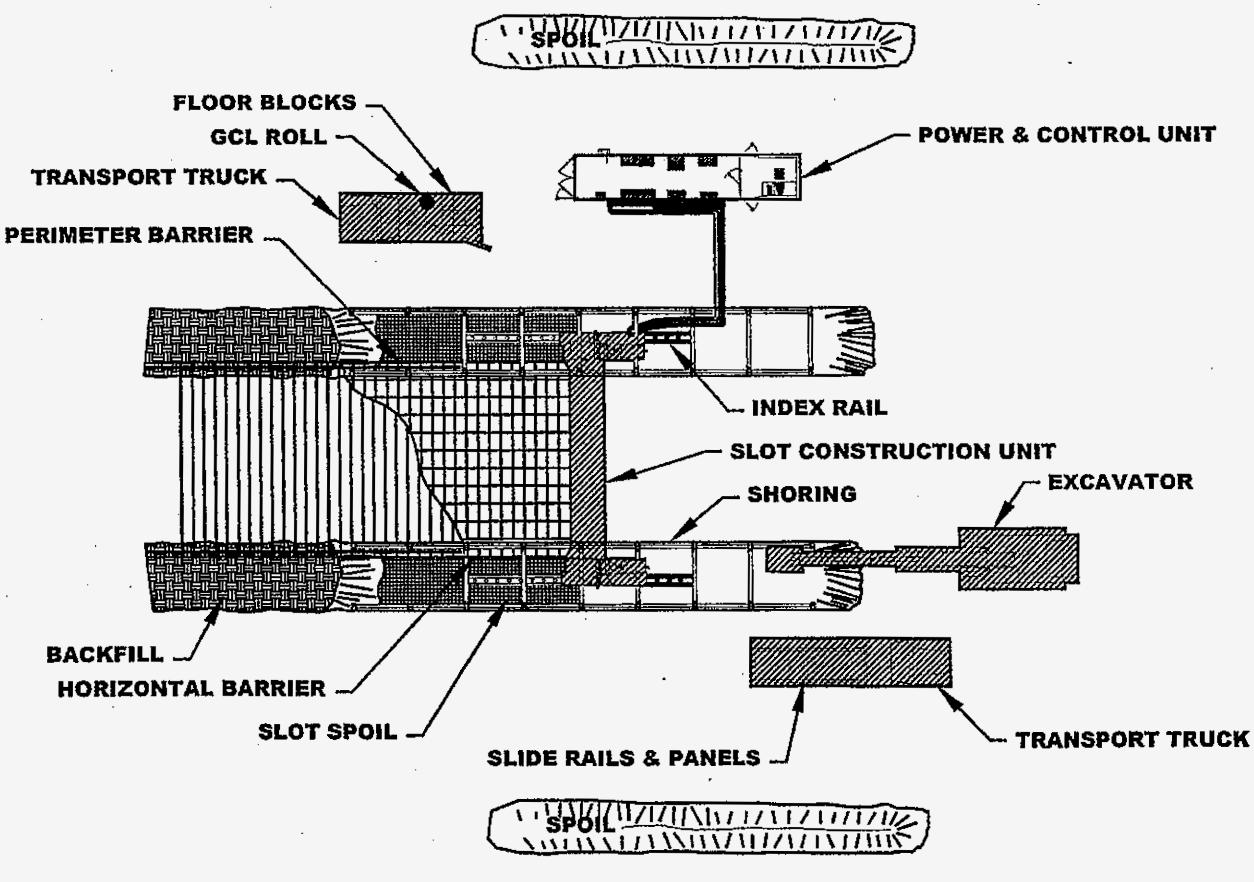



*Figure 2.3-3 Barrier Construction Operations*

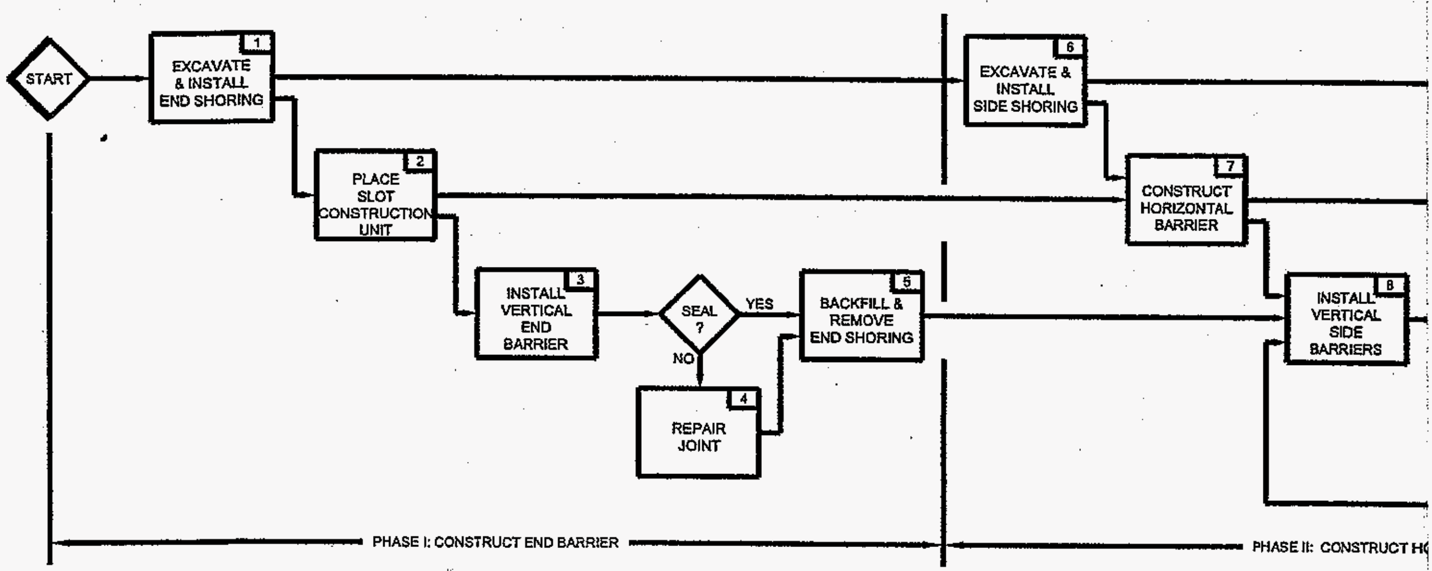
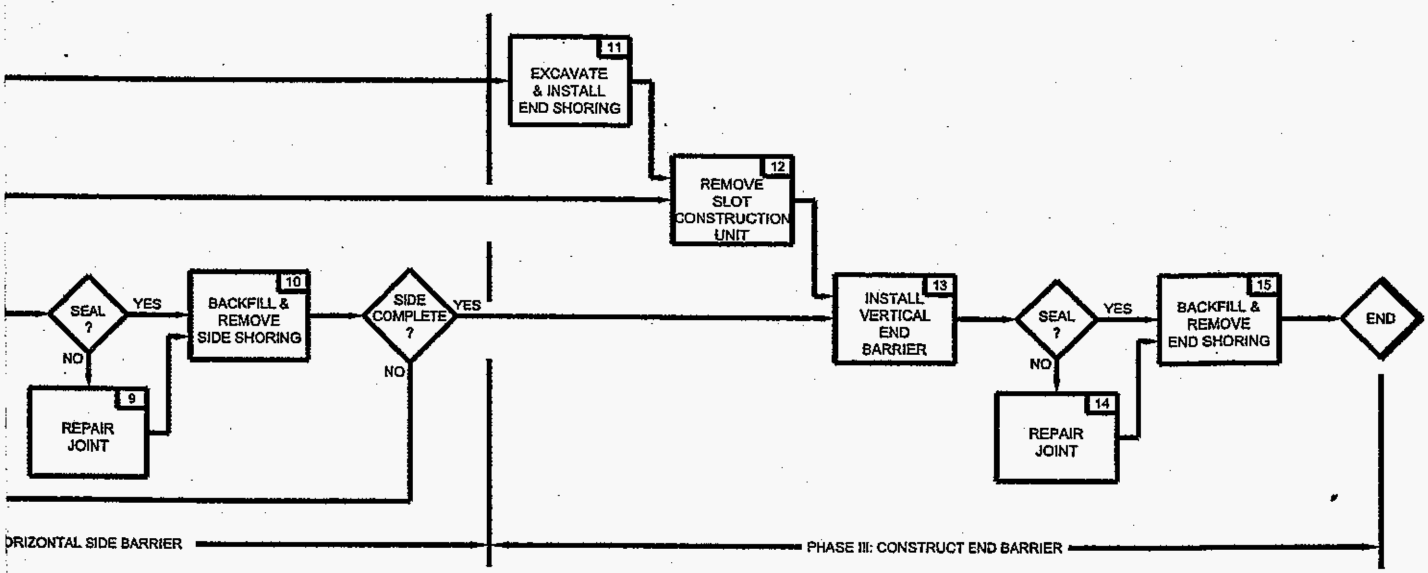



***Figure 2.3-4 Detail Co***




***istruction Flow Diagram***

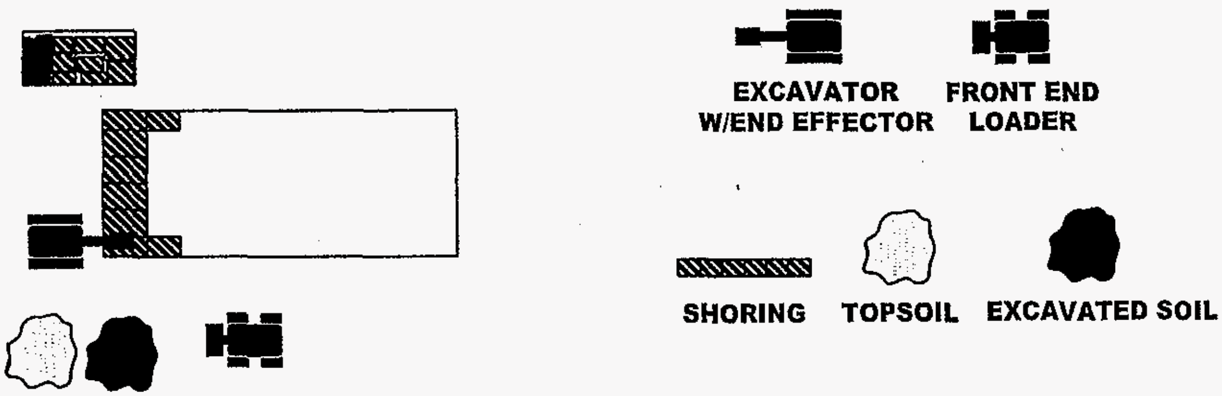
Table 2.3-2 highlights the four subsurface barrier construction operations.

| TABLE 2.3-2 CONSTRUCT SUBSURFACE BARRIER | |
|---|---|
| **Operation** | **Activities** |
| 1. Excavate Trench & Install Shoring | Excavate end and side trenches; install modular shoring system. |
| 2. Construct Horizontal Barrier | Install SCU support rails; perform equipment checkout; install block stops; excavate horizontal slot; construct horizontal barrier; remove SCU and rails. |
| 3. Install Vertical Barrier | Install vertical barrier panels; weld horizontal-vertical joint; inspect joint. |
| 4. Backfill Trench & Remove Shoring | Backfill and compact excavated soil; remove shoring. |

The following provides a brief description of these operations, highlights the key activities to be performed, and identifies the equipment and operating crew required.

### 2.3.2.1 Excavate Trench & Install Shoring

This operation excavates either a 16-ft-wide end trench or a 10-ft-wide side trench to depths of approximately 35 ft and installs the modular slide-rail shoring system. Figure 2.3-5 summarizes the activities, equipment, and crew required.




| Key Activities | Equipment | Operating Crew |
|---|---|---|
| • Establish Grades<br>• Selectively Remove & Stockpile Topsoil<br>• Excavate Trench<br>• Install Shoring<br>• Install/Activate Sump Pumps | • Excavators/End Effectors<br>• Overburden End Effectors<br>• Front End Loader<br>• Shoring System | • Foreman<br>• Equipment Operators<br>• Survey Crew<br>• Laborers |

*Figure 2.3-5 Excavate Trench & Install Shoring*

*Figure 2.3-6 Typical Shoring System Installation*

Figure 2.3-6 shows the trenching operation using the modular shoring system. The following describes the shoring system installation.

The linear rails with the appropriate spreader units are assembled in the staging area. Simultaneously, the excavator digs a pilot cut slightly larger than the outside dimensions of the shoring system to a depth of approximately 5 ft and places the slide-rail pair into the pilot cut perpendicular to the centerline of the trench as shown in Figure 2.3-7. The excavator then installs the two knife-edge panels in the tracks of the rails and places a second slide-rail pair at the free end of the two panels as shown in Figure 2.3-8.

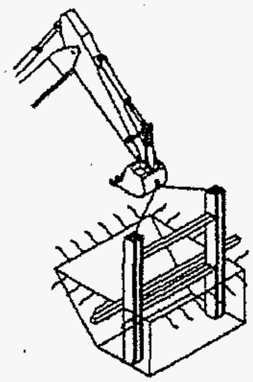


*Figure 2.3-7 Excavate Pilot Cut & Place Slide Rail*

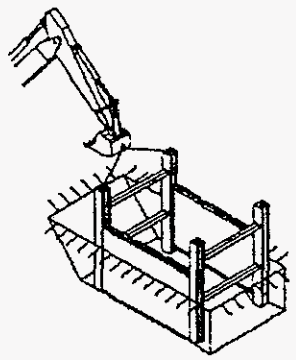


*Figure 2.3-8 Install Panels & Rails*

The excavator can now begin excavating inside the shoring as shown in Figure 2.3-9 to allow the slide-rails and panels to be placed to depth. The initial panels and slide-rails are pushed into place using the excavator bucket as shown in Figure 2.3-10.

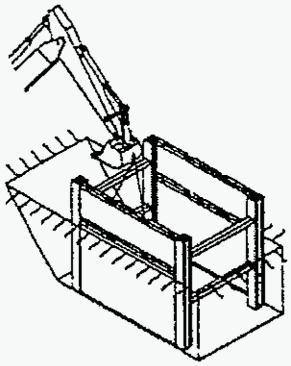


*Figure 2.3-9 Excavate Trench*

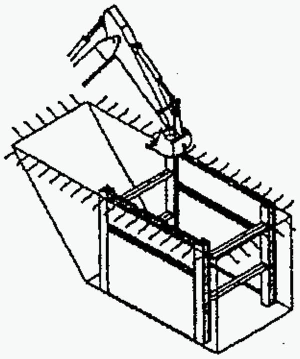


*Figure 2.3-10 Position Rails & Panels*

Following this operation, the excavator places two stacker panels on top of the installed panes as shown in Figure 2.3-11 and pushes the shoring into the ground as illustrated in Figure 2.3-12.

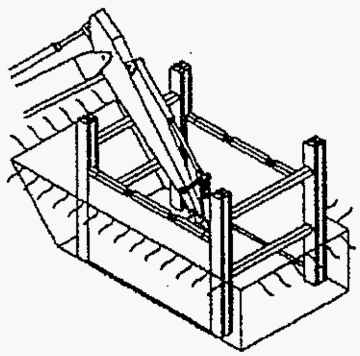


*Figure 2.3-11 Install Stacker Rails & Panels*

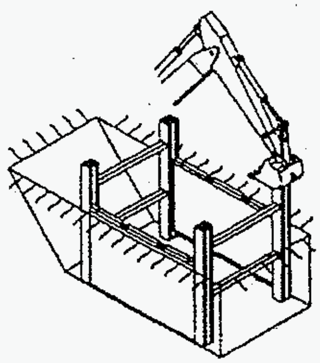


*Figure 2.3-12 Excavate & Position Rails & Panels*

The excavator then installs the two preassembled rail pairs onto the top of the installed rails and installs the two panels into the tracks of the newly installed rails and pushes the system into the ground as the excavation proceeds as shown in Figure 2.3-13. The process of installing slide-rail posts and panels is then repeated as illustrated in Figure 2.3-14 until the maximum depth of 35 ft is reached.

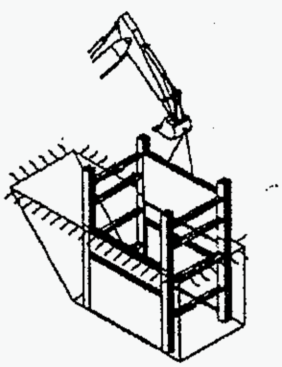


*Figure 2.3-13 Excavate & Install Components*

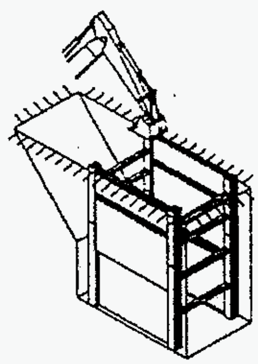
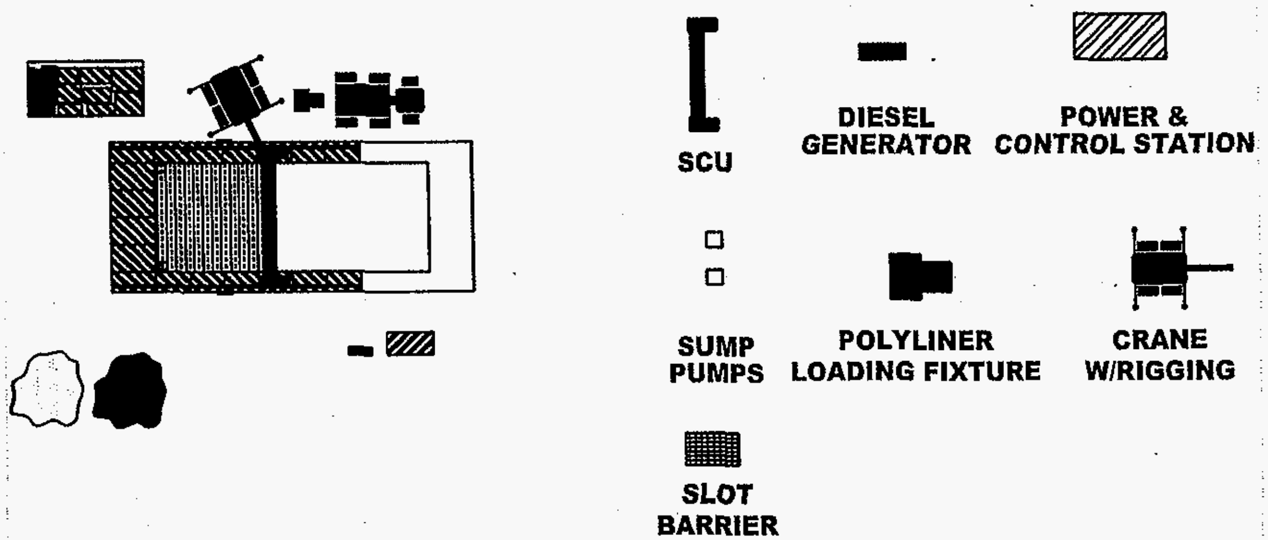


*Figure 2.3-14 Position Stacking Shoring*

Removal of the shoring is accomplished by reversing the above steps. The lower panels are removed first as backfill is placed and compacted.

### 2.3.2.2 Construct Horizontal Barrier

This activity as shown in Figure 2.3-15 installs the SCU support rails and the SCU in the end trench, performs equipment checkout, and installs the block stops. In addition, it excavates a 12-in., horizontal slot between the two side trenches; discharges the muck into the sides trenches; constructs the horizontal barrier; and removes the SCU.




| Key Activities | Equipment | Operating Crew |
|---|---|---|
| • Install/Remove SCU Support Rails<br>• Place/Remove SCU/PCU<br>• Perform Equipment Checkout<br>• Construct Horizontal Barrier<br>• Validate Barrier Placement | • SCU Support Rails<br>• SCU/PCU<br>• Diesel Generator<br>• Sump Pumps<br>• Cranes<br>• Transporter Truck<br>• Access Ladders<br>• Polyliner Loading Fixture | • Foreman<br>• SCU Operators<br>• Equipment Operators<br>• Laborers |

*Figure 2.3-15 Construct Horizontal Barrier*

Using a 40-ton crane, sections of the SCU support rail are installed on each side of the waste area, fastened to the support crossbraces, and shimmed to the proper vertical and horizontal positions.

Two 100-ton cranes are used to remove the 90,000-lb SCU from the flat bed truck and lower the unit into position in the end trench. Similarly, the two cranes are used to remove the PCU from the flat bed transport truck and position it near the waste area. A typical installation is shown in Figure 2.3-16.

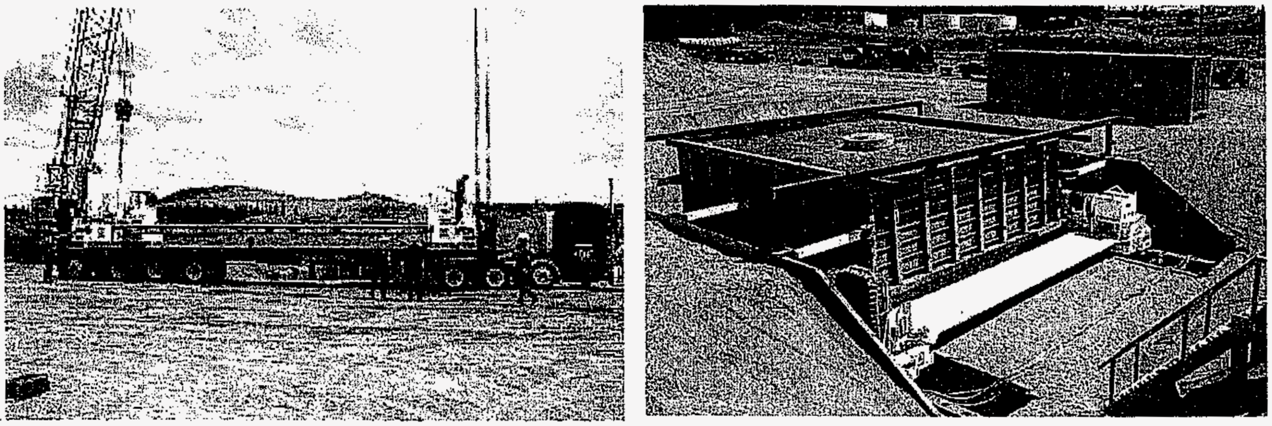


*Figure 2.3-16 SCU Installation*

Following installation of the SCU and PCU, the equipment is thoroughly checked out and advanced a distance of 6ft. Here, block stops are then installed across the end trench to provide structural support for the concrete floor blocks as the SCU advances and thrusts against the blocks. Figure 2.3-17 illustrates the block stop installation operation.

*Figure 2.3-17 Block Stop Installation*

The major activities to construct the horizontal barrier include: load and place block magazine, load and place GCL magazine, excavate horizontal slot, and install horizontal containment barrier.

**Load & Place Block Magazine:** The floor block magazine is capable of holding 11 precast concrete floor blocks. With the magazine located on the ground surface, a forklift will remove 11 blocks from the staging area and place them into the magazine. A crane with standard rigging will lower the magazine onto the SCU where it will be secured to the beam structure.

**Load & Place Polyliner Magazine:** Similar to the block loading activities above, a forklift will be used to remove a 150-ft roll of GCL from the staging area and place the roll in the polyliner magazine. A crane then lowers the magazine onto the SCU where it will be secured to the beam structure.

**Excavate Horizontal Slot & Install GCL Barrier:** This activity consists of excavating a 12-in.-high, horizontal slot between the two side trenches; installing a 24-in.-wide row of floor blocks and inserting a 30-in.-wide GCL strip on the top of the blocks. The following provides a detailed description of this activity.

During normal operations, the cutterhead will travel horizontally across the beam structure at speeds to 200 fpm and excavate a 12-in.-high, horizontal slot as illustrated in Figure 2.3-18. The cutterhead travel will be provided by a wire rope connected to a pair of opposing winches. These electric motor-powered winches operate alternately to pull the cutterhead back and forth across the beam structure. The muck is removed by the cutterhead plow and deposited into the side trenches.

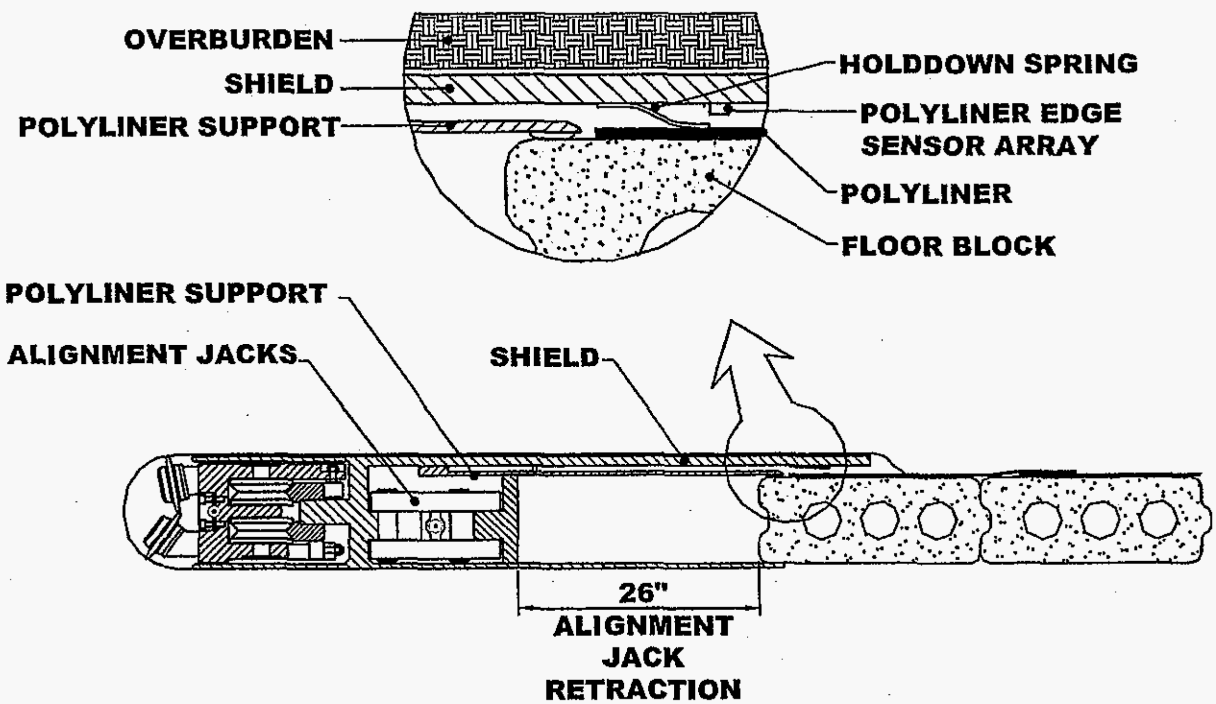



*Figure 2.3-18 Slot Excavation*

After a single pass (from one side to the other and back) of the cutterhead, the SCU Indexing Unit will advance the beam structure a distance up to 1/2 in. and the cutterhead will then be reactivated. After approximately 24 in. of advance, the rail locks and Indexing Unit will be retracted, advanced 24 in., and the rail locks reengaged into the SCU support rails.

Following this activity, the alignment jacks will be retracted 26 in. as shown in Figure 2.3-19, and the Block Inserter activated to insert 11 precast concrete blocks in a single row within the beam structure as illustrated in Figure 2.3-20.

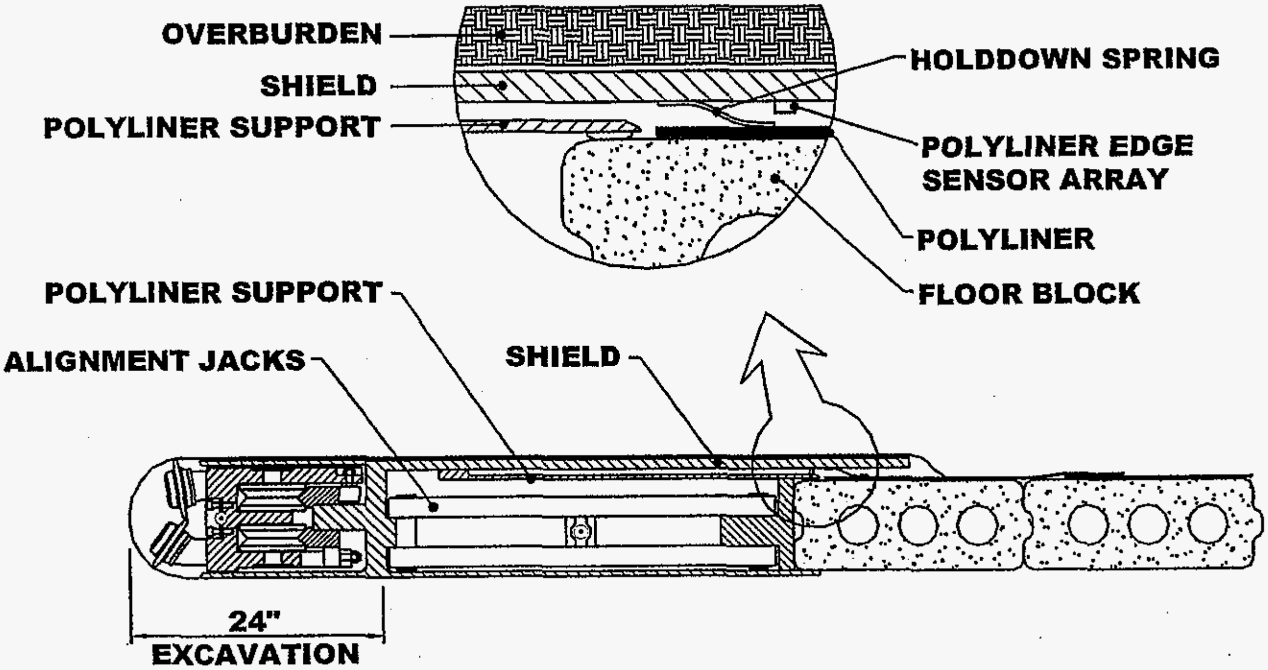



*Figure 2.3-19 Position Alignment Beam*

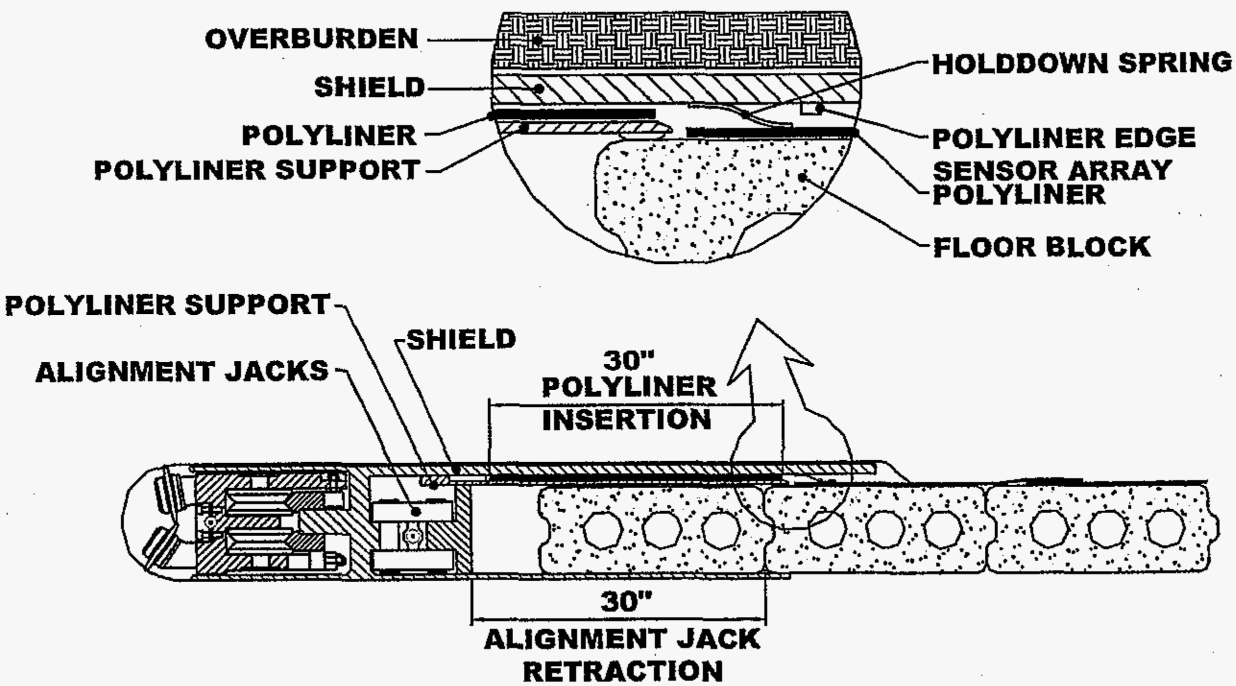



*Figure 2.3-20 Insert Floor Blocks*

The Polyliner Inserter will then be activated and a 30-in.-wide by 34-ft-long strip of geosynthetic clay liner (GCL) will be inserted in a slot formed by the upper beam structure and the polyliner support as illustrated in Figure 2.3-21. The GCL is then cut to length by the shear. The alignment jacks will then be reactivated as illustrated in Figure 2.3-22 to position the concrete blocks and GCL properly.

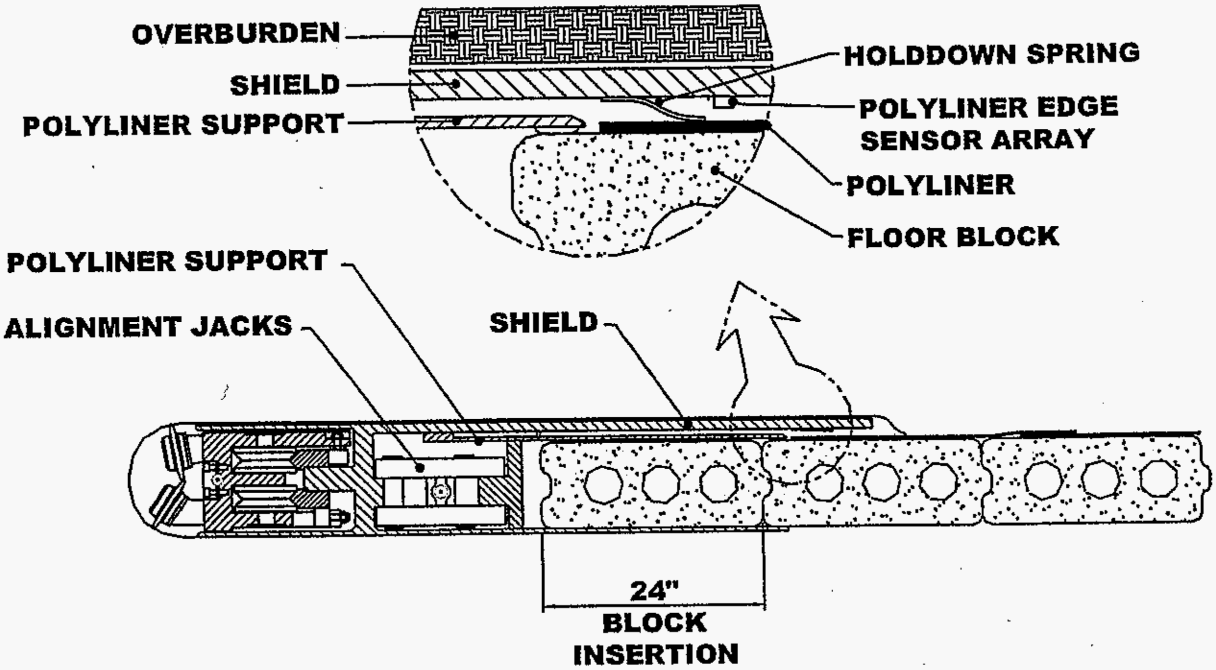



*Figure 2.3-21 Insert GCL*

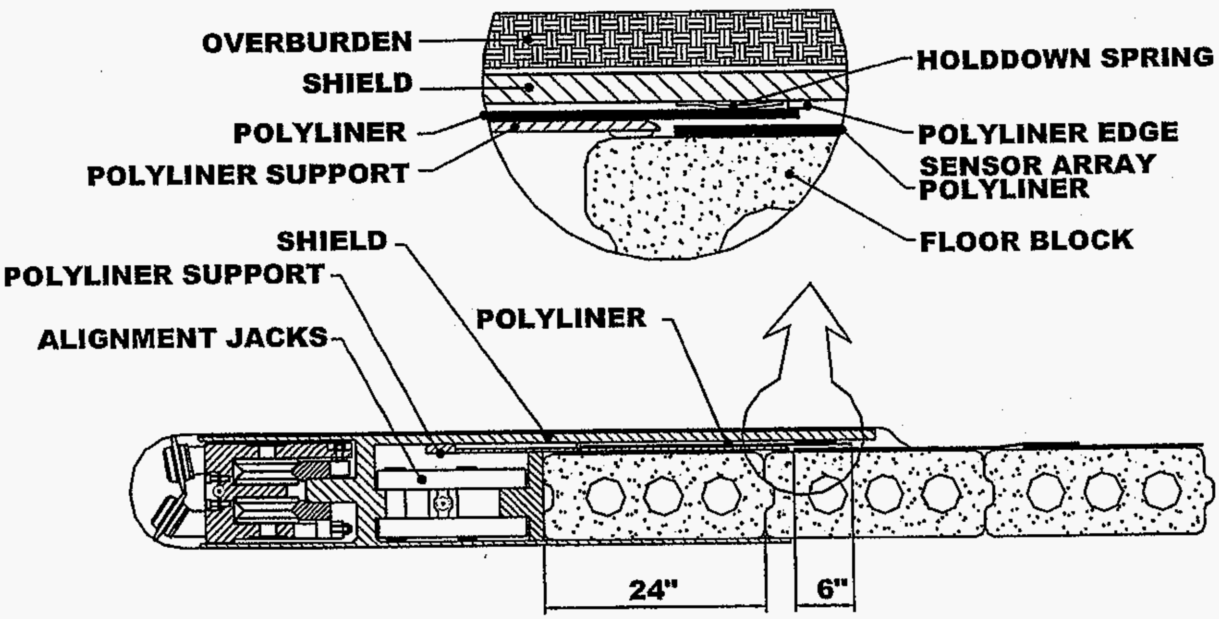



*Figure 2.3-22 Position GCL*

Finally, the SCU operator will verify that the GCL is properly positioned by reviewing the data provided by the edge sensor array as illustrated in Figure 2.3-23.

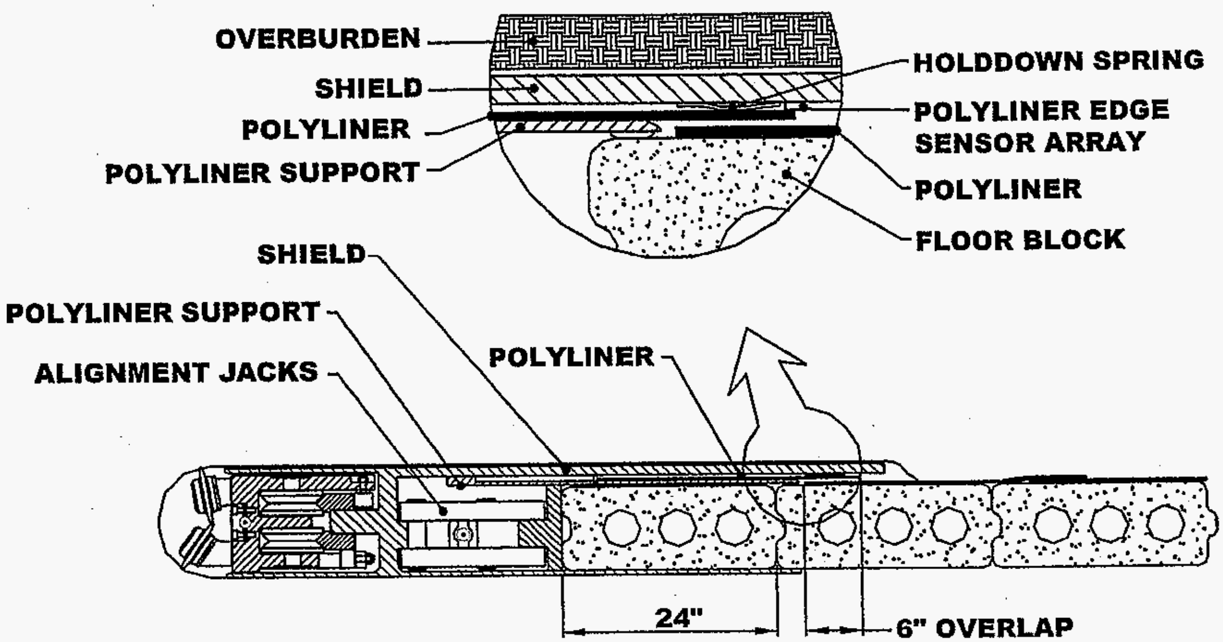
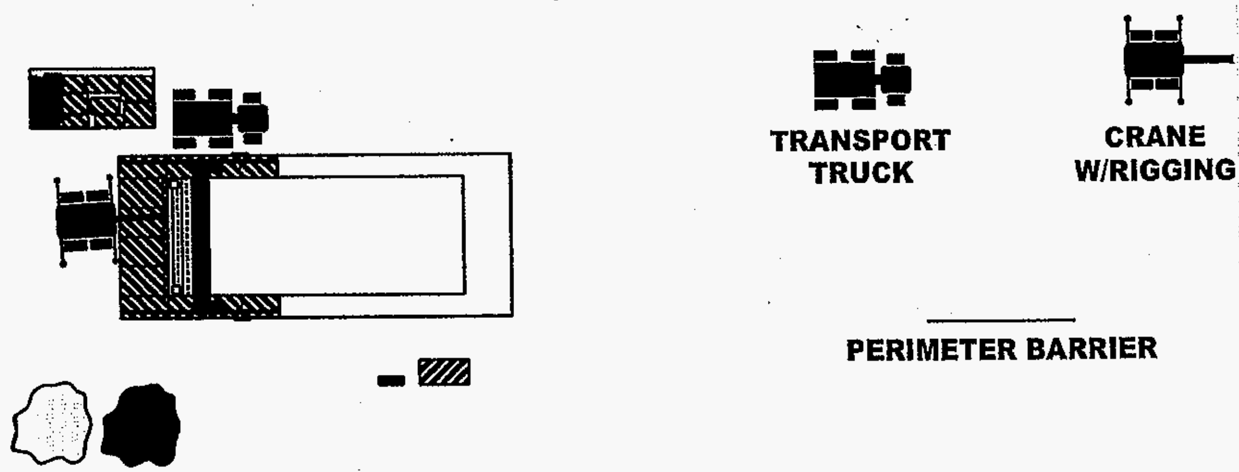



*Figure 2.3-23 Verify GCL Position*

### 2.3.2.3 Install Vertical Barrier

This activity as illustrated in Figure 2.3-24 installs the prefabricated vertical barrier panels and joins the horizontal and vertical barrier using state-of-the-art welding techniques.



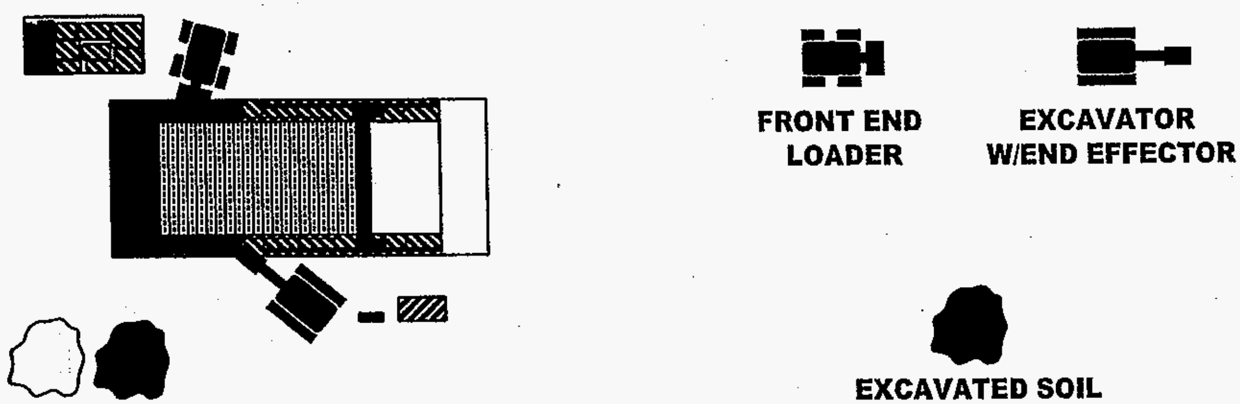

| Key Activities | Equipment | Operating Crew |
|---|---|---|
| • Remove/Install Spreaders<br>• Install Vertical Barrier<br>• Join Horizontal & Vertical Joints<br>• Inspect Joints | • Crane<br>• Transport Truck<br>• Access Ladders<br>• Welding Equipment<br>• Testing Equipment | • Foreman<br>• Equipment Operators<br>• Laborers<br>• Welders<br>• Inspector |

*Figure 2.3-24 Install Vertical Barrier*

A crane is used to place the 16-ft-wide, steel-framed geomembrane panels into the trench and interlocking the panel with the previously installed panel. The interlock is accomplished using an HDPE interlock joint. A hydrophillic rubber sealant is concurrently inserted and, when wetted, causes the joint to compress and provides a joint seal.

#### 2.3.2.4 Backfill Trench & Remove Shoring

This operation as illustrated in Figure 2.3-25 backfills and compacts the trench soil while concurrently extracting the shoring system components. The shoring would be monitored for contamination and decontaminated, if required.




| Key Activities | Equipment | Operating Crew |
|---|---|---|
| • Selectively Place & Compact Excavated Soil<br>• Remove & Decontaminate Shoring | • Excavator<br>• Compactor End Effector<br>• Front-End Loader | • Foreman<br>• Equipment Operators<br>• Laborers |

*Figure 2.3-25 Backfill Trench & Remove Shoring*

### 2.3.3 DEMOBILIZATION

The objective of this operation is to remove all construction equipment and materials and restore the site.

| TABLE 2.3-3 DEMOBILIZATION | |
|---|---|
| **Operation** | **Activities** |
| Demobilize & Restore Site | Remove test and construction equipment; remove test bed and construction materials; remove shoring system; and restore site. |

**Remove SCU & PCU:** Using multiple cranes and flat bed trucks, the SCU and PCU will be removed from the site.

**Remove Shoring System:** Using a mobile crane and standard rigging, the shoring system components will be loaded onto a flat bed truck and removed from the site.

**Remove Construction Materials:** The precast concrete blocks will be salvaged as much as possible and stored. Broken blocks will be removed.

**Restore Site:** Using the topsoil removed during the construction process, the site will be returned to its original topography.

**Remove All Construction Equipment:** All equipment will be removed from the site and returned to the contractor.

## 2.4 FACTORY TEST

Testing of the Slot Construction Unit (SCU) was conducted at the RAHCO International facility, Spokane, Washington, during the period of 27 February to 8 March 2001. The intent of the SCU factory test was to verify that the unit could be safely operated; verify equipment design principles; validate functional performance of the major subassemblies; and obtain system performance data.

A total of seven factory tests were performed. Test SCU-1 performed a safety assessment and an emergency stop test. Tests SCU-2 through SCU-5 verified design principles and validated the four key operating functions of the SCU that included: excavation and steering, thrusting, block insertion, and polyliner installation. Tests SCU-6 and 7 obtained SCU operating performance data.

### 2.4.1 TEST HARDWARE & MATERIALS

The Factory Test equipment included the Slot Construction Unit (SCU), Power and Control Unit (PCU), SCU support rails, and soil test bed. The test hardware configuration is shown in Figure 2.4-1.

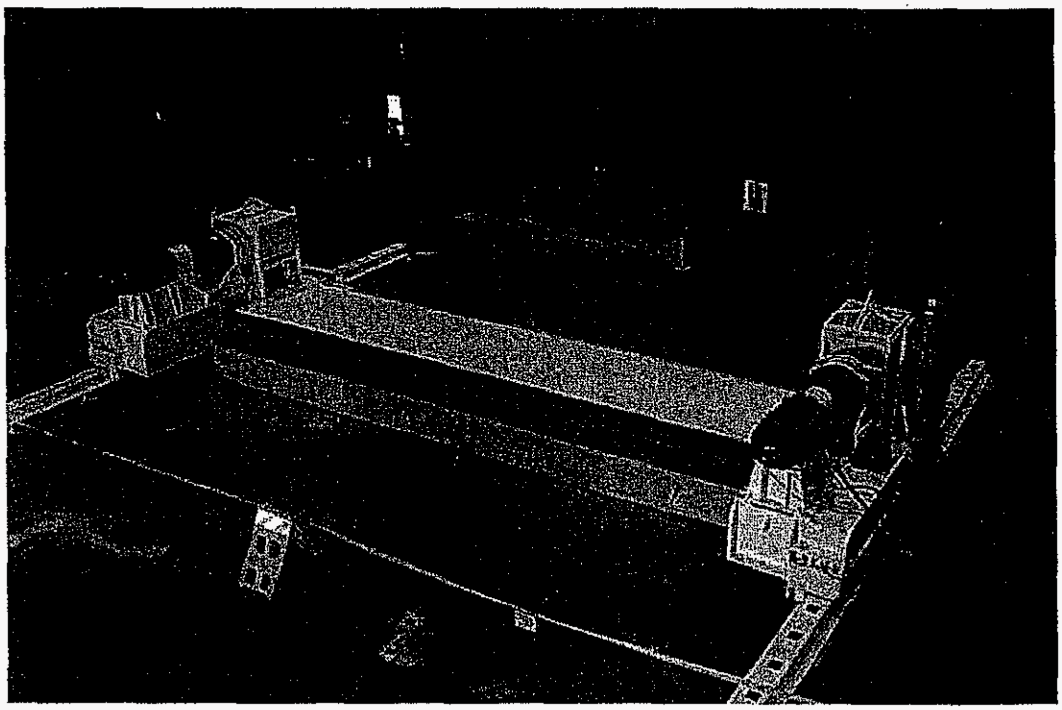


*Figure 2.4-1 Factory Test Equipment*

As shown, the SCU is supported on the floor-mounted support rails and connected to the containerized PCU by power and instrumentation cables. Shown beneath the SCU beam structure is the soil test bed. This test bed, using native sandy loam as the soil material, provided a soil foundation for the horizontal containment barrier during the test operation.

The test materials included 150-ft rolls of 30-in.-wide, geosynthetic clay liner (GCL) and the 37-in.-long X 24-in.-wide X 7-in.-high, precast concrete floor blocks. Figure 2.4-2 shows the concrete floor blocks and GCL placed on the soil test bed by the SCU.

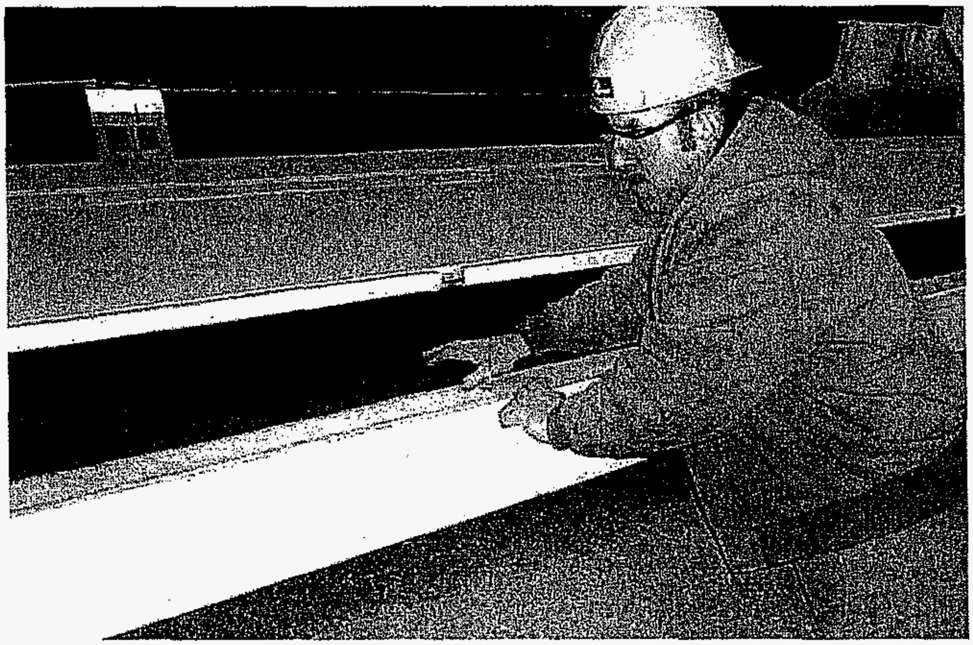


*Figure 2.4-2 SCU & Horizontal Barrier*

### 2.4.2 TEST RESULTS

The following provides a brief description of each test and the results obtained.

#### 2.4.2.1 SCU-1: Safety Assessment & Emergency Stop Test

The objective of this test was to verify equipment safety features, review the operating procedures, and verify adequacy of the emergency stop equipment and procedures.

**Test Procedure:**

SCU-1-A: Review Factory Test Safety Plan.

SCU-1-B: Conduct safety review of SCU system and subsystems.

SCU-1-C: Activate EMERGENCY STOP and verify that Indexing Unit and Cutterhead can be relocated to *home* position.

**Data Collection Requirements:**

1. Document concurrence with Factory Test Safety Plan.
2. Document concurrence of specific SCU safety features checklist.
3. Identify safety deficiencies and corrective action requirements.

**Test Results:**

The test results concluded that the SCU could be safely operated and that the emergency stop equipment and procedures were satisfactory. The results also identified safety issues and established procedures for the safe conduct of operation. The following briefly describes these issues and the necessary precautions taken.

**Electrical, Pinch Point, & General Hazards:** The machine is operated by electrical power. There are numerous high amperage electrical cables around the machine which operates at 480 V at variable frequencies. Care was taken to avoid standing on or tripping over these cables. Since a cable could be broken during machine operation, extreme caution was taken when working on or around the machine.

There are numerous pinch points at both the concrete block and polyliner loading ends. Only authorized personnel were allowed in these areas during testing. No one was allowed under the machine, on the machine, or in front of the machine while the SCU was in operation. This was because the cutterhead was moving back and forth beneath the machine while it was operating and anyone beneath the machine risked serious injury.

**Cable Rollers:** Both ends of the machine include cable rollers. Should a cable snap, an end may whip out and cause serious injury to anyone in the area. Unauthorized personnel were requested to stay clear of the cordoned-off test area.

**Start-Up & E-Stops:** Before machine start-up, a check of the area was made to ensure that no one was working on or under the machine. All test personnel approved start-up (using a thumbs-up sign) before machine start-up. A warning horn sounded prior to start-up to give workers an opportunity to clear the area before machine start-up.

If an emergency stop was needed, the "hand-cut-across-throat sign" was used to stop a machine. Two "floating" e-stops were available in an emergency. Authorized personnel checked the location of these e-stops at the start of each test day. In addition, there was an e-stop located on an electrical panel in the electric house and another on the polyliner house. The e-stop would completely shut down the machine immediately.

**Block Loading:** There was some real concern with this process. First, the magazine itself is heavy—when loaded, it weighs over 4000 lbs. Test personnel were required to stay completely clear of the area when the magazine was being loaded and moved to the block inserter end of the machine. Only authorized personnel were allowed on the machine to guide the block magazine into the block inserter. No one else was on the machine when the magazine was being placed in the inserter.

**Block Inserter:** The most serious injury risk was the block inserter area. Anyone working within this area would be subject to severe crushing injury should the inserter move while someone was inside. RAHCO's Lockout/Tag Out procedure was used to ensure safety.

**Polyliner End:** The polyliner latches may become loosened during loading. If this happens, the load may shift. All test personnel were required to stay clear of the polyliner end during loading procedures.

### 2.4.2.2 SCU-2: Excavation & Steering Test

This test was designed to verify that the cutterhead assembly and steering system could meet the functional requirements of excavating a 34-ft-long X 12-in.-high, horizontal slot; removing the muck; cleaning the cutterhead; and maintaining vertical and horizontal alignment of the beam structure to ensure proper placement of the horizontal containment barrier.

**Test Procedures:**

SCU-2-A: Verify fail-safe operation by simulating 1) cutterhead stall, 2) sensor failure, 3) wire rope failure, 4) electric motor failure, and 5) controller failure.

SCU-2-B: From *home* position, manually jog Cutterhead across beam and return. Repeat 2 additional times. Operate Cutterhead at travel speeds of 50 and 100 fpm for 6 passes each.

SCU-2-C: Lift front of Beam Structure 2 in. and verify tilt instrumentation accuracy. Load Beam Structure with dead weight and measure load cell accuracy.

SCU-2-D: Verify Cutterhead cutters can be manually adjusted 1 in. vertically. Verify support shoes can be manually adjusted ±1 in., vertically. Verify the alignment pins have a 2-in. adjustment.

SCU-2-E: Evaluate ease of operation.

SCU-2-F: Perform maintenance assessment.

**TABLE 2.4-1 SCU-2 DATA COLLECTION REQUIREMENTS**

| TEST PARAMETER | DATA TYPE | DATA SOURCE | SAMPLING METHOD |
|---|---|---|---|
| **Cutterhead** | | | |
| • Average Travel Speed | fpm | Automated Data Acquisition System (ADAS) | Electronic Measurements |
| • Cycle Time (Single Pass) | secs | ADAS | Electronic Measurements |
| • Horsepower | hp | Data Sheets | Manual Measurements |
| **Steering** | | | |
| • Loads | lbs | ADAS | Electronic Measurements |
| • Tilt | degrees | ADAS | Electronic Measurements |

**Test Results:**

Test results concluded that, with minor hardware and software modifications, the cutterhead is capable of excavating the horizontal slot and removing the muck. Testing of the cutterhead cleaning unit was not performed; however, ingress and egress of the cutterhead into the cleaning unit verified that the cleaning system performed as designed. Similarly, testing of the steering system concluded that, with minor mechanical adjustments and recalibration of sensors, the unit will maintain the beam structure alignment and install the horizontal containment barrier ±2 in. of the desired elevation and centerline.

The following checklist and table summarize the identified issues and the corrective action taken.

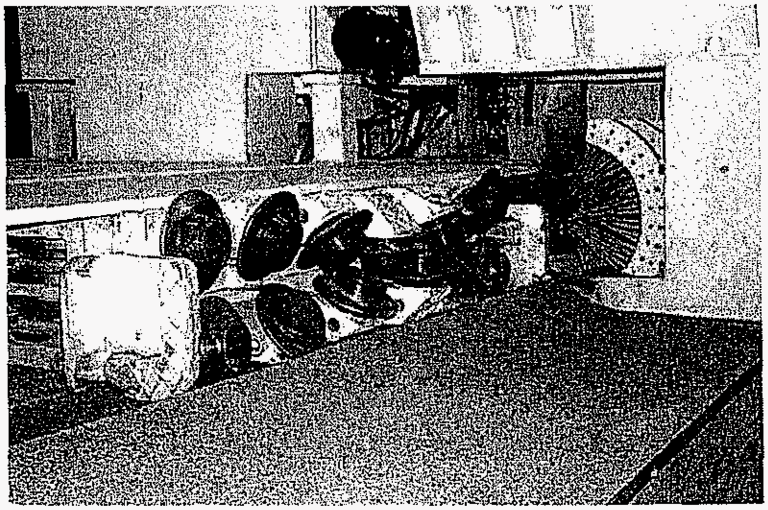


*Figure 2.4-3 Cutterhead Assembly*

| TABLE 2.4-2 EXCAVATION & STEERING TEST CHECKLIST | | | |
|---|---|---|---|
| **ITEM** | **DESCRIPTION** | **YES** | **NO** |
| 1 | Did the cutterhead assembly function as designed? | X | |
| 2 | Could the cutterhead complete a single pass (over and back) within 20 secs at 100 fpm? | X | |
| 3 | Was the cutterhead capable of traveling across the Beam Structure at maximum rates of 200 fpm? | Not Tested | |
| 4 | Was the cutterhead capable of accelerating/decelerating within the specified distance of 4 ft? | X | |
| 5 | Could the cutterhead cleaning unit remove impacted muck and debris? | Not Tested | |
| 6 | Could the cutterhead be stopped within ±1/2 in. of designated stop position? | X | |
| 7 | Was the wire rope tension maintained throughout the cutting operation (no rope slap) at 100 fpm? | X | |
| 8 | Was the wire rope properly fed and wrapped onto the winch? | X | |
| 9 | Was the wire rope tension maintained after motor shutdown? | X | |
| 10 | Did the steering system function as designed? | | X |
| 11 | Could the inclinometers properly measure beam tilt? | | X |
| 12 | Could the support shoe load cells accurately measure rail loads? | | X |
| 13 | Could the cutters be manually adjusted +1 in. vertically? | | X |
| 14 | Could the rail alignment pins be manually adjusted 2 in.? | X | |

| TABLE 2.4-2 EXCAVATION & STEERING TEST CHECKLIST (Continued) | | | |
|---|---|---|---|
| ITEM | DESCRIPTION | YES | NO |
| 15 | Could the support shoes be adjusted ±1 in.? | | X |
| 16 | Could the excavation operation be easily performed from the operator's station? | X | |
| 17 | Could the cutterhead and steering units be safely operated? | X | |
| 18 | Could the cutterhead and steering units be easily maintained? (See Note #1) | X | |

NOTES:

1. With the exception of the 3 tilt sensors located on the beam structure and the cutterhead slow speed proximity switch located on the beam structure.

| TABLE 2.4-3 PROBLEMS & CORRECTIVE ACTION | | |
|---|---|---|
| PROBLEM | DESCRIPTION | CORRECTIVE ACTION |
| 1. Cutterhead Jamming | The cutterhead jammed in the beam structure as it traveled across the cutting face. | • Modify cutterhead structure to provide additional clearance between cutterhead and beam structure.<br>• Modify plows to remove muck from within the beam structure.<br>• Modify cam follower design to increase torsional load carrying capability. |
| 2. Nylon Cleaning Rod Breakage | The nylon rods used to clean the cutterhead break as the cutterhead travels into the unit. | • Select a cleaning rod with different mechanical properties. |
| 3. Inability to Measure Beam Tilt & Rail Loads Accurately | The tilt sensors and load cells did not provide accurate data. | • Recalibrate instrumentation. |
| 4. Inability to Perform Steering | The cutterhead and support shoes could not be manually adjusted to allow steering of the unit. | • Modify the cutterhead to allow ±0.5-in. manual adjustments of the cutters.<br>• Modify the support to allow ±2-in. manual adjustment of the unit. |
| 5. Inability of Cutterhead Drive Software to Perform as Planned | The cutterhead drive software was not capable of operating the cutterhead at 200 fpm, achieving smooth acceleration and deceleration, and maintaining proper backloading of the winches. | • Modify and tune the cutterhead drive software. |

### 2.4.2.3 SCU-3: Thrusting & Rail Lock Test

The objective of the thrusting test was to verify that the indexing unit and rail lock mechanism could advance the SCU forward, lock the SCU to the support rails, and provide reactive thrust to the cutterhead as it travels across the cutting face.

**Test Procedures:**

SCU-3-A: Verify fail-safe operation by simulating 1) indexing stall, 2) sensor failure, 3) electric motor failure, and 4) controller failure.

SCU-3-B: Advance Beam Structure at increments of 0.25 and 0.5 in. for 4 cycles each.

SCU-3-C: With Indexing Unit in *home* position, advance Beam Structure 24 in. at increments of 0.5 in. at maximum cutterhead travel speed of 100 fpm. Reposition Indexing Unit to new *home* position.

SCU-3-D: Evaluate ease of operation.

SCU-3-E: Perform maintenance assessment.

| TABLE 2.4-4 SCU-3 DATA COLLECTION REQUIREMENTS | | | |
|---|---|---|---|
| **TEST PARAMETER** | **DATA TYPE** | **DATA SOURCE** | **SAMPLING METHOD** |
| **Indexing Unit** | | | |
| • Thrust | lbs | ADAS | Electronic Measurements |
| • Index Advance Rate | ipm | ADAS | Electronic Measurements |
| • Reposition Time | secs | ADAS | Electronic Measurements |
| • Horsepower | hp | Data Sheets | Manual Measurements |
| **Rail Lock Mechanism** | | | |
| • Insertion Speed | ipm | Data Sheets | Manual Measurements |
| • Retraction Speed | ipm | Data Sheets | Manual Measurements |
| • Horsepower | hp | Data Sheets | Manual Measurements |

**Test Results:**

This test concluded that both assemblies performed as designed and could precisely advance the SCU at increments from 1/16-in. through 1/2 in. and could successfully lock and unlock the SCU into the support rails. As this was a no-load test (the cutterhead was not actively cutting rock), reactive thrust capabilities could not be fully evaluated. The following checklist and table highlights the identified design issues and the necessary corrective action.

| TABLE 2.4-5 THRUSTING & RAIL LOCK TEST CHECKLIST | | | |
|---|---|---|---|
| ITEM | DESCRIPTION | YES | NO |
| 1 | Did the Indexing Unit function as designed? | X | |
| 2 | Could the Indexing Unit advance the Beam Structure at the rate of 2 ipm? | X | |
| 3 | Could the Indexing Unit advance the Beam Structure the prescribed increments (0.25 in. and 0.5 in., etc) within ±1/16 in.? | X | |
| 4 | Could the Indexing Unit reposition the rail lock within ±1/16 in.? | X | |
| 5 | Did the laser system accurately determine advance distance within ±1/16 in.? | X | |
| 6 | Did the rail lock mechanism function as designed? | | X |
| 7 | Could the rail lock mechanism be inserted and retracted a distance of 4 in. within 30 sec? | | X |
| 8 | Could the thrusting operations be easily performed from the operator's station? | X | |
| 9 | Could the Indexing Unit and rail lock mechanism be safely operated? | X | |
| 10 | Could the Indexing Unit and rail lock mechanism be easily maintained? | X | |

| TABLE 2.4-6 PROBLEMS & CORRECTIVE ACTION | | |
|---|---|---|
| PROBLEM | DESCRIPTION | CORRECTIVE ACTION |
| 1. Rail Lock Mechanism Failure | The rail lock actuators failed to insert and retract the rail lock pins. | • Modify drive motor and actuator connection to pin structure to provide additional flexibility.<br>• Modify pin structure to allow location sensors to operate successfully. |
| 2. Inability to Perform Automatic Control Functions | The control software required the machine operator to manually command the cut-index and regrip operations— which are laborious and prone to human error. | • Modify software to allow automatic command of the cut-index and regrip operations. |
| 3. Rail Lock Mechanism Inaccessibility | The rail lock mechanisms are located on the machine where, during normal operations, they are inaccessible for maintenance. | • Modify the beam structure to provide a maintenance access opening. |

### 2.4.2.4 SCU-4: Block Insertion & Alignment Test

The block insertion test was performed to verify that the block inserter could properly insert a row of 11 precast concrete blocks (24-in. wide X 37-in. long X 7-in. high) into the beam structure and that the block alignment system could align and position the blocks and maintain a load on the blocks as the SCU advanced.

**Test Procedures:**

SCU-4-A: Verify fail-safe operation by simulating 1) block jam, 2) sensor failure, 3) controller failure, and 4) motor failure.

SCU-4-B: Load concrete blocks into magazine and place magazine onto Beam Structure.

SCU-4-C: Activate Block Inserter and place row of 11 blocks. Activate Alignment Jacks to position blocks.

SCU-4-D: Evaluate ease of operation.

SCU-4-E: Perform maintenance assessment.

**Data Collection Requirements:**

**TABLE 2.4-7 SCU-4 DATA COLLECTION REQUIREMENTS**

| TEST PARAMETER | DATA TYPE | DATA SOURCE | SAMPLING METHOD |
|---|---|---|---|
| **Block Inserter** | | | |
| • Lift Horsepower | hp | Data Sheets | Manual Measurements |
| • Thrust Horsepower | hp | Data Sheets | Manual Measurements |
| • Cycle Time (Single Block) | secs | ADAS | Electronic Measurements |
| • Cycle Time (Row) | secs | ADAS | Electronic Measurements |
| • Block Alignment | degrees | Data Sheets | Manual Measurements |
| **Alignment Jacks** | | | |
| • Horsepower | hp | Data Sheets | Manual Measurements |
| • Thrust Loads | lbs | ADAS | Electronic Measurements |
| • Travel Speed | fpm | ADAS | Electronic Measurements |

**Test Results:**

The test results demonstrated that the concrete blocks could be rapidly installed and positioned within the beam structure, as shown in Figure 2.4-4. However, failure of the alignment jack load cells precluded verification of block loading while advancing the SCU.

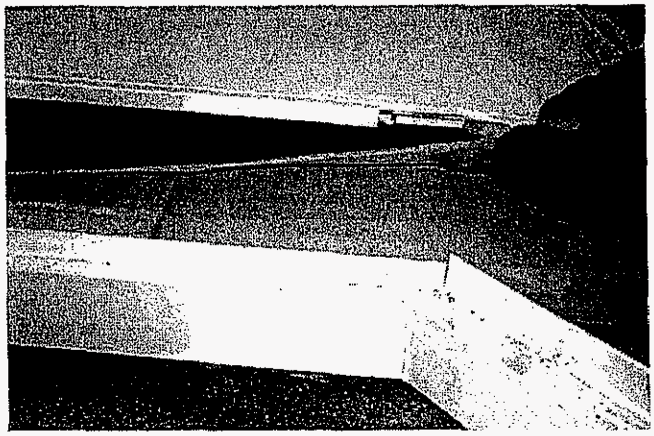
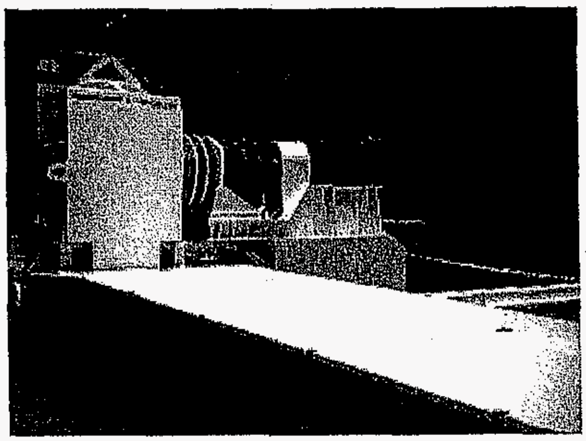



*Figure 2.4-4 Blocks & Polyliner Inserted into Beam Structure*

The following checklist and table highlight a number of problems identified.

| TABLE 2.4-8 BLOCK INSERTION & ALIGNMENT TEST CHECKLIST | | | |
|---|---|---|---|
| ITEM | DESCRIPTION | YES | NO |
| 1 | Did the Block Inserter and alignment assembly function as designed? | X | |
| 2 | Could the 11 blocks be easily and safely loaded into the block magazine? | X | |
| 3 | Could the block magazine be safely and remotely positioned onto the Beam Structure? (See Note #1) | | X |
| 4 | Could the block grabber lift the blocks without damage to the blocks? (See Note #2) | X | |
| 5 | Could the Block Inserter properly insert the blocks without damage to the blocks? (See Note #2) | X | |
| 6 | Could the blocks be properly positioned in the Beam Structure? | X | |
| 7 | Could the row of blocks be properly installed within 10 mins? (See Note #3) | | X |
| 8 | Did the alignment jacks function as designed? | X | |
| 9 | Could the alignment jacks be retracted 6 in. to allow the blocks to be inserted? | X | |
| 10 | Could the alignment jacks properly position the blocks after a row of blocks was inserted? | X | |
| 11 | Could the blocks be uniformly extracted from the Beam Structure? | X | |
| 12 | Could the alignment jacks maintain load on the blocks during the slot cutting operation? | Not Tested | |
| 13 | Could the alignment jacks extend a distance of 30 in. from home position? | X | |
| 14 | Could the alignment jack load cells accurately measure block loads during the cutting operation? | | X |
| 15 | Could the block insertion operation be easily performed from the operator's station? | X | |

| TABLE 2.4-8 BLOCK INSERTION & ALIGNMENT TEST CHECKLIST (Continued) | | | |
|---|---|---|---|
| ITEM | DESCRIPTION | YES | NO |
| 16 | Could the block insertion equipment be safely operated? | X | |
| 17 | Could the block insertion equipment be easily maintained? | X | |

NOTES:

1. Could not be loaded remotely onto the beam structure.
2. Some spalling of concrete occurred.
3. Approximately 30 mins were required to install blocks.

| TABLE 2.4-9 PROBLEMS & CORRECTIVE ACTION | | |
|---|---|---|
| PROBLEM | DESCRIPTION | CORRECTIVE ACTION |
| 1. Block Inserter Magazine Capacity | The block magazine did not have the capability to hold sufficient blocks to complete a block row. | • Modify the magazine structure to accommodate 11 blocks. |
| 2. Inability to Place Magazine on SCU Remotely | Placing the magazine on the SCU required manual assistance. | • Provide improved fairings and guide pins. |
| 3. Positioning of Blocks in Beam Structure | The Block Inserter did not properly position the blocks within the beam structure and resulted in block-machine interference problems. | • Modify Block Inserter to insert row of blocks an additional 2 in. |
| 4. Interference of Inserter Lift Motor with Shoring Clear Zone | The lift motor interfered with the clear zone required to ensure clearance with the shoring system. | • Replace existing motors with nonbrake units that are shorter and will not cause interference. |
| 5. Alignment Jacks Jamming | The alignment jacks interfered with the beam structure as they expanded which resulted in motor stall. | • Modify alignment jacks to eliminate interference and install HDPE shoes to reduce friction. |

#### 2.4.2.5 SCU-5: Polyliner Insertion Test

The objective of Test SCU-5 was to verify that the polyliner inserter could install a 34-ft-long X 30-in.-wide strip of 80-mil, geosynthetic clay liner (GCL) within the beam structure and that the alignment jacks could properly position the GCL to ensure a 6-in. overlap with the previously installed liner strip.

**Test Procedures:**

SCU-5-A: Verify fail-safe operation by simulating 1) polyliner jamming, 2) cutter malfunction, 3) sensor failure, and 4) motor failure.

SCU-5-B: Load polyliner roll into magazine and place magazine onto Beam Structure.

SCU-5-C: Activate Polyliner Inserter and place 30-in.-wide by 34-ft-long polyliner strip into place. Verify polyliner position.

SCU-5-D: Evaluate ease of operation.

SCU-5-E: Perform maintenance assessment.

**TABLE 2.4-10 SCU-5 DATA COLLECTION REQUIREMENTS**

| TEST PARAMETER | DATA TYPE | DATA SOURCE | SAMPLING METHOD |
|---|---|---|---|
| **Polyliner Inserter** | | | |
| • Insertion Speed | fpm | ADAS | Electronic Measurements |
| • Thrust Horsepower | hp | Data Sheets | Manual Measurements |
| • Polyliner Alignment | degrees | Data Sheets | Manual Measurements |
| • Abrasion | subjective | Data Sheets | Visual Observation |

***Test Results:***

The polyliner installation test concluded that the inserter could rapidly and successfully install the GCL within the beam structure and that the shear could successfully cut the GCL to the proper length. The alignment jacks were unable to maintain proper horizontal position of the GCL as the SCU advanced because the GCL was supported at only two locations. The addition of two support points will ensure proper positioning of the GCL in the beam structure. The following shows the checklist, results, and identifies the problem areas and corrective actions.

**TABLE 2.4-11 POLYLINER INSERTION TEST CHECKLIST**

| ITEM | DESCRIPTION | YES | NO |
|---|---|---|---|
| 1 | Could the roll of GCL be easily and safely loaded into the polyliner magazine? | X | |
| 2 | Could the polyliner magazine be safely and remotely positioned onto the SCU? (See Note #1) | | X |
| 3 | Could the insertion rollers properly feed the GCL into the SCU? | X | |
| 4 | Could the cutterhead mechanism cut the GCL? | X | |
| 5 | Could the alignment jack fingers properly position the GCL as the beam structure advanced? (See Note #2) | | X |
| 6 | Could the edge sensors identify the GCL? | Not Tested | |
| 7 | Was the 30-in.-wide GCL strip installed within 1 min? | X | |
| 8 | Was the 30-in.-wide GCL strip properly positioned within ±1/2 in. (ends and 6-in. overlap)? (See Note #2) | | X |
| 9 | Could the polyliner insertion operation be easily performed from the operator's station? | X | |
| 10 | Could the polyliner insertion equipment be safely operated? | X | |
| 11 | Could the polyliner insertion equipment be easily maintained? | X | |

NOTES:

1. Pin alignment prevented the magazine from being remotely loaded onto the beam structure.

2. The two fingers were insufficient to align the polyliner.

| TABLE 2.4-12 PROBLEMS & CORRECTIVE ACTION | | |
|---|---|---|
| **PROBLEM** | **DESCRIPTION** | **CORRECTIVE ACTION** |
| 1. Inability to Place Polyliner Magazine Remotely | The polyliner magazine required manual assistance to be placed on the SCU. | • Provide additional fairings and longer guide pins. |
| 2. Shear Failure | The shear was unable to cut the GCL cleanly. | • Modify the shear structure to provide rigidity to allow a clean cut. |
| 3. Inability of Alignment Jacks to Position GCL Properly | The alignment jack fingers do not maintain alignment of the GCL as the beam structure advances. | • Add additional alignment fingers. |
| 4. GCL Jamming | The GCL jams as the beam structure advances. | • Modify the magazine structure to allow greater GCL slot space. |

### 2.4.2.6 SCU-6: System Performance Test #1

The SCU Performance Test #1 was conducted to establish the overall performance of the SCU in installing the horizontal containment barrier.

**Test Procedures:**

SCU-6-A: From Cutterhead and Indexing Unit *home* positions, activate the SCU and place 2 rows each of concrete blocks and 2 polyliner strips. Cutterhead speed shall be 100 fpm, maximum, and machine advance rate shall be 1/4 in. per Cutterhead pass.

SCU-6-B: Evaluate ease of operation.

SCU-6-C: Perform maintenance assessment.

| TABLE 2.4-13 SCU-6 DATA COLLECTION REQUIREMENTS | | | |
|---|---|---|---|
| **TEST PARAMETER** | **DATA TYPE** | **DATA SOURCE** | **SAMPLING METHOD** |
| **Construction Rate** | fph | ADAS | Electronic Measurements |
| **Block Alignment** | degrees | Data Sheets | Manual Measurements |
| **Polyliner Alignment** | degrees | Data Sheets | Manual Measurements |
| **Polyliner Condition** | subjective | Visual Observation | Visual Inspection |
| **Ease of Operation** | subjective | Test Team | N/A |

| TABLE 2.4-13 SCU-6 DATA COLLECTION REQUIREMENTS (Continued) | | | |
|---|---|---|---|
| **TEST PARAMETER** | **DATA TYPE** | **DATA SOURCE** | **SAMPLING METHOD** |
| **Ease of Maintenance** | subjective | Test Team | N/A |
| **Safe Operation** | subjective | Safety Specialist | N/A |

**Test Results:**

This test demonstrated that the block and polyliner magazines could be safely and easily loaded and rapidly locked on the SCU beam structure. It also verified that the SCU could successfully perform the required operating functions and, with minor modifications, install a horizontal containment barrier as shown in Figure 2.4-5 at rates to 1 fph. Additional results showed that the SCU could be easily and remotely operated by a single operator in a remote control station.

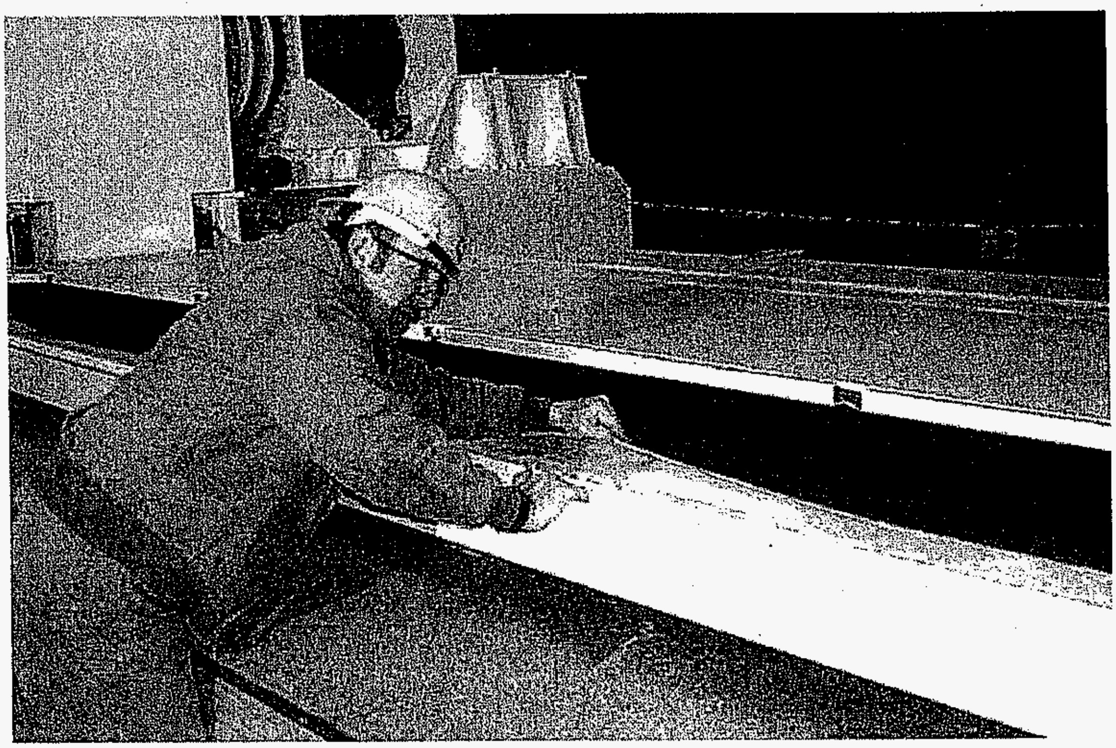


*Figure 2.4-5 Inserted Geosynthetic Clay Liner*

## 2.4.3 SUMMARY & CONCLUSIONS

Factory Tests SCU-1 through 6 were performed satisfactorily. These tests identified several design and operational deficiencies that required corrective action. Equipment modifications and operating procedures were modified as appropriate. Factory Test SCU-7 was performed successfully. This test fully demonstrated that the SCU could safely and successfully install a horizontal containment barrier within the desired construction tolerance of ±2 in. at construction rates to 12 ft/day with an operating crew of three.

## 2.5 CONTROL TEST

The objective of the Control Test was to demonstrate the capabilities of the SCS equipment and construction methods to install a subsurface horizontal containment barrier in a safe and cost-effective manner. This included demonstrating a safe operation and the ability of the SCS to meet environmental regulations during installation; demonstrating the ability of the equipment and construction methods to function at DOE sites; and establishing the performance capabilities and the cost-effectiveness of the equipment and construction method. It also included evaluating the man-machine interface for all operations and demonstrating a quality control procedure for real time evaluation of the acceptability of the horizontal barrier in its "as installed" condition. Testing was performed at the RAHCO facilities; Spokane, Washington; during the period of 1 June 2001 to 26 July 2001.

### 2.5.1 SCOPE OF TESTS

The Control Test was performed at the RAHCO facility in a subsurface environment representative of DOE sites. The test bed replicated consolidated soil and consolidated soil and boulders expected at DOE sites. The test was intended to construct a 34-ft-wide X 36-ft-long, horizontal containment barrier at a depth of 12 ft below ground level in an engineered test bed. The barrier consisted of an 80-mil, geosynthetic clay liner (GCL) supported by precast concrete blocks.

A total of four tests were planned. Test CT-1 was intended to perform a system safety and environmental assessment to ensure that the equipment and construction methods could be performed safely in accordance with the Environment Safety & Health Plan and Environmental Compliance Plan as defined in Sections 8.0 and 9.0 of the Operational Plan/Work Plan. Test CT-2 was designed to evaluate the shoring system equipment and installation process. This evaluation included assessing the ease and speed of installation and the ability of the shoring system to perform the primary functions of providing personnel and equipment protection, providing a foundation for the SCU, and allowing a horizontal slot to be constructed at a depth of 10 ft below the surface. Test CT-3, SCU performance test, was intended to demonstrate that the SCU could rapidly install a horizontal containment barrier in geological conditions expected at DOE sites. Test CT-4 was intended to validate the effectiveness of the GCL to minimize the leakage and spread of buried waste contaminants.

During testing, data was collected using both manual readings and an automated data acquisition system. Observations were made and results documented to verify that the SCS provides DOE a viable alternative to other buried waste remediation methods.

### 2.5.2 TEST SITE DESCRIPTION

The Control Test site is located east of the RAHCO office building, as shown in Figure 2.5-1 in an area used for equipment testing. The test site area is approximately 130 ft X 214 ft in size. The topography of the site is flat and the native soil is sandy loam with no vegetation.

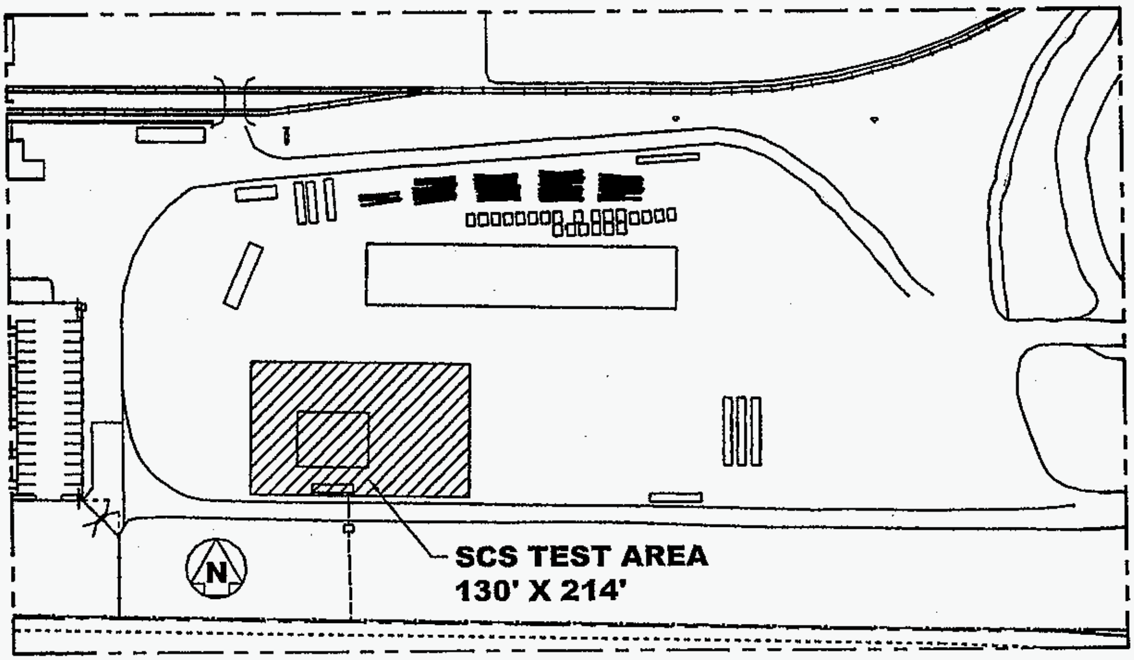



*Figure 2.5-1 Control Test Site Layout*

The test site layout is shown in Figure 2.5-2. The layout includes an area to stockpile soil removed during installation of the shoring system. It also includes a staging areas for the shoring system, GCL rolls, and concrete blocks. A 15-ft X 20-ft test viewing area is also provided for shelter of test personnel and visitors.

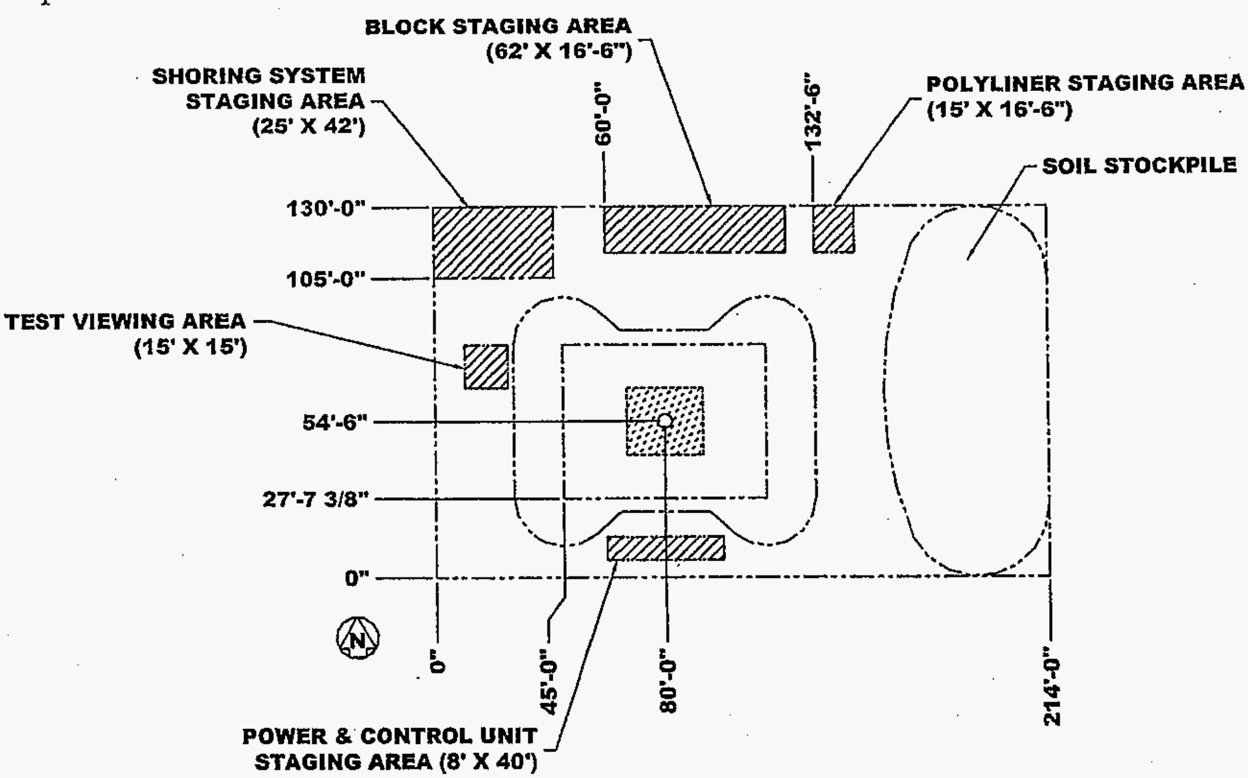



*Figure 2.5-2 Detailed Test Site Layout*

### 2.5.3 ENGINEERED TEST BED

The engineered test bed is 29 ft X 30 ft X 4-ft thick as shown in Figures 2.5-3 and 2.5-4 and was constructed of cemented sands, pea gravel, crushed aggregate, cobbles, and boulders as described in Table 2.5-1. Conventional construction equipment will be used to construct the engineered test bed.

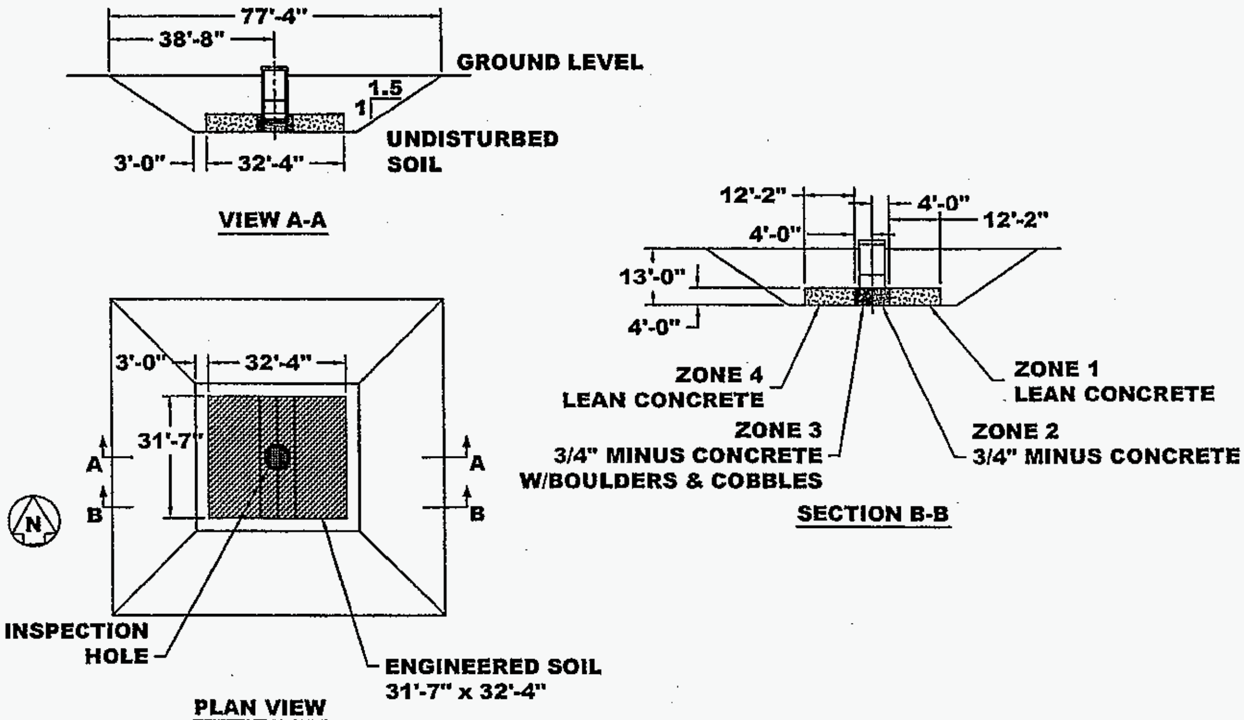



*Figure 2.5-3 Engineered Test Bed Layout*

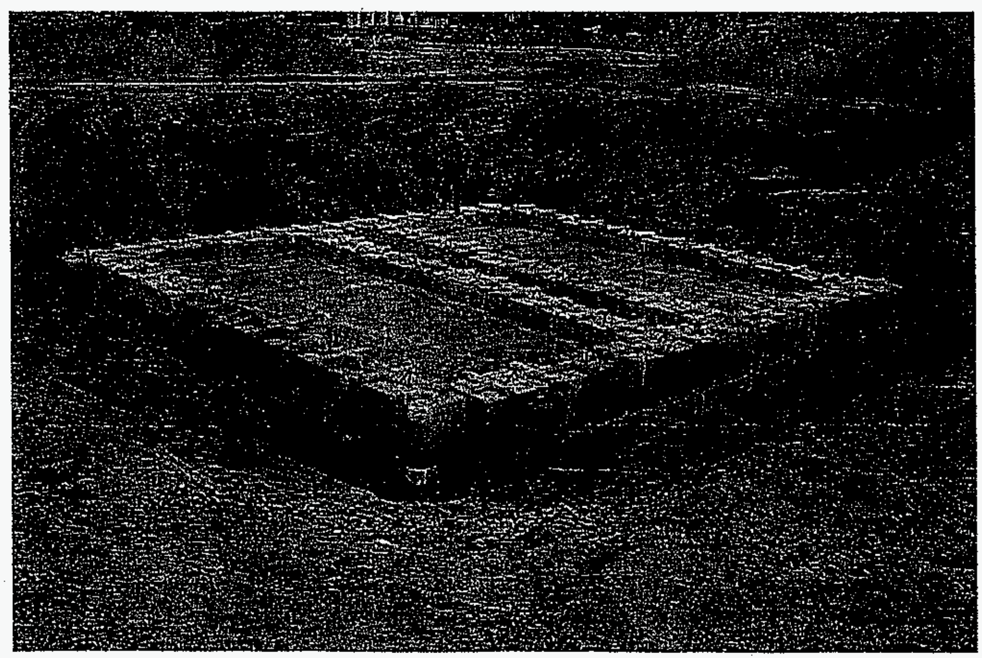


*Figure 2.5-4 Test Bed Construction*

| TABLE 2.5-1 ENGINEERED SOILS | | | | |
|---|---|---|---|---|
| | **Zone 1** | **Zone 2** | **Zone 3** | **Zone 4** |
| Soil Material | Cemented Sand | Cemented Sand & Aggregate | Cemented Sand, Cobbles, & Boulders | Cemented Sands |
| Rock Type | None | Crushed River Rock | Crushed River Rock & Basalt | None |
| Maximum Material Strength | Approximately 1,250 psi | Approximately 3,000 psi | Approximately 17,000 psi | Approximately 1,250 psi |
| Rock Distribution | None | 25% by Volume | 50% by Volume | None |
| Average Moisture Content | 8% | 8% | 8% | 8% |

*Figure 2.5-5 Test Bed Soils*

The test bed also includes a 5-ft-diameter X 13-ft-high, concrete manhole. This manhole, located in the center of the bed, provides personnel access to the test bed.

### 2.5.4 TEST EXECUTION

The Control Test installed the modular shoring system and constructed a 34-ft-wide X 4-ft-long, horizontal containment barrier consisting of GCL supported by precast concrete blocks in the engineered test bed as illustrated in Figure 2.5-6.

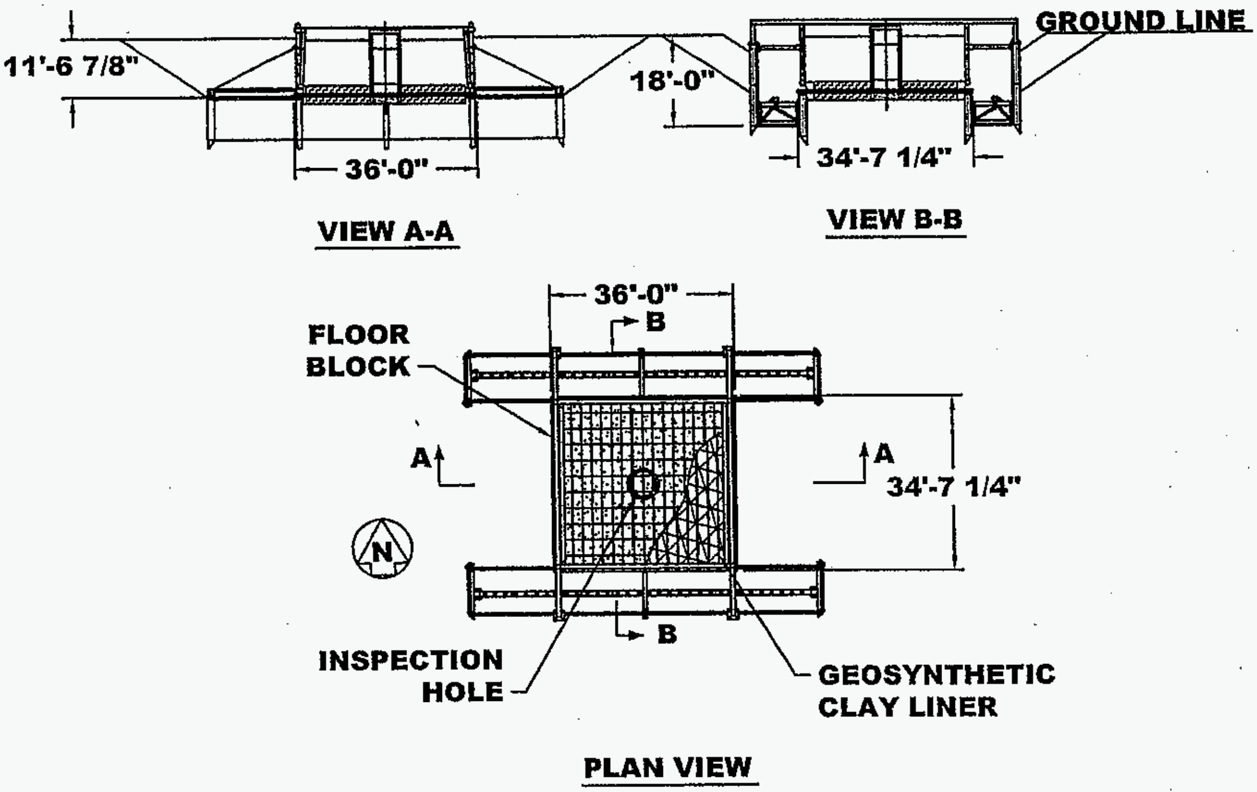



*Figure 2.5-6 Layout of Horizontal Barrier*

A total of three tests were conducted. Tests CT-1 and CT-2 were successfully completed Test CT-3 was partially completed. Table 2.5-2 highlights the three tests and identifies the specific test objective.

**TABLE 2.5-2 CONTROL TEST MATRIX**

| Test Number | Test Description | Test Objective |
|---|---|---|
| CT-1 | System Safety & Environmental Assessment | Verify that the equipment can perform the Control Test operations in a safe and an environmentally compliant manner. |
| CT-2 | Shoring System Functional Test | Demonstrate that the system can be safely and rapidly installed and removed and can perform its intended operating functions. |
| CT-3 | SCU Performance Test | Demonstrate that the SCU can safely and rapidly install the horizontal barrier in a controlled, subsurface environment. |

**Data quality objectives:** Data was obtained by observation using the available instrumentation on the SCU and manual data collection means using RAHCO's currently available instruments.

The following discussion of each test includes a statement of the test objectives, the data quality objective, and the test results.

### 2.5.4.1 Test CT-1: System Safety & Environmental Assessment

**Test Objective:** Verify the adequacy of the safety and environmental plans and demonstrate that test operations can be safely performed in an environmentally compliant manner.

**Data Quality Objectives:** Review the safety and environment compliance plans and determine their adequacy to address the safety and environment issues associated with both the SCS equipment and test operations.

**Test Results:** This test concluded that the test operations could be safely performed and that the emergency stop equipment and procedures were satisfactory. See Section 2.4, Factory Test, for additional safety comments.

### 2.5.4.2 Test CT-2: Shoring System Functional Tests

**Test Objective:** Demonstrate that the Slide-Rail Shoring System can be safely and rapidly installed and removed and verify that it provides adequate personnel and equipment protection and SCU structural foundation support.

**Data Quality Objectives:** Observe the Slide-Rail Shoring System installation and removal operations, complete the checklist, and document time durations.

**Test Conduct:** The shoring system was installed in three stages: Stage 1 included the installation of the lower side shoring as illustrated in Figure 2.5-7; Stage 2 consisted of installing the upper side shoring as shown in Figure 2.5-8; and Stage 3 installed the SCU support rails and the inner shoring system as shown in Figure 2.5-9.

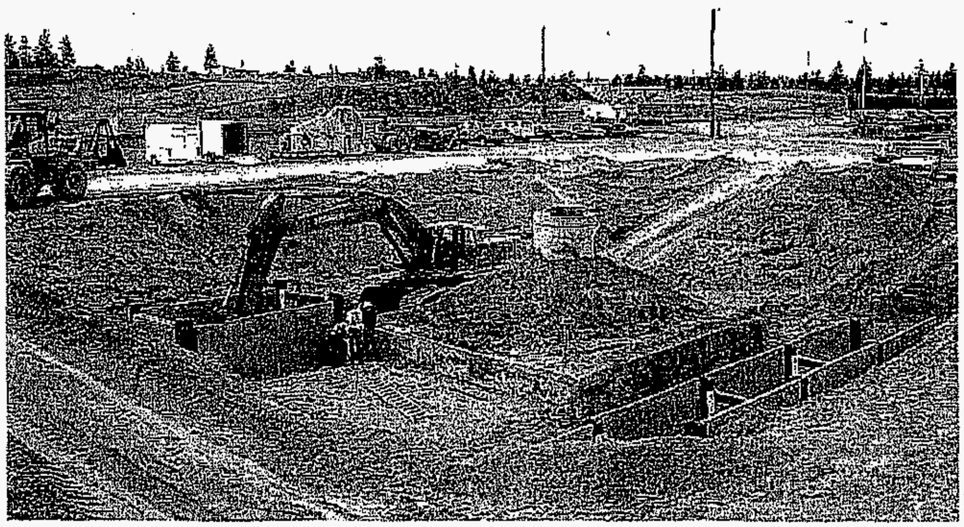


*Figure 2.6-7 Installation of Lower Side Shoring*

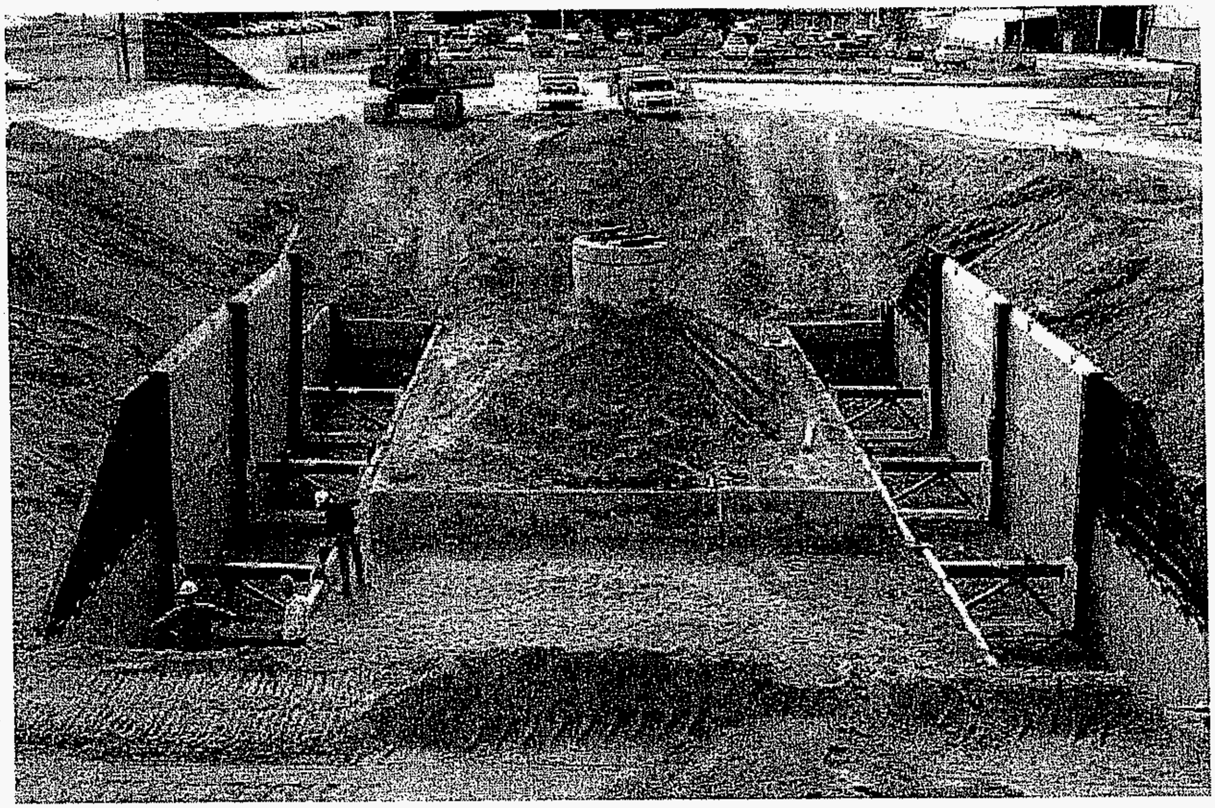


*Figure 2.5-8 Installation of Upper Side Shoring*

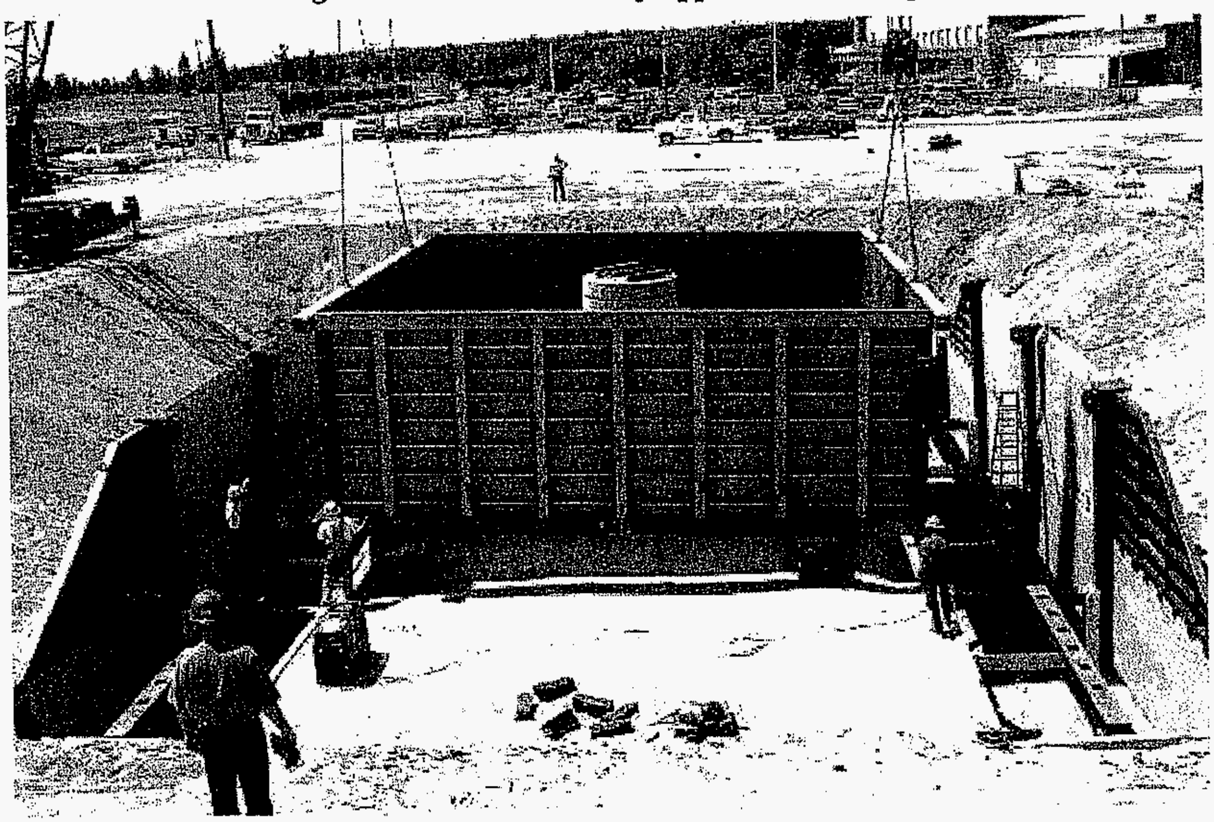


*Figure 2.5-9 Installation of SCU Support Rails & Inner Shoring System*

**Test Results:** The following checklist summarizes the shoring system performance.

| TABLE 2.5-3 SHORING SYSTEM CHECKLIST | | | |
|---|---|---|---|
| **Item** | **Description** | **Yes** | **No** |
| 1 | Did the shoring system function as designed? | X | |
| 2 | Could the shoring system modules be placed within a construction tolerance of ±3 in. of desired centerline? | X | |
| 3 | Could the rail connections be easily removed? | X | |
| 4 | Did the cross beams perform as designed? | X | |
| 5 | Did the crossbraces provide adequate structural support for the rails? | X | |

Timeline data for the trench excavation and shoring system installation activities was collected and analyzed. Table 2.5-4 shows the activity timelines for excavating the side trenches. The specific excavation activities included:

- **Swing Bucket**—This activity consisted of swinging the bucket from the trench location to the bucket discharge location and returning to the trench location.
- **Empty Bucket**—This activity consisted of emptying the bucket at the discharge location.
- **Fill Bucket**—This activity included lowering the bucket into the trench, filling the bucket, and raising the bucket to clear the trench.

Based on observations, the bucket fill factor was 110% and the operator efficiency was observed to be approximately 75%.

| TABLE 2.5-4 TRENCH EXCAVATION DATA | | | | | |
|---|---|---|---|---|---|
| **Activity** | **Source** | **Collection Method** | **Sample Size** | **Average Time Duration (sec)** | **Comments** |
| Swing Time | | | | | Test Started 6/12/01 |
| 30° | Test | Manual | 6 | 3.12 | Test Completed 6/15/01 |
| 60° | Test | Manual | 3 | 3.83 | |
| 90° | Test | Manual | 3 | 4.5 | |
| 120° | Test | Manual | 3 | 5.83 | |
| 180° | Test | Manual | 4 | 6.13 | |
| Empty Time | Test | Manual | 7 | 2.57 | Test Started 6/12/01 Test Completed 6/15/01 |
| Bucket Fill | | | | | Test Started 6/12/01 |
| Surface | Test | Manual | 10 | 6.00 | Test Completed 6/15/01 |
| 4 ft | Test | Manual | 9 | 6.72 | |
| 8 ft | Test | Manual | 9 | 9.44 | |
| 12 ft | Test | Manual | 3 | 9.70 | |

| TABLE 2.5-4 TRENCH EXCAVATION DATA (Continued) | | | | | |
|---|---|---|---|---|---|
| **Activity** | **Source** | **Collection Method** | **Sample Size** | **Average Time Duration (sec)** | **Comments** |
| Bucket Fill Factor<br>Surface<br>4 ft<br>8 ft<br>12 ft | <br>Test<br>Test<br>Test<br>Test | <br>Manual<br>Manual<br>Manual<br>Manual | <br>9<br>9<br>9<br>3 | <br>1.25<br>1.10<br>0.75<br>0.60 | Test Started 6/12/01<br>Test Completed 6/15/01 |

Table 2.5-5 summarizes the shoring system installation timelines. The specific activities included:

- **Assemble Rail**—Installing the driving shoe and push plates and rigging the rail for handling.
- **Place Rail**—Picking the rail from the staging area and placing the rail in the trench.
- **Place Panel**—Picking the slide-rail panel from the staging area and placing the panel in the trench.
- **Position Rail/Panel**—Driving the rails and panels to the proper grade and position.
- **Move Excavator**—Reposition excavator to install new shoring system cell.

| TABLE 2.5-5 SHORING SYSTEM INSTALLATION TIMELINE DATA | | | | | |
|---|---|---|---|---|---|
| **Activity** | **Source** | **Collection Method** | **Sample Size** | **Average Time Duration (sec)** | **Comments** |
| Assemble Rail | Test | Manual | 4 | 120 | Test Started 6/12/01<br>Test Completed 6/15/01 |
| Install Shoring<br>- Place Rail<br>- Place Panel<br>- Place Spreader | <br>Test<br>Test<br>Test | <br>Manual<br>Manual<br>Manual | <br>16<br>11<br>4 | <br>174<br>191<br>615 | Test Started 6/12/01<br>Test Completed 6/15/01 |
| Position Shoring | Test | Manual | 5 | 2325 | Test Started 6/12/01<br>Test Completed 6/15/01 |
| Move Excavator | Test | Manual | 8 | 300 | Test Started 6/12/01<br>Test Completed 6/15/01 |

The following table highlights the calculated shoring system installation time based upon the test data. As shown, it is estimated that a single shoring system cell (16-ft long X 10-ft wide X 8-ft deep) can be installed in 92 mins, with the total 8 cells installed in approximately 12.3 hrs. Test observations confirmed the validity of this installation time.

| TABLE 2.5-6 CALCULATED SHORING SYSTEM INSTALLATION TIME | | | |
|---|---|---|---|
| **Activity** | **Per Shoring Cell** | **Per Side Trench (4 Cells)** | **Total Shoring (8 Cells)** |
| Excavate Trench | 7 mins | 28 mins | 56 mins |
| Assemble Rails/Panels | 24 mins | 96 mins | 192 mins |
| Place Shoring Components | 37 mins | 148 mins | 296 mins |
| Position Shoring | 52 mins | 208 mins | 416 mins |
| **Total Installation Time** | **92 mins** | **384 mins** | **768 mins** |
| Notes: Operating efficiency is 75%.<br>Assembling rails and panels are concurrent activities. | | | |

**Test Summary:** The RAHCO-designed shoring system installation was conducted as planned. The slide-rail shoring system was easily installed and positioned within the established construction tolerances. The custom-designed spreaders were easily installed and provided adequate structural support for the support rail and SCU. Data collected concluded that a single 16-ft-long X 10-ft-wide X 8-ft-deep cell could be installed with a single excavator and a crew of four in approximately 90 mins. No movement of the shoring system was observed during the horizontal barrier construction activities.

The customized shoring system performed as designed: It was safely and rapidly installed using conventional construction equipment (excavator and crane) and a crew of four; it provided satisfactory ground support; and it successfully provided support for the SCU. Removal of the shoring system was not completed.

### 2.5.4.3 Test CT-3: SCU Performance Tests

**Test Objective:** Demonstrate that the SCU can safely install the GCL containment barrier and verify the functional and performance capabilities of the SCU subsystems and components to perform the six major functions: excavation and muck removal, steering, thrusting, block insertion, polyliner insertion, and operator control.

**Data Quality Objectives:** Observe the barrier construction operation and document the ability of the SCU to operate safely and perform the six critical operating functions within the specified time durations. This documentation shall include completion of the checklists, photographs, video tape, log books, and operator interviews.

**Test Conduct:** A total of six tests were to be performed as the SCU constructed the horizontal barrier (HB). Table 2.5-7 identifies the six tests and their status at the time of test suspension.

| TABLE 2.5-7 SCU PERFORMANCE TEST MATRIX | | | | | |
|---|---|---|---|---|---|
| Test Number | Material Type | Penetration Depth | Travel Speed | Advance Distance | Status |
| CT-3A | Cemented Sand | 1/8-1/2 in. | 50-200 fpm | 6 ft | Completed |
| CT-3B | Cemented Sand | 1/4 in. | 100 fpm | 6 ft | Partially Completed |
| CT-3C | Cemented Sand & Aggregate | 1/2 in. | 200 fpm | 4 ft | Not Complete |
| CT-3D | Cemented Sand, Cobbles, & Boulders | 1/8 in. | 50 fpm | 4 ft | Not Complete |
| CT-3E | Cemented Sand | 1/4 in. | 100 fpm | 6 ft | Not Complete |
| CT-3F | Cemented Sand | Optimum | Optimum | 6 ft | Not Complete |

The SCU performance test was conducted in three stages: Stage 1 included the transport of the SCU to the test site and placement of the unit in the trench as illustrated in Figure 2.5-10. Stage 2 consisted of performing SCU checkout as shown in Figure 2.5-11 and Stage 3 performed horizontal barrier construction as shown in Figures 2.5-12 and 2.5-13. Testing was suspended on 26 July 2001 after the SCU had excavated approximately 10 ft of horizontal slot and 4 ft of horizontal containment barrier was placed.

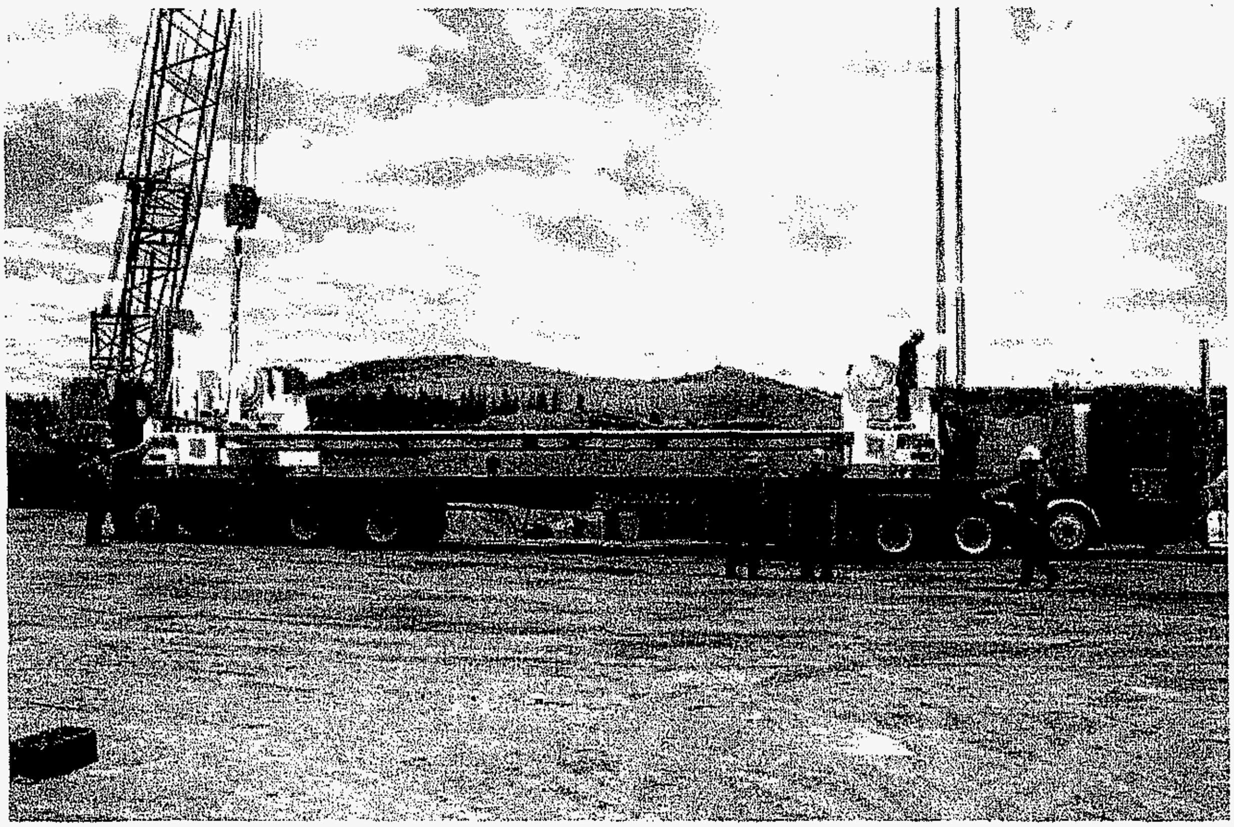


*Figure 2.5-10 SCU Transport & Placement*

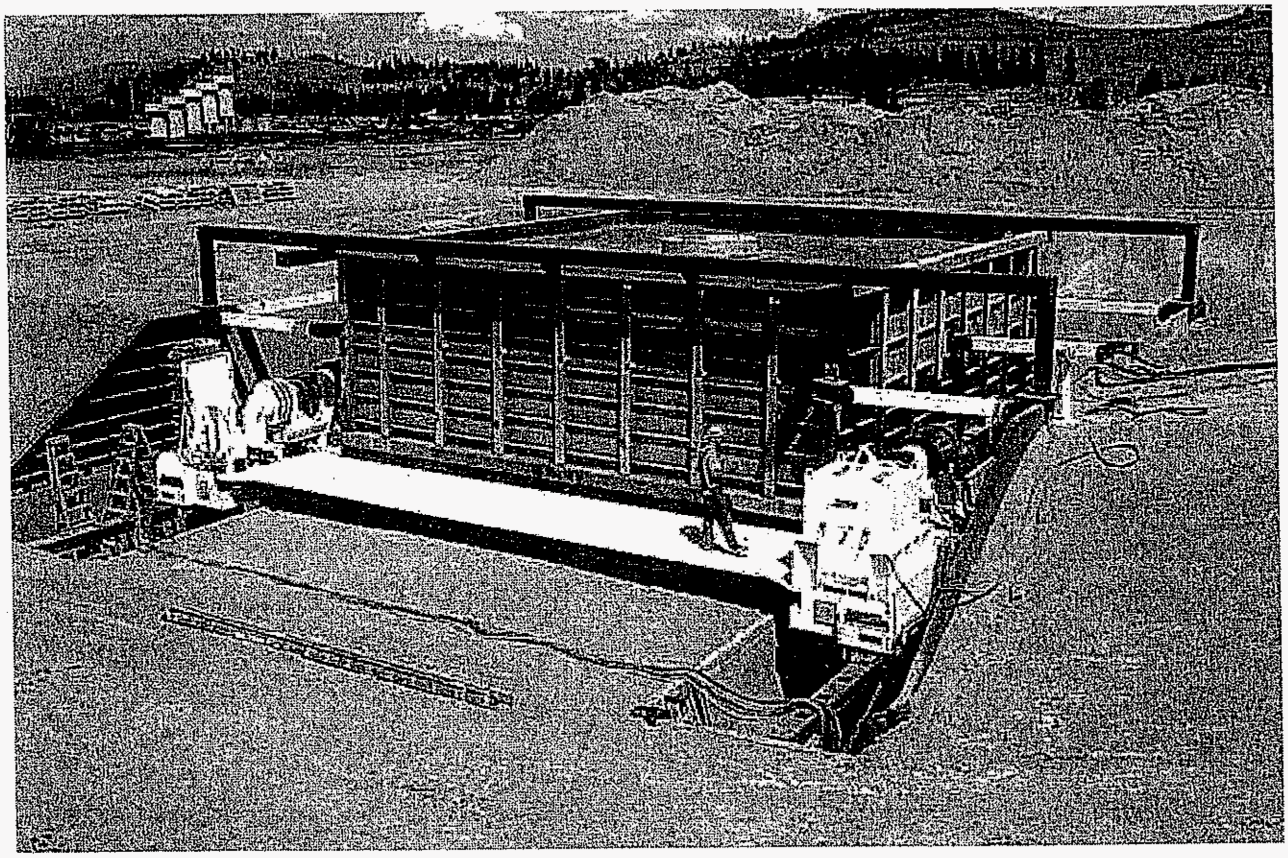


*Figure 2.5-11 SCU Checkout*

*Figure 2.5-12 Horizontal Slot Excavation*

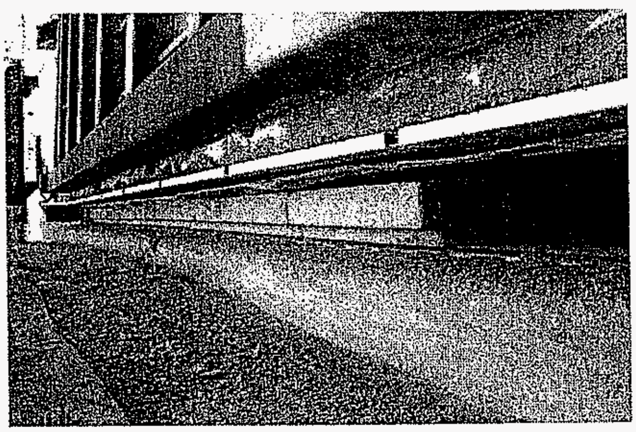


*Figure 2.5-13 Horizontal Barrier Placement*

**Test Results:** The Control Test results are described in the form of a function checklist, problems and corrective action, and operating performance data. The following table summarizes the SCU functional performance.

| TABLE 2.5-8 SCU FUNCTIONAL CHECKLIST | | | |
|---|---|---|---|
| **Excavation Checklist** | | | |
| **Item** | **Description** | **Yes** | **No** |
| 1 | Did the cutterhead assembly function as designed? | X | |
| 2 | Could the cutterhead complete a single pass (over and back) within 20 secs at 100 fpm? | X | |
| 3 | Was the cutterhead capable of traveling across the Beam Structure at maximum rates of 200 fpm? | X | |
| 4 | Was the cutterhead capable of accelerating/decelerating within the specified distance of 4 ft? | X | |
| 5 | Could the cutterhead be stopped within ±1/2 in. of designated stop position? | X | |
| 6 | Was the wire rope tension maintained throughout the cutting operation (no rope slap) at 100 fpm? | X | |
| 7 | Was the wire rope properly fed and wrapped onto the winch? | X | |
| 8 | Was the wire rope tension maintained after motor shutdown? | X | |
| 9 | Did the muck removal plows function as designed? | | X |
| 10 | Could the cutterhead cleaning unit remove impacted muck and debris? | X | |
| **Steering Checklist** | | | |
| 11 | Did the steering system function as designed? | X | |
| 12 | Could the inclinometers properly measure beam tilt? | X | |
| 13 | Could the support shoe load cells accurately measure rail loads? | | X |
| 14 | Could the cutters be manually adjusted +1 in. vertically? | X | |
| 15 | Could the rail alignment pins be manually adjusted 2 in.? | X | |
| 16 | Could the support shoes be adjusted ±1 in.? | X | |
| 17 | Could the excavation operation be easily performed from the operator's station? | X | |
| 18 | Could the cutterhead and steering units be safely operated? | X | |
| 19 | Could the cutterhead and steering units be easily maintained? | X | |
| **Thrusting Checklist** | | | |
| 20 | Did the Indexing Unit function as designed? | X | |
| 21 | Could the Indexing Unit advance the Beam Structure at the rate of 2 ipm? | X | |
| 22 | Could the Indexing Unit advance the Beam Structure the prescribed increments (0.25 in., 0.5 in., etc.) within ±1/16 in.? | X | |
| 23 | Could the Indexing Unit reposition the rail lock within ±1/16 in.? | X | |
| 24 | Did the laser system accurately determine advance distance within ±1/16 in.? | | X |
| 25 | Did the rail lock mechanism function as designed? | X | |
| 26 | Could the rail lock mechanism be inserted and retracted 4 in. within 30 sec? | X | |

| TABLE 2.5-8 SCU FUNCTIONAL CHECKLIST (Continued) | | | |
|---|---|---|---|
| **Item** | **Description** | **Yes** | **No** |
| 27 | Could the thrusting operations be easily performed from the operator's station? | X | |
| 28 | Could the Indexing Unit and rail lock mechanism be safely operated? | X | |
| 29 | Could the Indexing Unit and rail lock mechanism be easily maintained? | X | |
| | **Block Insertion & Alignment Checklist** | | |
| 30 | Did the Block Inserter and alignment assembly function as designed? | X | |
| 31 | Could the 11 blocks be easily and safely loaded into the block magazine? | X | |
| 32 | Could the block magazine be safely and remotely positioned onto the Beam Structure? | X | |
| 33 | Could the block grabber lift the blocks without damage to the blocks? | X | |
| 34 | Could the Block Inserter properly insert the blocks without damage to the blocks? | X | |
| 35 | Could the blocks be properly positioned in the Beam Structure? | X | |
| 36 | Could the row of blocks be properly installed within 10 mins? | | X |
| 37 | Did the alignment jacks function as designed? | X | |
| 38 | Could the alignment jacks be retracted 6 in. to allow the blocks to be inserted? | X | |
| 39 | Could the alignment jacks properly position the blocks after a row of blocks was inserted? | X | |
| 40 | Could the blocks be uniformly extracted from the Beam Structure? | X | |
| 41 | Could the alignment jacks maintain load on the blocks during the slot cutting operation? | X | |
| 42 | Could the alignment jacks extend a distance of 30 in. from home position? | X | |
| 43 | Could the alignment jack load cells accurately measure block loads during the cutting operation? | | X |
| 44 | Could the block insertion operation be easily performed from the operator's station? | X | |
| 45 | Could the block insertion equipment be safely operated? | X | |
| 46 | Could the block insertion equipment be easily maintained? | X | |
| | **Polyliner Insertion Checklist** | | |
| 47 | Could the roll of GCL be easily and safely loaded into the polyliner magazine? | X | |
| 48 | Could the polyliner magazine be easily and safely positioned onto the SCU? | X | |
| 49 | Could the insertion rollers properly feed the GCL into the SCU? | X | |
| 50 | Could the cutterhead mechanism cut the GCL? | X | |
| 51 | Could the alignment jack fingers properly position the GCL as the beam structure advanced? | X | |
| 52 | Could the edge sensors identify the GCL? | | X |
| 53 | Was the 30-in.-wide GCL strip installed within 1 min? | X | |

| TABLE 2.5-8 SCU FUNCTIONAL CHECKLIST (Continued) | | | |
|---|---|---|---|
| **Item** | **Description** | **Yes** | **No** |
| 54 | Was the 30-in.-wide GCL strip properly positioned within ±1/2 in. (ends and 6-in. overlap)? | X | |
| 55 | Could the polyliner insertion operation be easily performed from the operator's station? | X | |
| 56 | Could the polyliner insertion equipment be safely operated? | X | |
| 57 | Could the polyliner insertion equipment be easily maintained? | X | |
| | **Operator Control Checklist** | | |
| 58 | Could the operator safely control the SCU? | X | |
| 59 | Is the SCU easily operated? | X | |
| 60 | Could the operator perform autosequencing operations? | | X |
| 61 | Did the software perform as designed? | | X |

The following table identifies the function deficiency and the corrective action.

| TABLE 2.5-9 PROBLEMS & CORRECTIVE ACTION | | |
|---|---|---|
| **PROBLEM** | **DESCRIPTION** | **CORRECTIVE ACTION** |
| 1. Inadequacy of Muck Plows | The muck plows did not remove the muck from inside the beam structure. | • Modify plows with the addition of wire brushes. |
| 2. Inability to Measure Rail Loads | The support shoe load cells could not measure the rail loads beyond 30,000 lbs. | • Replace load cells units having a 100,000-lb range. |
| 3. Laser System Inaccuracy | The laser system could not provide the 1/16-in. accuracy. | • Modify laser software to improve accuracy. |
| 4. Inadequate Block Insertion Speed | Design requirements stated the need to insert 11 blocks in 10 mins; test results showed 18 mins. | • Modify Block Inserter design to improve installation time. |
| 5. Inability to Detect GCL | The edge sensors could not detect GLC (manufacturing error). | • Install aluminum tape on GCL. |
| 6. Inability to Measure Block Loads | The alignment jack load cells failed. | • Replace load cells. |
| 7. Inability to Perform All Autosequencing Operations | The "regrip" and "block insertion" autosequencing operations were not operable. | • Modify software. |
| 8. Software Problems | A number of operating features were not available because of software problems. | • Modify software. |

The following SCU performance data was obtained.

The excavation time as a function of cutterhead speed, as shown in Figure 2.5-14, was verified at both the 50- and 100-fpm levels.

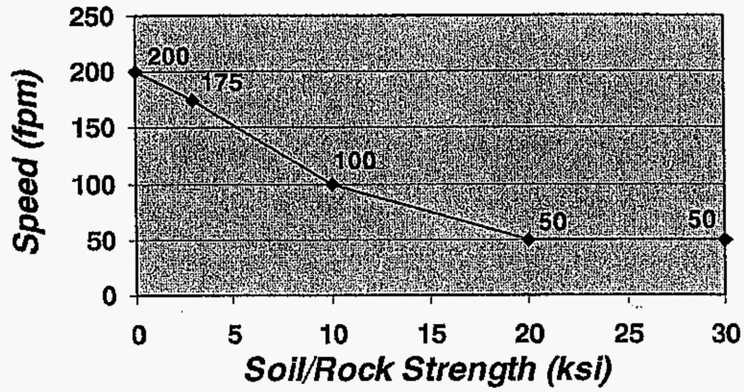



*Figure 2.5-14 Excavation Time*

The indexing time as a function of the indexing distance was also verified for the 0.125-in. and 0.25-in. distance.

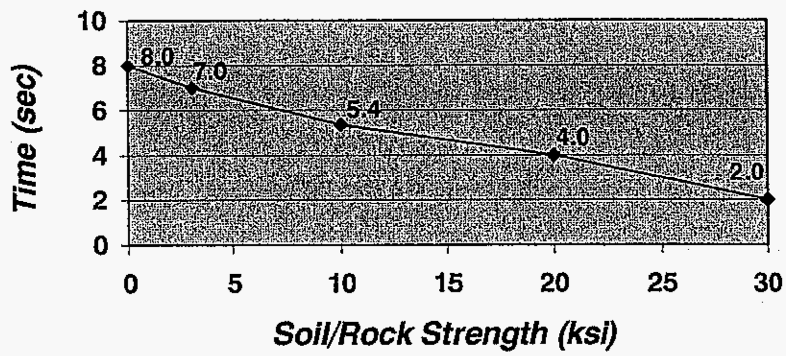



*Figure 2.5-15 Indexing Time*

Additionally, the following performance capabilities were verified during the Control Test.

| TABLE 2.5-10 SCU PERFORMANCE TIMES | |
|---|---|
| **Function** | **Cycle Time** |
| Reposition Rail Lock | 7.7 mins |
| Block Magazine Loading | 6 mins |
| Block Insertion | 18.7 mins |
| Alignment Jack Engage | 4 secs |
| Alignment Jack Retract | 21 secs |
| Polyliner Magazine Loading | 5 mins |
| Polyliner Insertion | 47 secs |

The Control Test can be deemed a success for several reasons:

- The SCS successfully installed a shoring system and placed a 4-ft-long, horizontal barrier.
- Sufficient data was collected to establish the SCS performance capabilities.

**Visitor Day:** An SCS Visitor Day was successfully held on 26 July 2001 at the RAHCO facility. A total of 18 representatives from U.S. DOE, EPA, DOE site contractors, unions, and State of Washington Congressional offices attended. The visitors were given an overview of the SCS and had the opportunity to witness equipment operations and obtain detailed information regarding the test hardware and equipment and test results as shown in Figure 2.5-16.

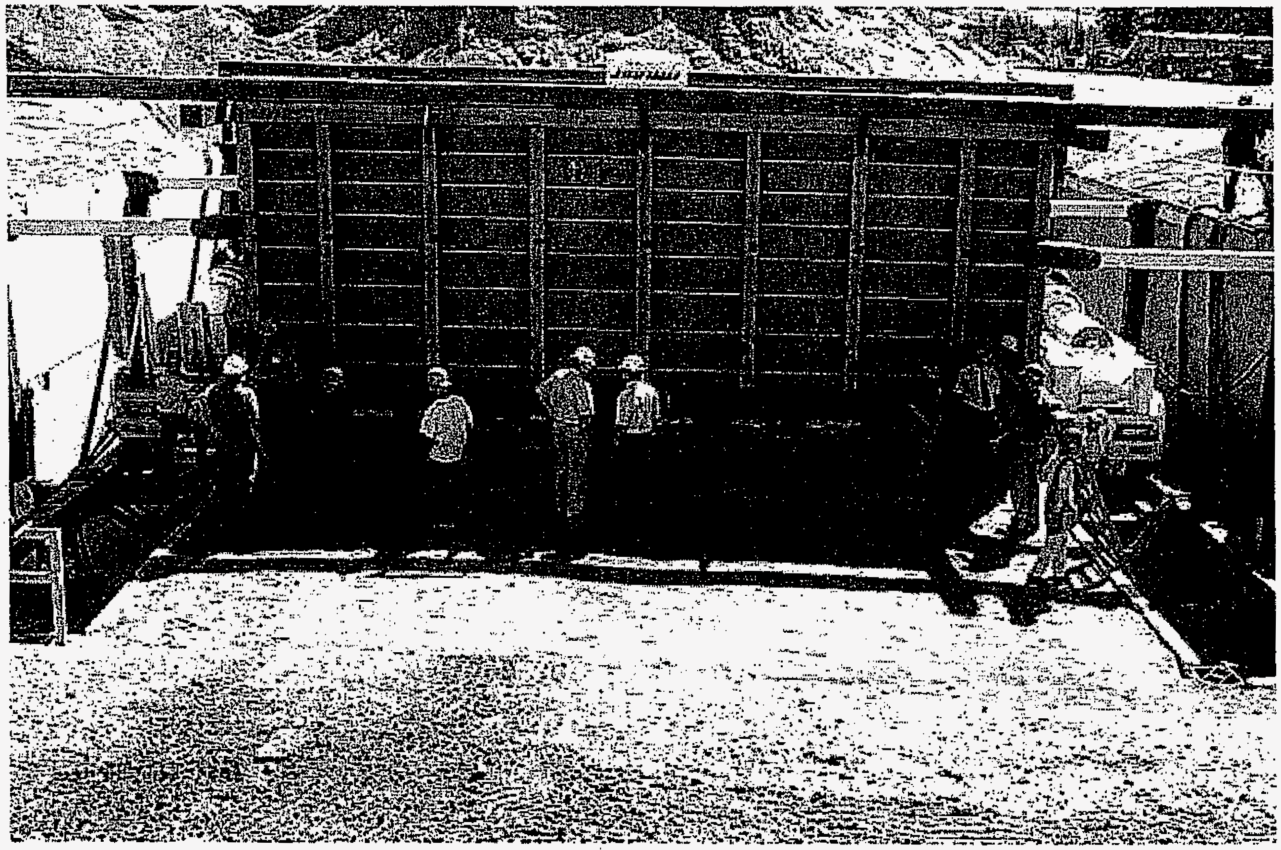


***Figure 2.5-16 SCS Visitor Day***

## 2.6 PERFORMANCE CAPABILITIES

This section provides data and information regarding the construction rate of the SCS in varying geological conditions expected at DOE sites. It addresses the performance capability issue by providing advance rate data for each of the four major construction operations. All performance data is based upon a 1000-ft-long X 34-ft-wide X 29-ft- deep containment barrier as depicted in Figure 2.6-1.

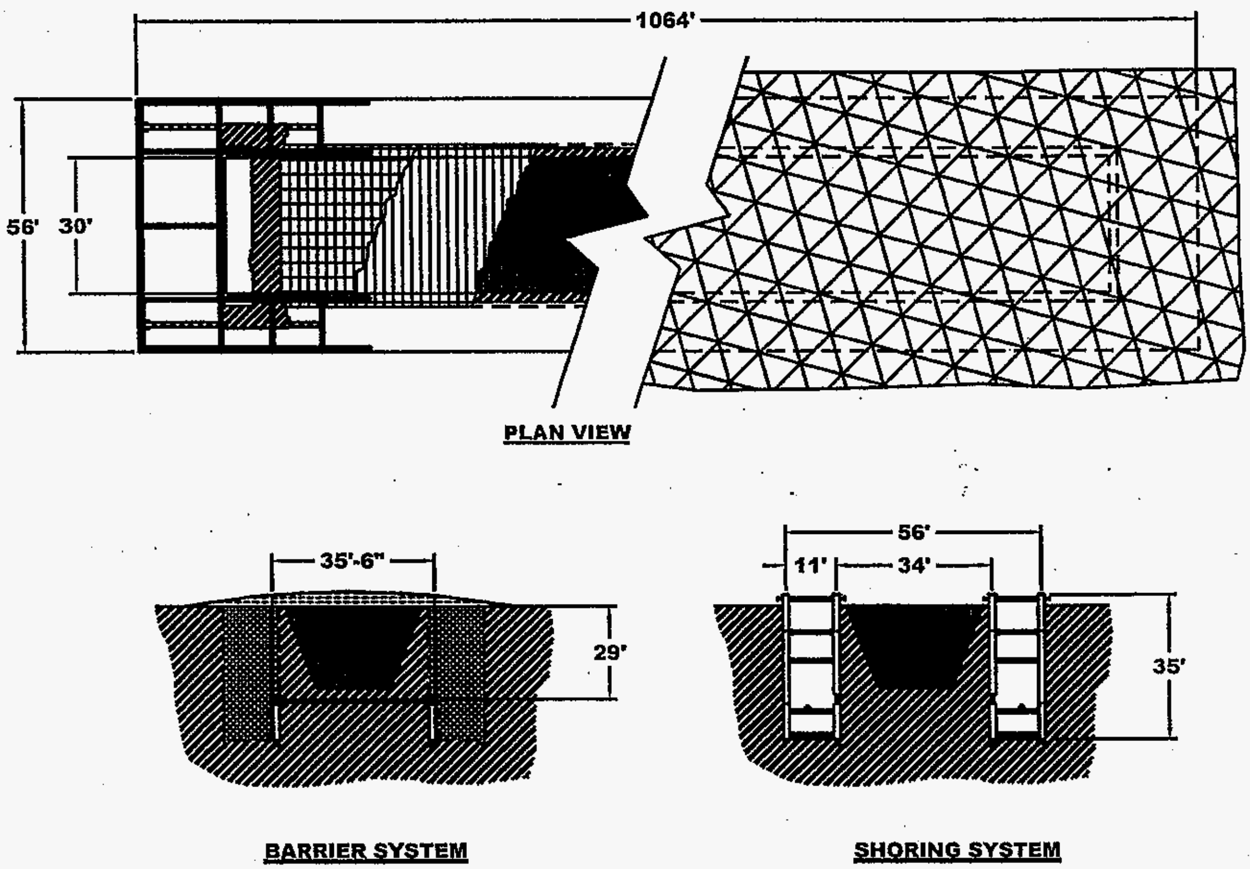



*Figure 2.6-1 Subsurface Containment Barrier Configuration*

The following assumptions were used to establish SCS construction rate data.

| TABLE 2.6-1 SCS CONSTRUCTION RATE ASSUMPTIONS | |
|---|---|
| Waste Geometry | 1000-ft long X 30-ft wide X 25-ft deep |
| End Trench Geometry | 47-ft long X 16-ft wide X 35-ft deep |
| Side Trench Geometry | 1000-ft long X 9.5-ft wide X 35-ft deep |
| Horizontal Barrier Depth | 29 ft |
| Horizontal Barrier Size | 1002-ft long X 34.7-ft wide |
| Vertical Barrier Size | 2069-ft long X 29-ft high |

| TABLE 2.6-1 SCS CONSTRUCTION RATE ASSUMPTION (Continued) | |
|---|---|
| Horizontal-Vertical Joint Length | 2069-ft long |
| Weathered Soil/Rock | 0-15 ft |
| Competent Soil/Rock | 15-35 ft |
| Operating Efficiency | 75%-100% |
| Operating Day | 8 hrs/day |
| Operating Month | 22 days/mo |

### 2.6.1 SCS CONSTRUCTION RATE

The SCS was designed to achieve a maximum construction rate[1] of 12 ft/day for an 8-hr/day operation. However, actual construction rates will vary depending on specific site conditions including waste area geometry; site geology, topology, and hydrology; and system utilization. Figure 2.6-2 shows the SCS construction rate as a function of the unconfined compressive strength of the soil/rock surrounding the waste with operating efficiencies of 75% and 100%.

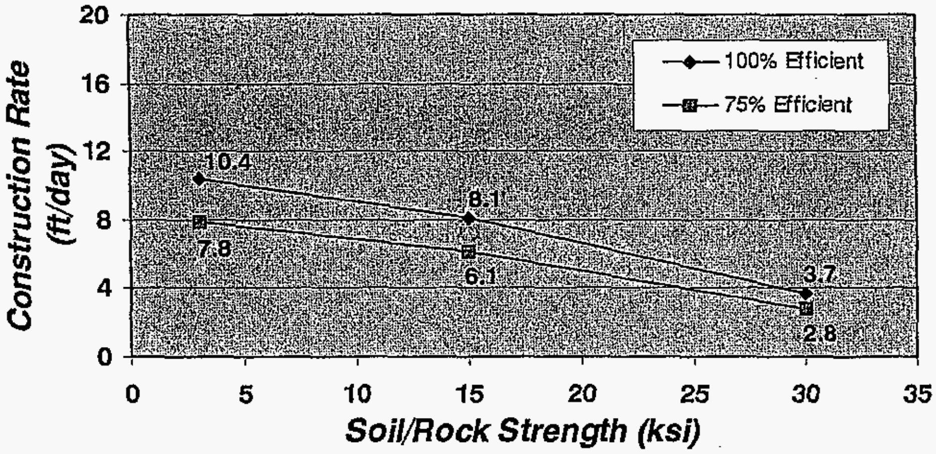



*Figure 2.6-2 SCS Construction Rate*

As shown, for soils such as cemented sands and gravel with a soil/rock strength of 3 ksi, the expected construction rate is 8-10 ft/day. Similarly, for laminated shales and limestones with a soil/rock strength of 15 ksi, the expected construction rate is approximately 6-8 ft/day; and, finally, for sites that have intermingled rock such as basalt with a soil/rock strength of 30 ksi, an overall construction rate of 3-4 ft/day is expected.

The following figure summarizes the advance rate for each of the four major operations using the equipment and operating crew identified in Section 2.3 with an operating efficiency of 75%.

[1]Excludes mobilization and demobilization operations.

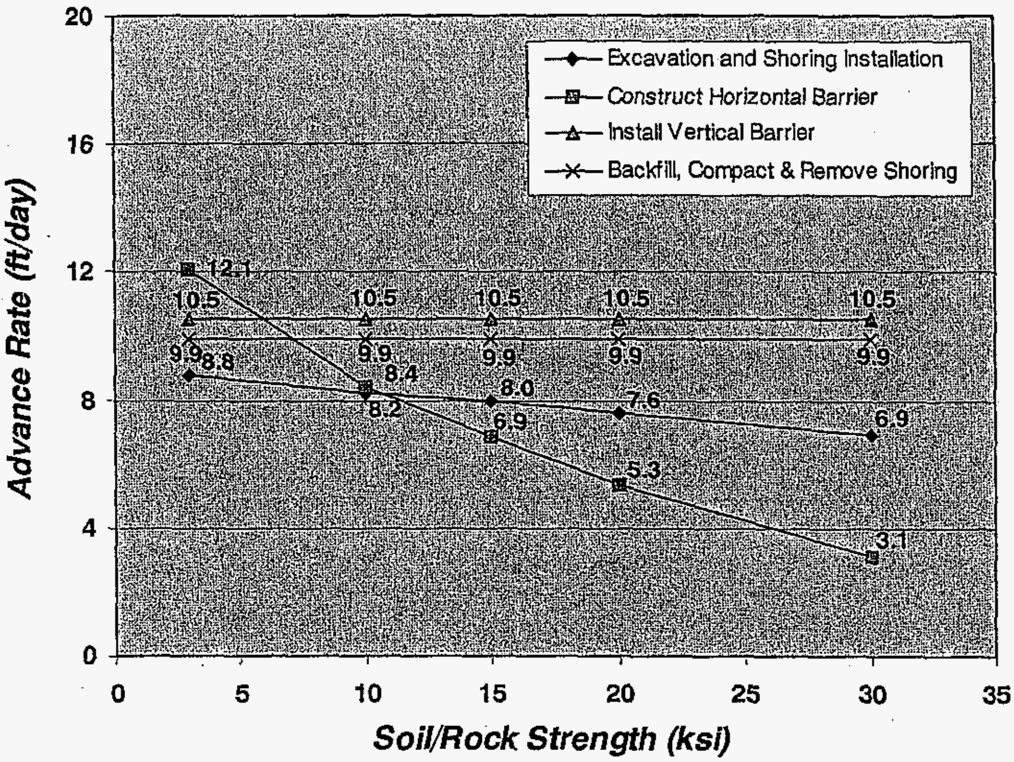



*Figure 2.6-3 Major Operations Construction Rate*

The following provides a brief description of the performance capabilities of each of the four operations.

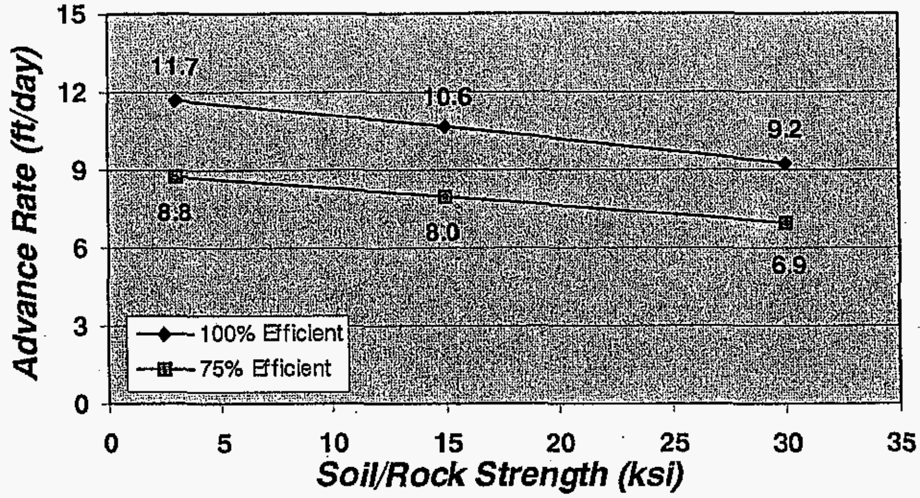
## 2.6.2 EXCAVATE & INSTALL SHORING

The construction rate for this operation for a nominal trench depth of 35 ft as a function of the soil strength of the material surrounding the waste area is shown in Figure 2.6-4.

As shown, the advance rate for this operation varies from approximately 7 ft/day to 9 ft/day dependent on the soil/rock strength. This variation is primarily due to the change in production rate of the hydraulic hammer used for soil strengths greater than 15,000 psi.

Four factors that influence the excavate trench and install shoring advance rate include the bucket fill factor, bucket fill time, hydraulic hammer production, and shoring installation penetration rate.

**Bucket Fill Factor:** During construction, the excavator operator will attempt to fill the excavator bucket to capacity or more on every pass. However, test results showed that the shoring system obscured the operator's view of the bucket and, in many cases, the bucket was less than full. At trench depths to 35 ft, it is expected that the bucket fill factor will decrease to 0.4 as shown in Figure 2.6-5.




| ASSUMPTIONS | |
|---|---|
| End Trench Size | 47-ft long X 16-ft wide X 35-ft deep |
| Side Trench Size | 1000-ft long X 9 ft-5 in. wide X 35-ft deep |
| Bucket Size | 3 cu yds |
| Bucket Fill Factor | See Figure 2.6-4 |
| Bucket Fill Time | See Figure 2.6-6 |
| Bucket Swing Angle | 90° |
| Bucket Swing Time | 9 sec for 90° |
| Bucket Empty Time | 2.6 sec |
| Penetration/Blow | 2 in. @ 5 ft/1 in. @ 35 ft |
| Soil Swell Factor | 25% |
| Operating Efficiency | 75% |

*Figure 2.6-4 Excavate Trench & Install Shoring Construction Rate*

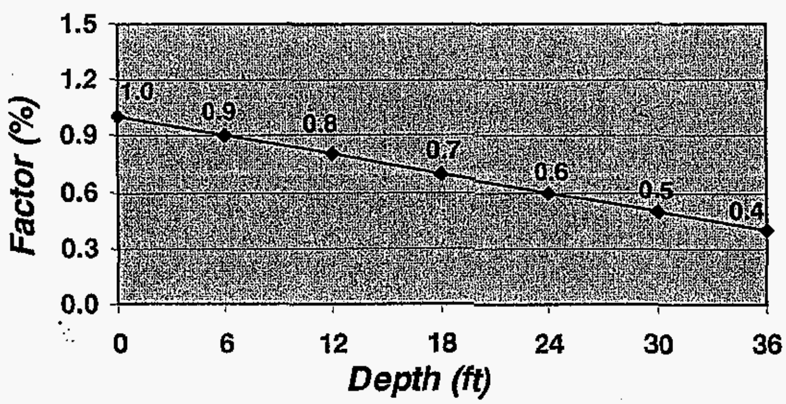



*Figure 2.6-5 Bucket Fill Factor*

**Bucket Fill Time:** Proficient excavator operators rapidly fill the excavator bucket even when constrained by the presence of a shoring system. However, the time to fill the bucket is relatively short in soft soils and significantly longer in more competent soils. As soil strengths approach a compressive strength of 15,000-20,000 psi, a hydraulic hammer is required to rubblize the material. Figure 2.6-6 shows the production rate for a standard Caterpillar Rock Hammer Model H180S.

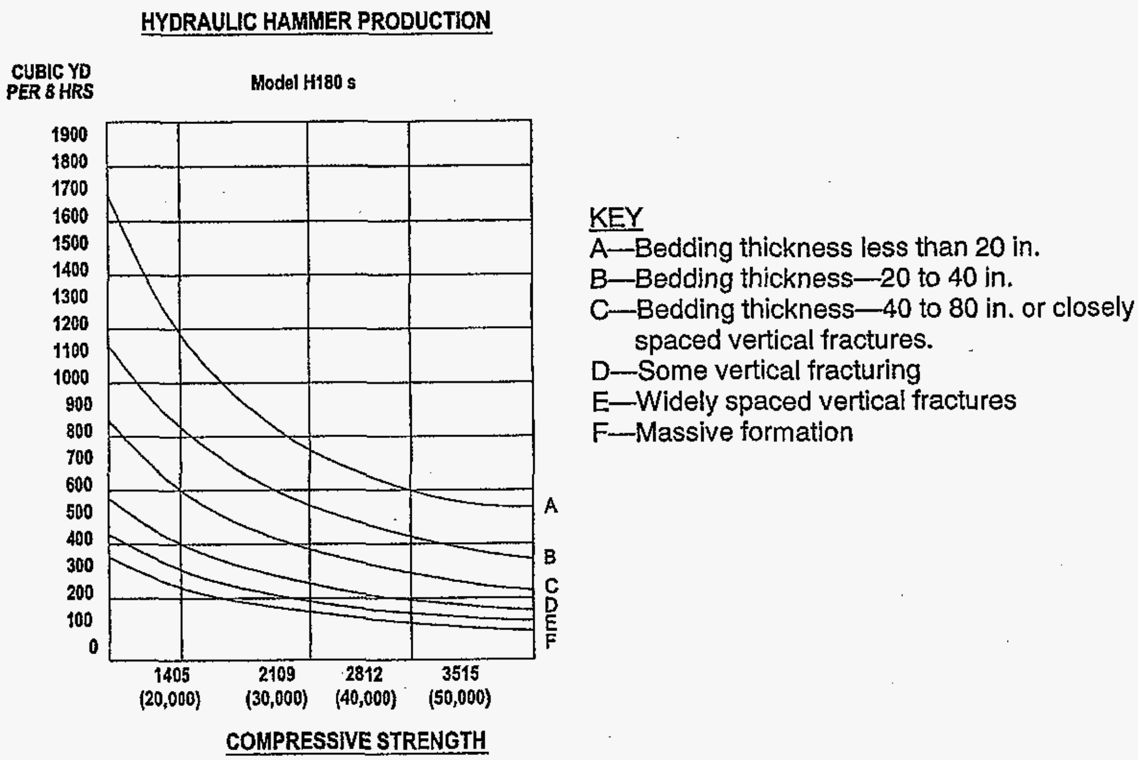



*Figure 2.6-6 Hydraulic Hammer Production Rate*

Assuming a bedding thickness of less than 20 in., the following figure shows the bucket fill time using a hydraulic hammer to rubblize the soil at depths greater than 18 ft at a soil/rock strength of 15 ksi. Bucket fill time charts for other soil/rock strengths are included in Appendix 1.

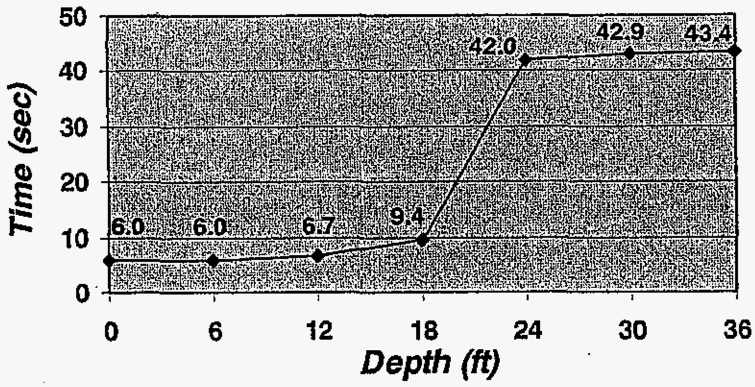



*Figure 2.6-7 Excavator Bucket Fill Time*

**Shoring Installation Time:** Time required to install the modular shoring system is a function of the operator's skill and the depth of the trench. Most skilled excavator operators become proficient at installing the shoring system after installing two to three shoring system cells. Control Test results supported this learning curve.

The depth of the trench impacts the shoring system installation time as ground friction increases as the depth increases. This requires additional blows by the excavator to push the shoring down as shown in Figure 2.6-8.

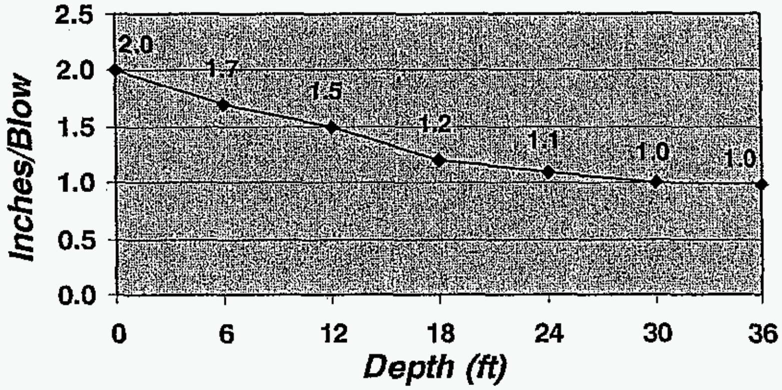



*Figure 2.6-8 Shoring Penetration Rate*

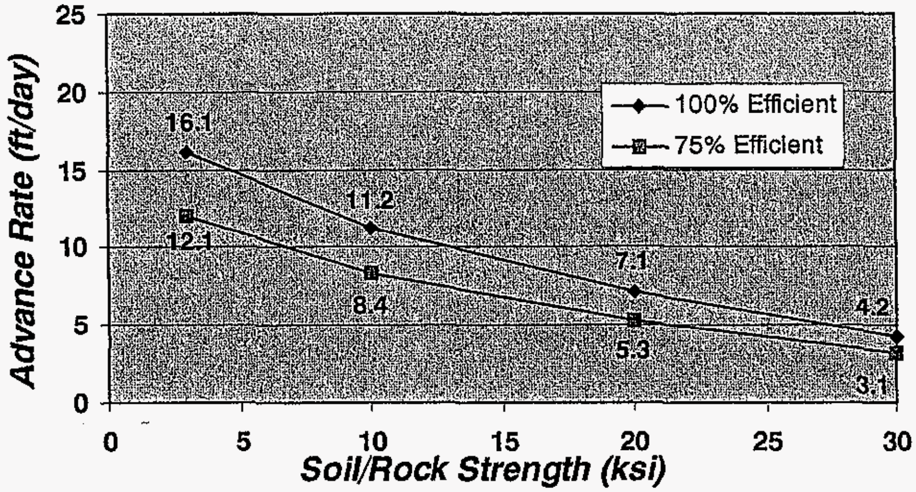
### 2.6.3 INSTALL HORIZONTAL BARRIER

The advance rate of the horizontal barrier construction operation and the assumptions used are shown in Figure 2.6-9. Construction rates to 12 ft/day for an 8-hr/day operation are achievable in soft soils, whereas construction rates of 3-4 ft/day are achievable in soils that include basalt-type boulders and cobbles.

A key factor that influences the horizontal barrier advance rate is the cutterhead speed and depth of cutterhead penetration.

**Cutterhead Speed:** The cutterhead design as described in Section 2.1 employs 14 each, 6-in.-diameter roller disc cutters capable of providing approximately 150,000 lbs of cutting thrust. However, higher thrust loads result in increased cutter temperatures. To maintain cutter life expectancy of 10,000 hrs and minimize cutter failures, it is necessary that the cutterhead speed be reduced in more competent soil/rock. Therefore, the recommended cutterhead speed as a function of soil strength is shown in Figure 2.6-10.

As shown, in softer soil/rock, a maximum cutterhead speed of 200 fpm is acceptable. However, in more competent soil/rock, maximum cutterhead speed should be in the range of the 50 to 100 fpm.




| ASSUMPTIONS | |
|---|---|
| Horizontal Barrier Size | 1002-ft long X 35-ft wide |
| Numbers of Blocks/Row | 11 |
| Polyliner Rolls | 150 ft |
| SCU Placement/Checkout Time | 6 hrs |
| Block Magazine Loading Time | 6 mins |
| Polyliner Magazine Loading Time | 5 mins |
| Regrip Time | 7.7 mins |
| Block Insertion Time | 18.7 mins |
| Alignment Jack Engage Time | 4 sec |
| Alignment Jack Retract Time | 21 sec |
| Polyliner Insertion Time | 47 sec |
| Operating Efficiency | 75% |

*Figure 2.6-9 Horizontal Barrier Construction Rate*

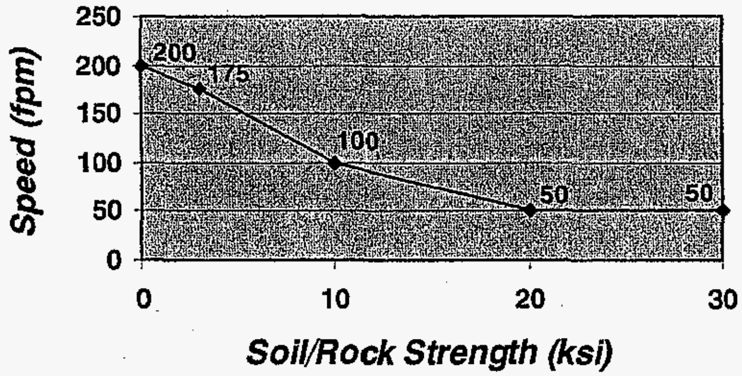



*Figure 2.6-10 Cutterhead Speed Versus Soil/Rock Strength*

**Cutterhead Penetration Depth:** The 6-in.-diameter disc cutters are designed to penetrate the cutting face up to 1/2 in. per pass. However, the 200-hp cutterhead electric drive, winch, and cable is limited to 140,000 lbs of cutterhead pull force. This force is not sufficient to pull the cutterhead at maximum depth of penetration in higher strength materials. The recommended depth of penetration per pass is shown in Figure 2.6-11.

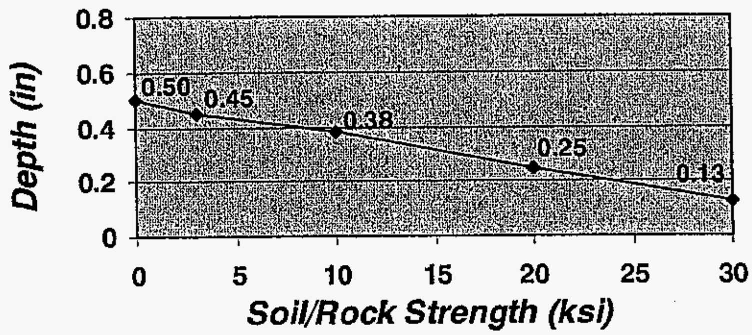



*Figure 2.6-11 Cutterhead Penetration Versus Soil/Rock Strength*

As shown, in soft soil/rock a depth of penetration to 0.5 in. is acceptable. However, in a cemented soil with basalt boulders and cobbles, the maximum depth of penetration would be 0.20 in. The recommended cutterhead operating parameters are shown in Table 2.6-2.

**TABLE 2.6-2 CUTTERHEAD OPERATING CHARACTERISTICS**

| Rock Type | Depth of Penetration | Maximum Cutterhead Speed | Single Pass (Time) | Cycle Time (min) |
|---|---|---|---|---|
| Soft Rock/Competent Soil (<10,000 psi) | 0.5 in. | 200 fpm | 40 sec | 60 mins |
| Medium Rock (10,000 to 25,000 psi) | 0.3 in. | 125 fpm | 42 sec | 108 mins |
| Hard Rock (>25,000 psi) | 0.125 in. | 50 fpm | 59 sec | 216 mins |

The SCU advances in increments of 2 ft, which represents a single cycle. Each cycle consists of six sequential activities. The estimated time to complete a single cycle can be described by the follow equation and is illustrated in Figure 2.6-12.

$$T_{cycle} = T_E + T_{RL} + T_{AR} + T_B + T_P + T_{AE}$$

Where:

| | | | |
|---|---|---|---|
| $T_{cycle}$ = | Time to Advance 2 ft | $T_B$ = | Block Insertion |
| $T_E$ = | Excavation & Index | $T_P$ = | Polyliner Insertion |
| $T_{RL}$ = | Reposition Rail Lock | $T_{AE}$ = | Alignment Jack Engage |
| $T_{AR}$ = | Alignment Jack Retract | | |

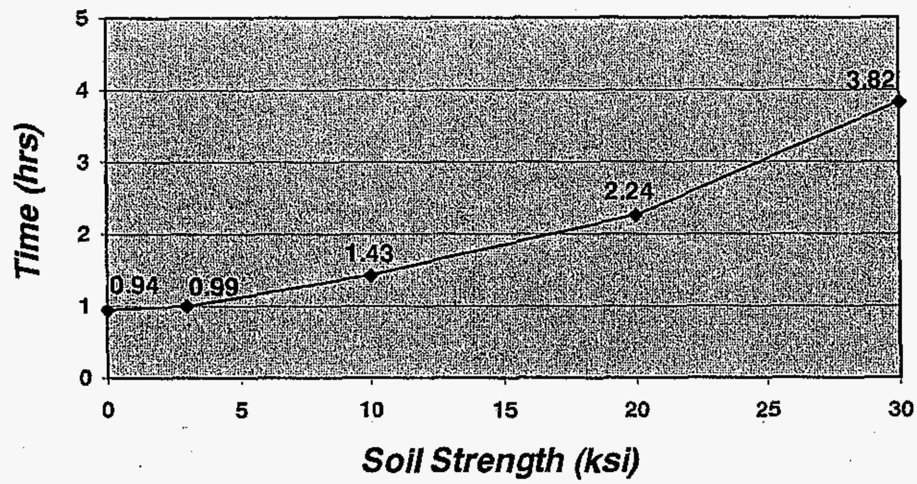
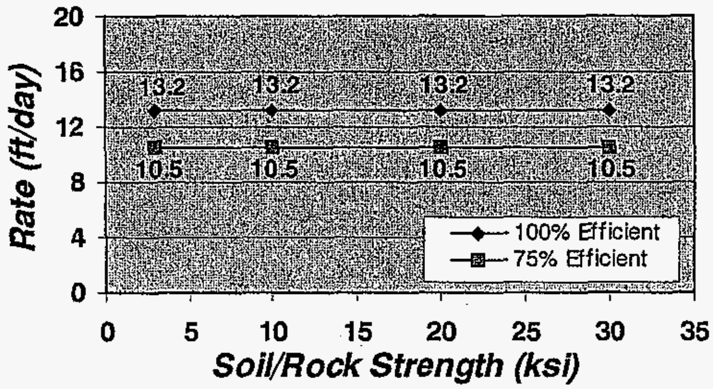



*Figure 2.6-12 SCU Cycle Time Versus Soil/Rock Strength*

## 2.6.4 INSTALL VERTICAL BARRIER

The vertical barrier panels can be installed at an advance rate of approximately 11 ft/day according to the assumptions as shown in Figure 2.6-13.

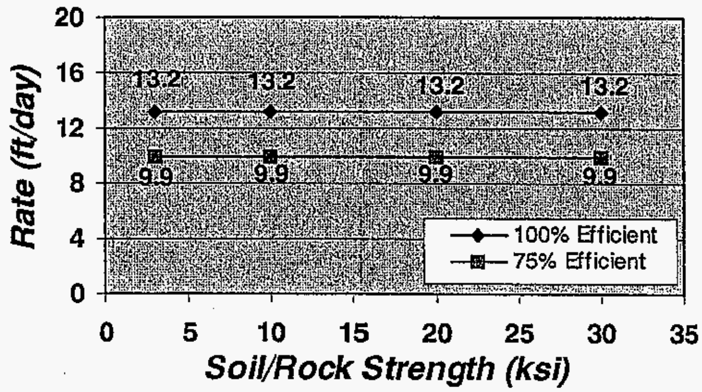



| ASSUMPTIONS | |
|---|---|
| Barrier Wall Panel Size | 16-ft long X 29-ft high |
| Install Hydraulic Actuator | 1 hr |
| Install Barrier Wall Time | 1 hr |
| Weld Horizontal-Vertical Barrier | 2 in./min |
| Test Horizontal-Vertical Joint | 1 hr/panel |

*Figure 2.6-13 Install Vertical Barrier Wall Versus Soil/Rock Strength*

## 2.6.5 BACKFILL TRENCH & REMOVE SHORING

The shoring system is simultaneously removed as the soil is backfilled and compacted. The advance rate and assumptions for this operation are shown in Figure 2.6-14.




| ASSUMPTIONS | |
|---|---|
| Remove Slide-Rail Pair | 8 mins |
| Remove Stacker Slide-Rail Pair | 8 mins |
| Remove Panel | 5 mins |
| Remove Spreader | 6 mins |
| Remove Whaler | 15 mins |
| Remove Cross Beam | 15 mins |
| Backfill End Cell | 65 mins |
| Backfill Corner Cell | 45 mins |
| Backfill Side Cell | 25 mins |
| Compact a Cell | Every 2 ft for 10 mins or 175 mins |

*Figure 2.6-14 Backfill Trench & Shoring Removal Versus Soil/Rock Strength*

## 2.7 CONSTRUCTION COST & SCHEDULE

This section provides a preliminary cost estimate and schedule for the construction of a buried waste containment system at the DOE Oak Ridge Reservation Bear Creek Valley Burial Grounds in east Tennessee. The Bear Creek Burial Grounds, as shown in Figure 2.7-1, are located 2 mi west of the Oak Ridge Y-12 Plant. The burial grounds were a disposal area for liquid and solid industrial waste.

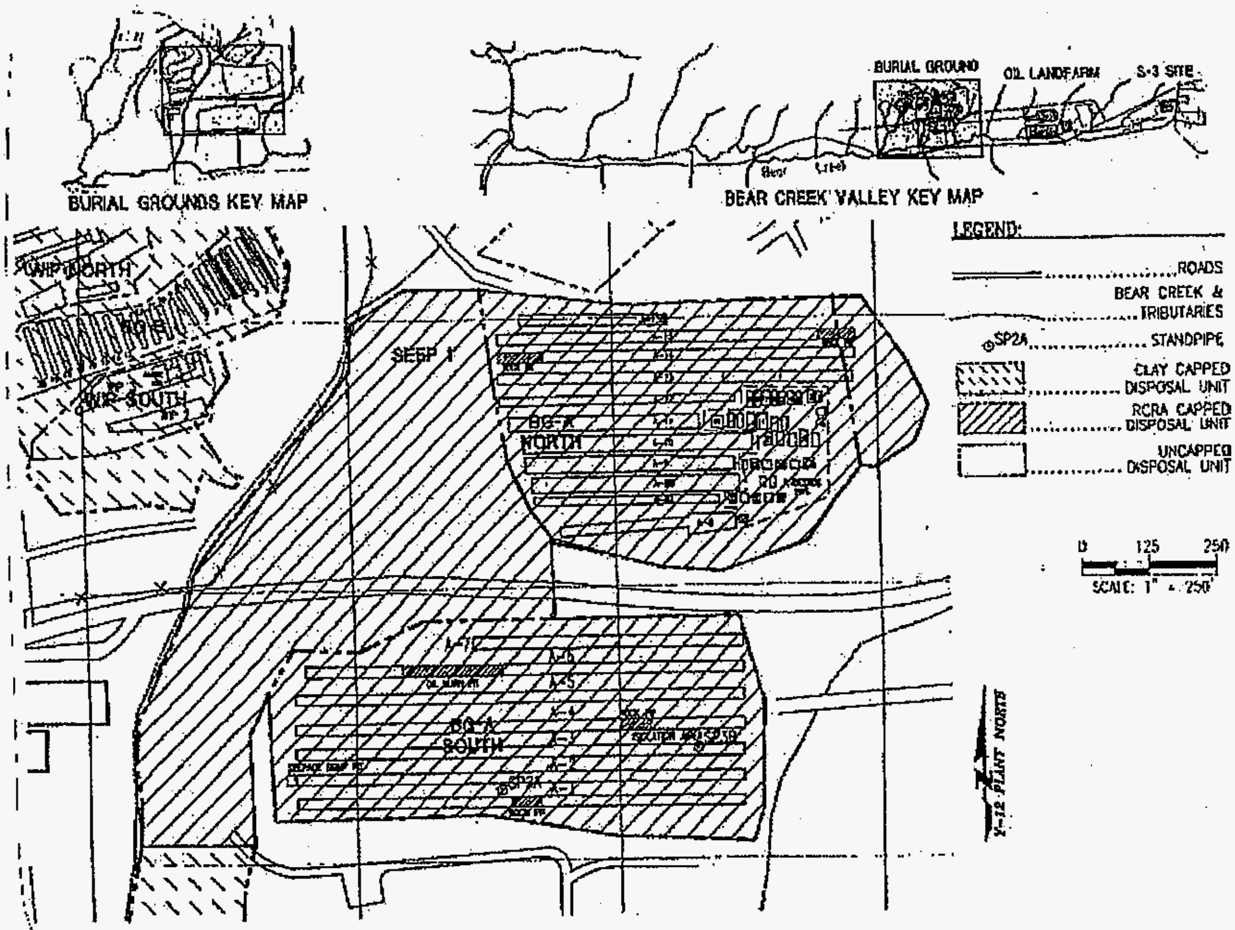



*Figure 2.7-1 Bear Creek Valley Burial Grounds*

The ground surface slopes gently to the south and west. The topographic relief from the crest of Pine Ridge to the floor of Bear Creek Valley ranges from 260 to 300 ft.

### 2.7.1 SUBSURFACE GEOLOGICAL CONDITIONS

The subsurface geological conditions are depicted in Figure 2.7-2. BG-A South and the area immediately south of BG-A South is underlain by the Nolichucky Shale. Shale is the dominant lithology in the formation with an approximate shale-to-limestone ratio of 1:1.75. Shale intervals range from less than 1-in. to approximately 3-ft thick.

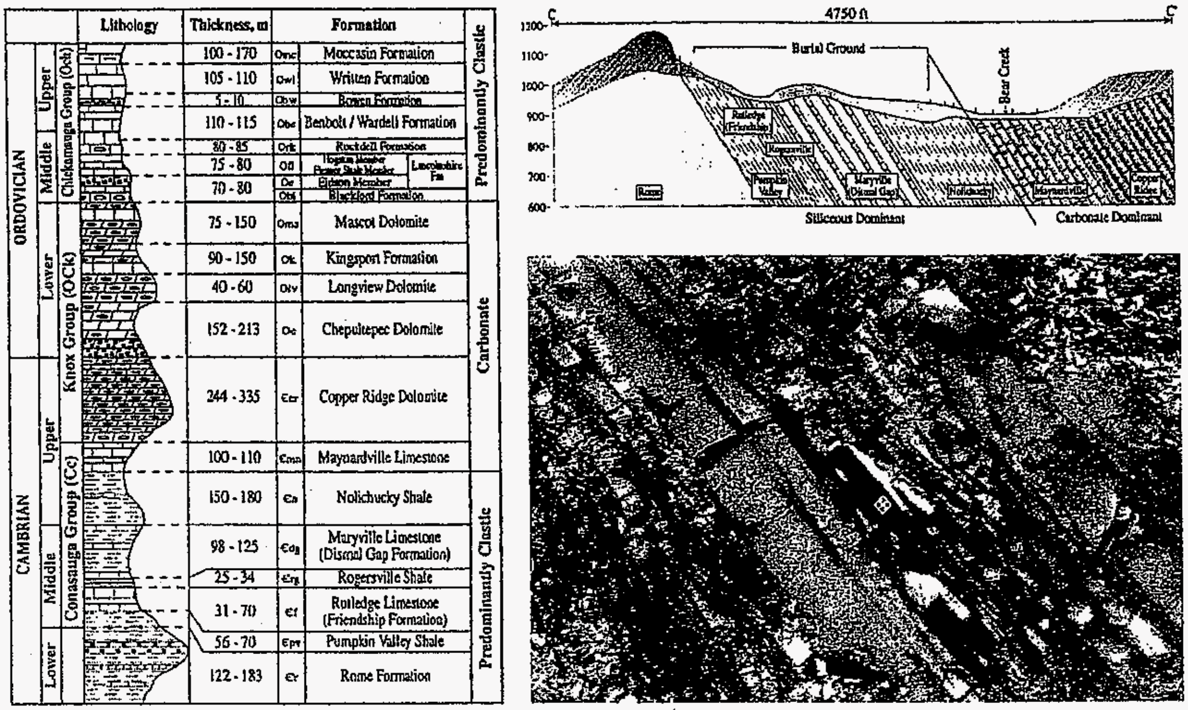



*Figure 2.7-2 Subsurface Geological Conditions*

The depth to bedrock at the selected site ranges from approximately 7.5 to 38 ft, based on drilling logs from monitoring well installation. A clayey residuum overlies the Nolichucky Shale. The residuum is slightly sandy. Some of the residuum is saprolitic and retains vestiges of bedrock structure such as relict fractures. Shallow fill soils may also be present.

The rock beds strike to the northeast (generally, N55°E) and dip steeply to the southeast. The angle of dip ranges from 35° to vertical, but most commonly is in the range of 45° to 70° (DOE, 1984).

The bedrock is very weak along bedding planes and the fracture density is highly variable and decreases with depth.

The weathered rock consists principally of weak, thin-bedded shale and sandstone with some siltstone beds. The weathered-to-fresh rock transition occurs over a relatively short interval, usually less than 10 ft, and in many cases less than 5 ft.

Beneath the weathered rock, the bedrock comprises a sequence of interbedded shale, limestone, sandstone, and siltstone. The rocks are thinly interbedded to laminate.

The limestone interbeds are hard to very hard; the shale ranges from weak to strong and is fissile and laminated. The sandstone and siltstone are moderately hard to hard and fracture in a blocky pattern.

### 2.7.2 ACCESSIBILITY

Interstate highways, state and local highways, rail, and river transportation systems serve the ORR. ORR is located within 50 mi of three major interstate highways. Additional paved roads within ORR include northeast-to-southwest-oriented Bear Creek Road and Bethel Valley Road, and Blair road near Technology Park. Current site conditions provide access to the site from Bear Creek via an existing gravel road system. Bear Creek Road is a paved, two-lane, limited access road on the ORR serving commuter, freight, and business traffic in and out of the Y-12 Plant Site.

### 2.7.3 CONSTRUCTION ASSUMPTIONS

Table 2.7-1 highlights the assumptions that were used to develop and estimate cost and schedule.

| TABLE 2.7-1 CONSTRUCTION ASSUMPTIONS | |
|---|---|
| Unconfined Compressive Strength of Bedrock | 15,000 psi |
| Construction Rate | 6.1 ft/day |
| Operating Day | 8 hrs/day |
| Operating Efficiency | 75% |
| RCRA Cover Cost | $6.75/sq ft |
| Mobilization/Demobilization Cost | $100,000 each |

### 2.7.4 PRELIMINARY COST ESTIMATE

Table 2.7-2 summarizes the estimated life cycle cost for a 1000-ft-long X 29-ft-deep containment barrier. The initial construction cost is $8.5 million with a life cycle cost of $10.3 million.

| TABLE 2.7-2 OAK RIDGE CONSTRUCTION & LIFE CYCLE COSTS | |
|---|---|
| Subsurface Containment Barrier | $ 8.0 million |
| RCRA Cover | $ 0.3 million |
| Long-Term Monitoring | $ 2.0 million |
| **TOTAL** | **$10.3 million** |

This results in an estimated cost of $420/cu yd of waste contained, or approximately $110/sq ft of placed barrier. A detailed summary of the estimated cost is provided in Appendix 2.

### 2.7.5 PRELIMINARY CONSTRUCTION SCHEDULE

A preliminary construction schedule for the Oak Ridge site is shown in Figure 2.7-3. As shown, the overall construction duration is 10 mos.

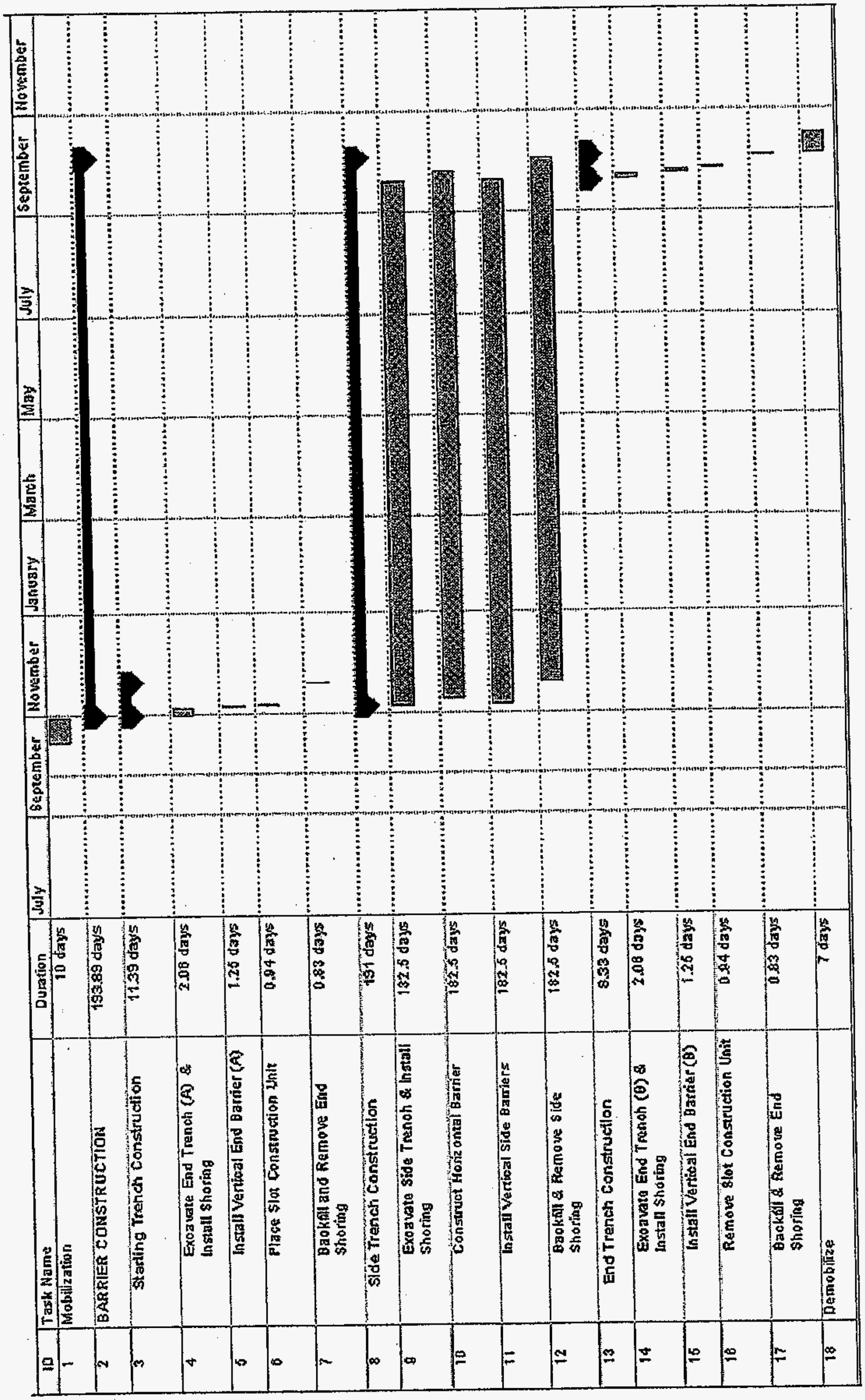



*Figure 2.7-3 Construction Schedule*

## 2.8 ADVANCED CONTROL TEST

### 2.8.1 ADVANCED CONTROL TEST DESCRIPTION

#### 2.8.1.1 Executive Summary

This document is an addendum to the original Draft Phase 1 Topical Report submitted 26 September 2001. This Topical Report identified the conventional construction equipment, special construction equipment, and the process of installing a horizontal barrier. The four tests that were conducted as part of the Control Test validated the adequacy of the safety and environmental plans; verified the Slide-Rail Shoring could be installed safely and efficiently; and demonstrated the SCU performance and placement of the horizontal barrier.

The Advanced Control Test takes this one step further by testing the installation procedures and effectiveness of adding a vertical perimeter barrier that will provide the hydraulic isolation necessary for containing buried waste in situ.

Test bed and test site modifications were necessary to accommodate the vertical wall placement for the Hydraulic Test. Please note that these modifications are not necessary in actual, operational conditions.

#### 2.8.1.2 Test Location & Schedule

The Advanced Control Test was performed at RAHCO International in Spokane, Washington, between September and May 2003.

#### 2.8.1.3 Advanced Control Test Scope

The Advanced Control Test (ACT) was performed on the same test site identified in Section 2.5.2, Test Site Description. The intent of the ACT was to establish the feasibility of the construction equipment, materials, and methods to install a vertical perimeter barrier on top of the horizontal barrier to form a hydraulic containment barrier in a controlled subsurface environment. The specific test objectives were to: 1) verify safe operations, 2) verify ease of operation, 3) obtain operating performance data, and 4) determine hydraulic effectiveness of the containment barrier. Even though some of these objectives are repeated from our Control Test, the opportunity existed in the construction of the barrier system to verify our previously collected data.

The test equipment was the same as described in Section 2.1, Test Equipment Description– except, again, we will not be welding any barrier material.

The test activities, as described in Section 3.0 of the OP/WP, include: safety assessment, site preparation, mobilization of equipment, placement of SCU, construction of a horizontal barrier, construction of a vertical perimeter barrier, testing of the containment barrier, trench backfill, shoring system removal, and site restoration.

A total of three tests were performed. They were Test ACT-1 that verified the safety and environmental assessment. Test ACT-2 evaluated the vertical barrier installation process. Test ACT-3 verified the containment barrier provides hydraulic isolation necessary to contain contaminated waste.

Testing was documented by manual and automated data collection, photographs, and video.

## 2.8.2 RESULTS & DISCUSSION

The SCS system is made up of several parts: conventional construction equipment, specialized construction equipment, horizontal barrier, vertical perimeter barrier, and the horizontal-vertical joint that brings the barriers together to form the hydraulic barrier. The descriptions of the specialized construction equipment (Section 2.1.2 of the Topical Report ) and the horizontal barrier (Section 2.2.1 of the Topical Report) all remain the same. The conventional construction equipment (Section 2.1.1 of the Topical Report) is the same except the Portable Extrusion Welder to weld the HDPE was not used. This section will address the vertical perimeter barrier, horizontal-vertical joint, and the hydraulic effectiveness of the containment system.

A review of the key DOE requirements and ability of the SCS to comply with these requirements provides evidence of the technical results achieved.

**DOE Requirement #1:** Construct a prototype subsurface test barrier in a setting that simulates in-ground field conditions.

The SCS successfully installed a horizontal barrier in simulated field conditions. The SCS system successfully installed the vertical perimeter barrier.

**DOE Requirement #2:** Conduct hydraulic testing of the containment barrier to assess its hydraulic performance. The constructed barrier must meet required technology performance requirements and must also meet site-specific and regulatory requirements that exist as a result of the demonstration.

The SCS successfully demonstrated the system hydraulic performance by testing the containment barrier in simulated field conditions.

### 2.8.2.1 Barrier Materials

This section provides a brief description of the barrier materials used to construct the subsurface containment barrier and how they differ from the Advanced Control Test OP/WP.

#### 2.8.2.1.1 Horizontal Barrier

The GCL used for the horizontal barrier is the same. However, there is a 5-in. gap between the placed blocks and the top of the cut. This space will be filled with a mixture of 50% bentonite and 50% spoils from the cut. This accomplishes three things: 1) fills the void. 2) uses excess spoils that might otherwise need to be hauled away. 3) and provides additional sealing capabilities. If there are concerns about the bentonite spilling onto the area where the vertical perimeter walls will be placed, premanufactured holding bags can be used to confine this material.

#### 2.8.2.1.2 Vertical Perimeter Barrier

The vertical perimeter barrier HDPE curtain wall material is the same as described in Section 2.2.1 of the Draft Topical Report. However, the vertical HDPE curtain walls are held rigid by a rectangular 3-in. by 3-in. angle iron frame (see Figure 2.8-1). The bottom of the angle iron frame also provides an attachment point for the horizontal-vertical joint seal.

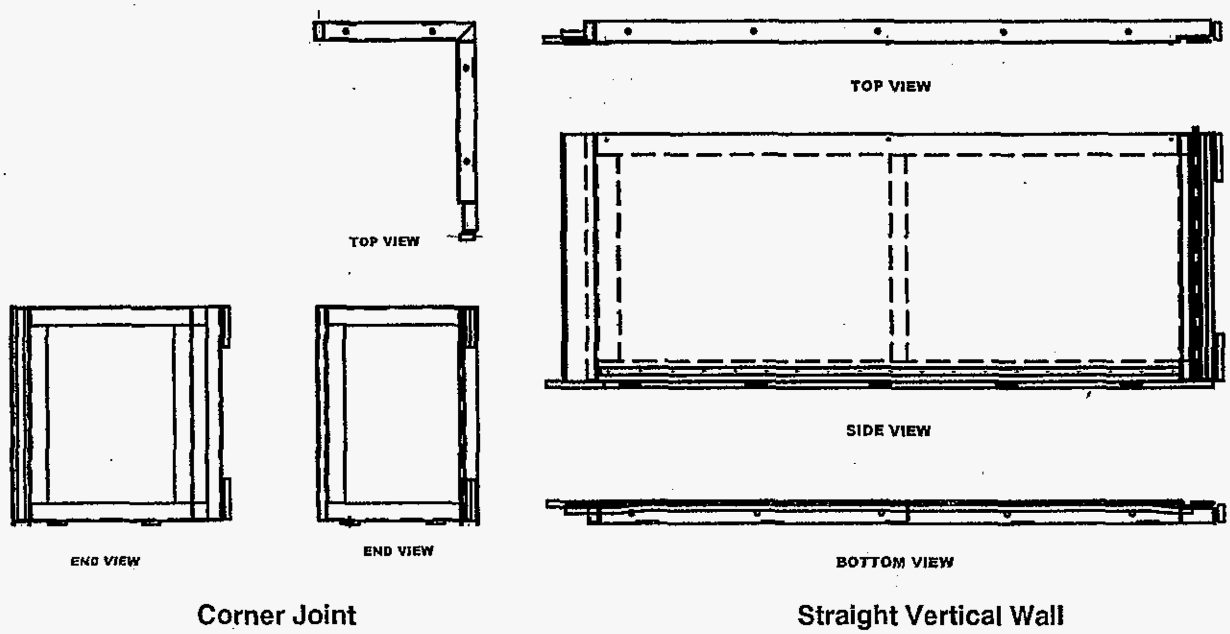



*Figure 2.8-1 Vertical Wall Frames*

A frame is installed using a small crane with cables attached to lifting eyes, the frames slide together to lock into place. The HDPE curtain wall that is attached also slides together at the interlocking joints. There are two styles of frames: 1) the corner joint and 2) the straight vertical wall with interlocking joints at both ends. One special frame modification made just for this hydraulic test is to use a thin sheet metal backing to support the HDPE curtain wall. This was added especially for the test to inspect the joints and since the area up to vertical barrier frame would not be backfilled until all the equipment and shoring was removed. In an operational situation, moving equipment and shoring would be ongoing processes and backfilling would occur as the equipment progresses through the cut.

There are two areas of the vertical perimeter walls that require additional products to form the hydraulic seal. A small bead of Leakmaster® LV-1 is placed between the HDPE liner and the angle iron frame. This ensures the hydraulic isolation of the frame itself. Two of the HDPE curtain wall interlocking joints has the Hydrotite® RSS-080-P rope installed prior to joining its adjacent curtain wall panel. The rope goes down one joint, loops underneath and around the bottom, and up through the next joint. The ends of the rope are then tied together at the top so that they stay intact during installation. The Leakmaster® LV-1 is applied to the bottom of all the interlocking joints and full length in the farthest interlocking joint. This combination of material ensures the vertical hydraulic seal.

**New Perimeter Joint Materials:** Leakmaster® LV-1, a polyurethane sealant, is a hydrophilic product sold by Greenstreak. The Hydrotite® RSS-080-P rope used in the vertical walls is very resistant to most corrosive materials. The principal component of the Hydrotite® products is chloroprene (see Appendix 5, Exhibit B, Greenstreak Hydrotite® Chemical Resistance of Chloroprene). When a Hydrotite® product is exposed to water, it will expand to eight times its size (see Table 2.8-1).

**TABLE 2.8-1 CHLOROPRENE RUBBER PRODUCTS**

| | | *Chloroprene* | *Modified Chloroprene* |
|---|---|---|---|
| **Property** | **Test Method** | **Required Limits** | **Required Limits** |
| Tensile Strength | ASTM D 412 | 1300 psi, minimum | 350 psi, minimum |
| Ultimate Elongation | ASTM D 412 | 400%, minimum | 600%, minimum |
| Hardness (Shore A) | ASTM D 2240 | 50±5 | 52±5 |
| Tear Resistance | ASTM D 624 | 100 lbs/in., minimum | 50 lbs/in., minimum |
| Expansion Ratio | Volumetric Change—Distilled Water @ 70°F | N/A | 3:1, minimum |

### 2.8.2.1.3 Horizontal-Vertical Joint

The horizontal-vertical joint is different than reported in Section 2.2.1 of the Draft Topical Report in that the barriers are joined by several Hydrotite® products (see Figure 2.8-2) supplied by Greenstreak . Contrary to what was previously reported in the Draft Topical Report, no materials will be welded together after installation of the horizontal and vertical perimeter barriers.

Two rows of the Hydrotite® CJ-3030-M, blue square hydrophilic tubing is attached to the bottom of the 3-in. X 3-in. angle iron frame by contact cement. This is different than was reported in Section 4.3 of the Advanced Control Test OP/WP. This tubing extends past the full length of the bottom angle iron frame to overlap with the next frame. A third row of CJ-3030-M is used at the joint of the HDPE curtain wall/frame. The additional rows provide redundancy. If there are any possible leak paths, the Leakmaster® LV-1 can be applied where two rows of Hydrotite® CJ-3030-M are spliced together and between cracks or crevices to get a good seal. Finally, the frame is attached by anchor bolts to the block (through the GCL). The bolting compresses the Hydrotite® CJ-3030-M in the horizontal-vertical joint to assist in providing hydraulic isolation at that joint.

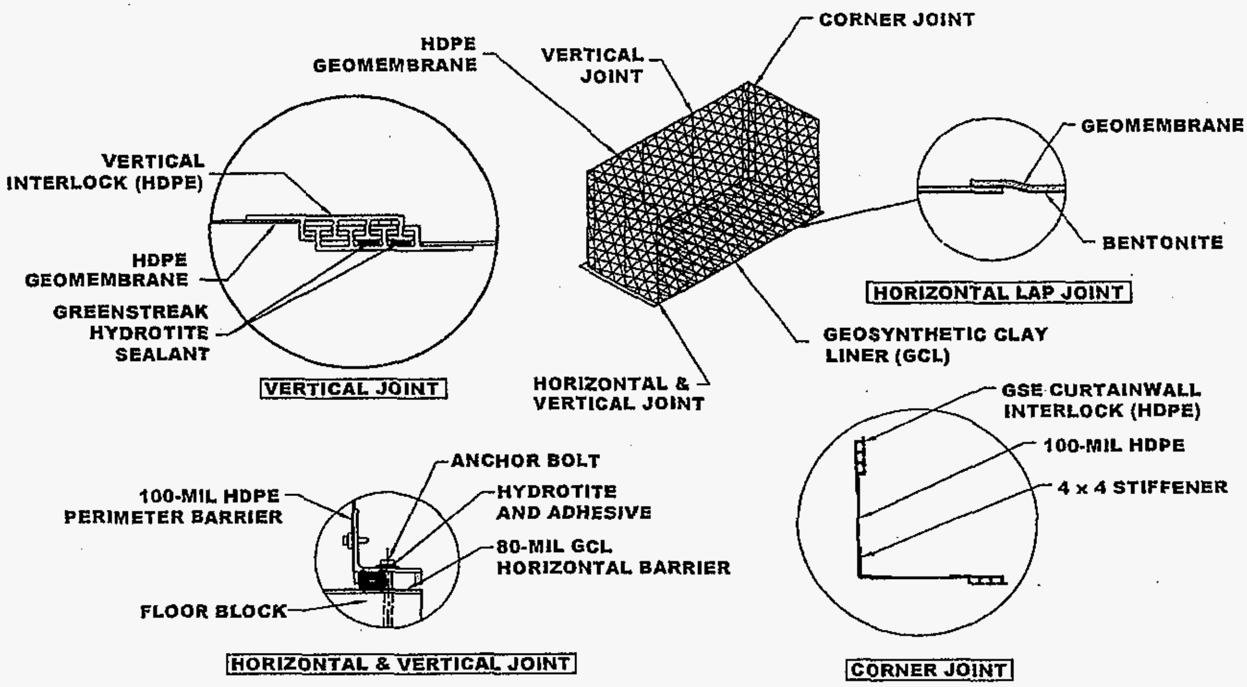



*Figure 2.8-2 Hydraulic Joint Construction Details*

**New Horizontal-Vertical Joint Materials:** The Hydrotite® product being used for this joint is Hydrotite® CJ-3030-M supplied by Greenstreak. The principal component of the Hydrotite® products is chloroprene. This material is very resistant to most corrosive materials (see Appendix 5, Exhibit B, Greenstreak Hydrotite® Chemical Resistance of Chloroprene).

#### 2.8.2.1.4 Precast Concrete Floor Blocks

The precast concrete blocks as stated in Section 2.2.2 of the Draft Topical Report remain the same except for the blocks that lay around the perimeter of the test bed. The perimeter blocks have the inside holes inside filled solid with 3000-psi concrete.

### 2.8.3 ADVANCED CONTROL TEST

The overall objective of the ACT was to demonstrate the capabilities of the SCS equipment, materials, and construction methods to install a vertical perimeter subsurface containment barrier that provides hydraulic isolation in a safe and cost-effective manner. To achieve this, three tests were performed at the RAHCO facilities in Spokane, Washington, during the period of July through May 2003.

#### 2.8.3.1 Scope of Tests

The ACT was performed at the RAHCO facility in a subsurface environment representative of DOE sites. This test is the same test bed as identified in Section 3.2 of the OP/WP. The test bed was the same test bed used for the original Control Test as described in Section 3.3, Engineered Test Bed, of the OP/WP.

Three tests were performed in the ACT. Test ACT-1 performed a system safety and environmental assessment to ensure that the equipment and construction methods can perform safely in accordance with the Environment Safety & Health Plan and Environmental Compliance Plan as defined in Sections 8.0 and 9.0 of the OP/WP. Test ACT-2 demonstrated that the equipment and procedures can safely and rapidly install a Perimeter Vertical Barrier. Test ACT-3 verified that the installed subsurface containment barrier provides hydraulic isolation.

During these tests, data was collected using both manual readings and an automated data acquisition system. Observations were made and results documented to verify that the SCS provides DOE a viable alternative to other buried waste remediation methods.

#### 2.8.3.2 Test Site Description

The ACT site is the same as in Section 2.5, Test Site Description.

#### 2.8.3.3 Engineered Test Bed

The Engineered Test Bed, shown in Figure 48, Section 3.3 of the OP/WP, was modified in several ways due to the result of the Control Test performed last year. The first 12 ft of the test bed (Zone 1) was cut away as part of that test, see Table 2.8-2. Additional concrete was poured on the east and west ends of the test bed, making the new dimensions of the test bed 36 ft X 35 ft-8-5/8 in., see Figure 2.8-3. Additional steel framework was welded to the shoring along the perimeter on the north and south sides to support the additional concrete blocks necessary for the Hydraulic Test. This steel framework was at the same level as the top of the cut concrete minus 1 in. This framework was lower to prevent interference with the SCU cutterhead. After the SCU passed, wood was installed between the blocks and steel to make the perimeter horizontal barrier level with the rest of the test bed.

**TABLE 2.8-2 ENGINEERED SOILS**

| | Zone 1 | Zone 2 | Zone 3 | Zone 4 |
|---|---|---|---|---|
| Soil Material | None | Cemented Sand & Aggregate | Cemented Sand, Cobbles, & Boulders | Cemented Sands |
| Rock Type | None | Crushed River Rock | Crushed River Rock & Basalt | None |
| Maximum Material Strength | Not Applicable | Approximately 3,000 psi | Approximately 17,000 psi | Approximately 1,250 psi |
| Rock Distribution | None | 25% by Volume | 50% by Volume | None |
| Average Moisture Content | N/A | 8% | 8% | 8% |

The test bed also contained a 5-ft-diameter X 13-ft-high concrete manhole for observation. Since the first 12 ft of the horizontal barrier was exposed, this manhole was no longer necessary. Nine feet of the manhole above the concrete slab were removed so that the manhole extended just over the top of the 4-ft-deep concrete slab. The concrete was then scored every 2 ft so that the test bed would replicate the fractured properties of rock.

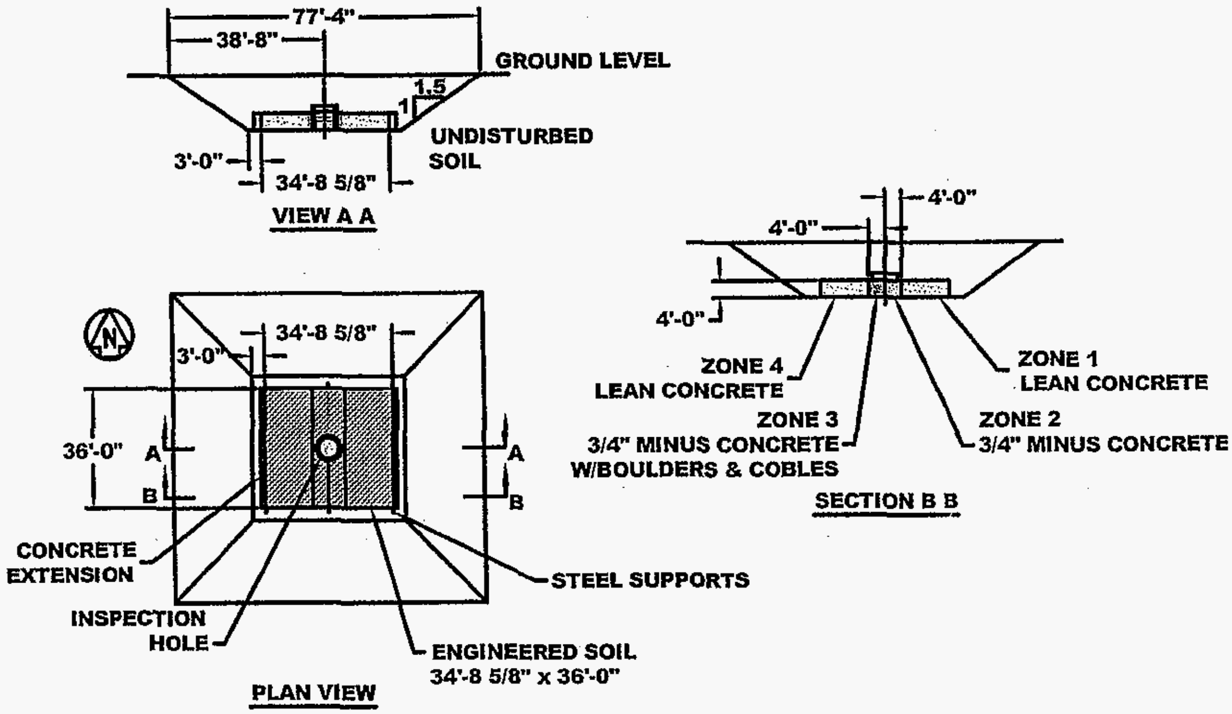



*Figure 2.8-3 Engineered Test Bed*

### 2.8.3.4 Test Execution

The Advanced Control Test constructed a 35.75-ft-wide X 36-ft-long X 4-ft-high containment barrier in the engineered test bed. A total of three tests were performed. Table 2.8-3 highlights the three tests and identifies the specific test objectives.

**TABLE 2.8-3 ADVANCED CONTROL TEST MATRIX**

| Test Number | Test Description | Test Objective |
|---|---|---|
| ACT-1 | System Safety & Environmental Assessment | Verify the SCS equipment can perform the Advanced Control Test operations in a safe and an environmentally compliant manner. |
| ACT-2 | Perimeter Barrier Installation Test | Demonstrate the SCS equipment and procedures can safely and rapidly install a vertical perimeter barrier. |
| ACT-3 | Passive Hydraulic Test | Verify the installed subsurface containment barrier provides hydraulic isolation. |

The following discussion of each test includes a statement of the test objectives, the data quality objective, and a statement of the uncertainty for the measurements to be taken.

#### 2.8.3.4.1 Test ACT-1: System Safety & Environmental Assessment

**Test Objective:** Verify the adequacy of the safety and environmental plans and that the test operations can be safely performed in an environmentally compliant manner (see ES&H Plan, Section 8 of OP/WP).

**Data Quality Objectives:** Review the safety and environmental compliance plans and determine their adequacy to address the safety and environment issues associated with both the SCS equipment and test operations.

**Test Results:** This test concluded that the test operations could be safely performed.

#### 2.8.3.4.2 Test ACT-2: Vertical Perimeter Barrier Installation Test

**Test Objective:** Demonstrate that the perimeter containment barrier can be safely installed within the specified construction tolerances and time durations.

**Data Quality Objectives:** Observe the perimeter barrier installation operation and document the ability of installation within safety constraints and specified time durations. This document shall include completion of the checklists, photographs, video tape, log books, and installer interviews.

**Test Conduct:** Perimeter barriers were installed in two stages: Stage 1 included attachment to crane, swing time, and frame placement; Stage 2 consisted of holes being drilled and bolts attached.

**Test Results:** The following checklist summarizes the first perimeter barrier installation performance. See Appendix 9, Perimeter Barrier Installation Test Quick-Look Report for additional details. Overall, the results of the perimeter barrier installation was a success. As a result of this test, the relationship between out-of-tolerance HDPE and the need for a larger tolerance in the frame was discovered. This has been addressed in the design drawings of the perimeter barrier.

A second perimeter barrier installation was performed towards the end of the project. This installation proved very successful and even reduced the amount of time necessary for installation. It incorporated the new frame design that was found to be more tolerant and fit up easily with the interlocking HDPE joints.

| TABLE 2.8-4 PERIMETER BARRIER INSTALLATION TEST CHECKLIST | | | |
|---|---|---|---|
| **Item No.** | **Description** | **Yes** | **No** |
| 1 | Could the perimeter frames be easily installed using the crane? | X | |
| 2 | Did perimeter frame panels slide together easily? | X | |
| 3 | Could the perimeter frame segments be installed within ±1/2 in. | X | |
| 4 | Could the perimeter barrier segments be installed safely? | X | |
| 5 | Could the anchor bolts be installed easily from the top of the framework? | X | |
| 6 | Did the anchor bolts grab the concrete for a secure attachment? | X | |
| 7 | Was it possible to get a good compression of the frame to the block? | X | |
| 8 | Did the HDPE interlocking joints lock into mating joint easily? | X | |
| 9 | Was it possible to get a good seal at the bottom of the HDPE interlocking joints? | X | |

**Comments:**

**Item #2:** On the first test stand, most perimeter panels installed easily, but because of the internal shoring used, it was difficult to move the bracing out of the way to install. The upper internal shoring to be used at the site is different than what was used here. In building the second test stand, all of the panels installed easily.

**Item #5:** Special equipment was not used to install the bolts for this test, RAHCO's ability to do this was demonstrated in the Fluor-Hanford Spent Nuclear Fuel Transport System Installation Test where bolts were installed from 27 ft above the attachment.

**Item #8:** On the first test stand, the frame that held the HDPE did not have enough tolerance in its slip joint to allow for out-of-tolerance HDPE. Therefore, the HDPE interlocking joints were sometimes stretched and caused the rope in the interlocking joints to break. In the second test stand, this was not a problem either. Modifications to the fame eased installation.

| TABLE 2.8-5 PERIMETER BARRIER INSTALLATION | | | | | |
|---|---|---|---|---|---|
| **Activity** | **Source** | **Collection Method** | **Sample Size** | **Average Installation Time (min)** | **Comments** |
| Place Straight Panel | Test | Manual | 12 | 13.5 | Range of times from 3 mins to 30 mins. |
| Place Corner Panel | Test | Manual | 4 | 12.6 | Some shoring interferences due to test bed configuration. |
| Attach Anchor Bolt | Estimate | Manual | 12 | 2.0 | |

| TABLE 2.8-6 SCS PERIMETER BARRIER PERFORMANCE DATA | | |
|---|---|---|
| 1 | Segment Installation Rate (peak) | 1.5 ft/hr |
| 2 | Segment Installation Rate (average) | 10 ft/day |
| 3 | Anchor Bolt Installation Rate | 30/hr |

**Comments:**

**Items #1 & #2:** The segment installation rates for the perimeter walls are dependent on how many hours in a day the SCU has cut and what soil type is being cut.

**2.8.3.4.3 Test Act-3: Passive Hydraulic Test**

**Test Objective:** Demonstrate the effectiveness of the subsurface containment barrier to form a continuous, long-term, hydraulic conductivity containment barrier in simulated field conditions that can gain regulatory approval and commercial success. The Quick-Look Report for the Bench-Level Hydraulic Test outlines how this concept has been proven.

**Data Quality Objectives:** The volume of water to be injected will be measured with a flowmeter connected to a data logger. The water volume's measurements sampling rates will be continuous with an accuracy of ±2%. The pressure transducer sampling frequency will vary from 6-min to 1-hr intervals as hydraulic conditions approach equilibrium. The accuracy of the pressure measurements are expected to be ±5%.

**Test Conduct:** A second test bed was constructed to minimize the effect of damage to the original test bed. This new test bed was 16 ft X 26 ft X 4 ft. Perimeter walls with the new interlocking design were used, as well as the modified application of the vertical joint, the horizontal-vertical joint, and addition of bentonite. Test equipment was installed. Three feet of sand was added to the test bed and water was added up to 30 in., nominal.

**Test Results:** The positive results of this test were seen almost immediately. There was minimal water leakage after only one day. Normally, it takes up to 3 days to see results this positive (see the Hydraulic Test Quick-Look Report, Appendix 11).

**Advanced Control Test Measure of Success:** The Advanced Control Test was deemed a success if sufficient data and operational experience were gained to assess the capabilities of this technology to accomplish its goals and if RAHCO and DOE are provided with qualitative and quantitative data to perform a feasibility assessment. This determination was made based on the following:

1. Sufficient data were gathered and recorded to evaluate the ability of the SCS equipment and procedures for safe and rapid installation of a vertical perimeter barrier.

2. Sufficient data were gathered and recorded to evaluate the ability of installed subsurface containment barrier to provide effective hydraulic isolation.

3. Information regarding the ability of the system to operate in a contaminated environment was gathered and recorded for future use.

### 2.8.4 TEST OPERATIONS

#### 2.8.4.1 Mobilize Equipment & Materials

Any mobilization of equipment and materials followed the original plan as outlined in Section 4.2 of the OP/WP. In addition, staging of the vertical perimeter walls will be after the installation of the horizontal barrier.

#### 2.8.4.2 Demobilize & Restore Site

Demobilization and site restoration is the same as described in Section 2.3.3.

# SECTION 3.0
# CONCLUSIONS

DOE disposal practices used decades ago has left approximately three million cubic meters of radioactive and hazardous buried waste that is becoming harmful to human safety and health. Several alternative technologies and approaches are available to the DOE for remediation of these buried waste sites. These include: 1) full-scale retrieval, 2) hot spot retrieval, and 3) in situ stabilization. All of these methods present challenging technical issues, create safety hazards to the workers and local community, and are expensive to implement. The SCS provides DOE with a promising alternative. This system provides an interim solution until treatment options and ultimate disposal issues are resolved. The SCS:

- Uses state-of-the-art technology.
- Is proven.
- Is cost-competitive.

## • Uses State-of-the-Art Technology

The equipment used to construct the subsurface containment barrier is either off-the-shelf trenching, civil construction equipment, or specialized equipment using commercially available mining and tunneling technology that has been adapted to the DOE buried waste problem. Both the conventional and specialized equipment meet all the functions and performance requirements identified by the DOE. This equipment is safe, robust, highly reliable, and easily operated and maintained. In many cases, this equipment is already in use at DOE remediation sites.

The subsurface barrier materials selected have been used world wide for the containment of waste, liquids, and industrial products in cells, ponds, pits, and lagoons. Flexible geomembrane lining systems are used extensively in containment systems for the prevention of groundwater contamination and environmental damage. This material is proven suitable for DOE applications and complies with all the established barrier material performance requirements.

## • Is Proven

The three specialized equipment items and two of the four construction operations have been demonstrated successfully in both factory and control testing which has simulated DOE subsurface conditions. Tests have ranged from single component testing; e.g., cutterhead, to testing of major elements of the overall system; e.g., shoring system installation, barrier installation, and hydraulic performance testing. To date, results have been positive and test data continues to confirm the technical feasibility of the SCS. Equally significant, no technological "show stoppers" have been identified.

- **Is Cost-Competitive**

  Los Alamos National Laboratories (LANL TA-21, MDA V site) has done a cost analysis using the RACER Envest cost estimating model estimating the cost of excavation at $4710/cu yd (for an area of 9000 cu yds of soil). Included in the LANL analysis, but not in RAHCO's, are the bonds, insurance, and state and local taxes. Nonetheless, indications are that the RAHCO-developed buried waste containment system is cost-competitive.

This report highlights the significant progress made, summarizes the results obtained, and identifies a number of major accomplishments. These include:

- Preliminary system design completed.
- Slot Construction Unit Factory Test successfully conducted.
- Shoring Installation Control Test successfully conducted.
- Horizontal Barrier Placement Control Tests partially completed.
- Vertical Perimeter Barrier Placement Tests successfully completed.
- System performance capabilities successfully conducted.
- System hydraulic performance capabilities successfully conducted.
- Cost and schedule estimates developed.
- Potential DOE endusers identified and contacted.

This Phase I effort has been a success. It demonstrated that the SCS complies with all DOE buried waste containment requirements and meets environmental cleanup standards while reducing schedules, risk, and cost.

## Recommended Path Forward

The results of these tests demonstrated not only the ability of the SCS to construct a subsurface barrier, but also demonstrated conclusively the effectiveness of the installed containment barrier. This evidence can be presented to DOE endusers, federal and state regulators, and local stakeholders. There is sufficient data and information in this report for stake holders to evaluate this system's technology for possible applicability for a specific site given the site's desired remediation actions. With these test results RAHCO is prepared to conduct a full-scale demonstration at a DOE site as planned in Phase II of this contract effort.

# LIST OF ACRONYMS

| | |
|---|---|
| ACGIH | American Conference of Governmental Industrial Hygiene |
| AIDS | Acquired Immune Deficiency Syndrome |
| ASTM | American Society of Testing and Materials |
| CAA | Clean Air Act |
| CFR | Code of Federal Regulations |
| CPR | Cardiopulmonary Resuscitation |
| dBA | Decibels |
| DOE | U.S. Department of Energy |
| DOL | U.S. Department of Labor |
| EPA | U.S. Environmental Protection Agency |
| ESH | Environmental Safety & Health |
| ESHO | Environmental Safety & Health Officer |
| °F | Degrees Fahrenheit |
| FY | Fiscal Year |
| GCL | Geosynthetic Clay Liner |
| HBV | Hepatitis B Virus |
| HDPE | High-Density Polyethylene |
| HEPA | High-Efficiency Particulate Air |
| HIV | Human Immunodeficiency Virus |
| HSWA | Hazardous & Solid Waste Amendments |
| MSHA | Mine Safety & Health Agency |
| MSDS | Material Safety Data Sheet |
| NEPA | National Environmental Policy Act of 1969 |
| NESHAP | National Emission Standards for Hazardous Air Pollutants |
| NETL | National Energy Technology Laboratory |
| NIOSH | National Institute of Occupational Safety & Health |
| OSHA | Occupational Safety & Health Administration |
| PCB | Polychlorinated Biphenyl |
| PCU | Power & Control Unit |
| PPE | Personal Protective Equipment |
| RAHCO | RAHCO International, Inc. |
| RCRA | Resource Conservation & Recovery Act |
| SCS | Subsurface Containment System |
| SCU | Slot Construction Unit |
| U.S. DOE | United States Department of Energy |
| WIMS | Waste Information Management System |
| WSS | Work Smart Standards |

# APPENDIX 1
# SCS PERFORMANCE ANALYSIS

# SCS PERFORMANCE ANALYSIS

Prepared by Jalene Greer

# USER INPUT

| | Description | Unit of Measure | Value | Source |
|---|---|---|---|---|
| CL | Construction Length | ft | 1064 | Project Description |
| CW | Construction Width | ft | 56 | Project Description |
| CD | Construction Depth | ft | 35 | Project Description |
| ET | Number of End Trenches | ft | 2 | Project Description |
| ST | Number of Side Trenches | ft | 2 | Project Description |
| LC | Corner Cell Length | ft | 10 | Project Description |
| WC | Corner Cell Width | ft | 16 | Project Description |
| HC | Corner Cell Height | ft | 12 | Project Description |
| LE | End Cell Length | ft | 16 | Project Description |
| WE | End Cell Width | ft | 16 | Project Description |
| HE | End Cell Height | ft | 12 | Project Description |
| LS | Side Cell Length | ft | 16 | Project Description |
| WS | Side Cell Width | ft | 10 | Project Description |
| HS | Side Cell Height | ft | 12 | Project Description |
| BL | Horizontal Barrier Length | ft | 1002 | Project Description |
| BW | Horizontal Barrier Width | ft | 35.5 | Project Description |
| BD | Horizontal Barrier Depth | ft | 29 | Project Description |
| PL | Vertical Panel Length | ft | 16 | Project Description |
| PH | Vertical Panel Height | ft | 29 | Project Description |
| SF | Soil Swell Factor | | 125% | Engineering Estimate |
| BC | Bucket Capacity | cu yds | 3 | Equipment Description |
| WD | Hours Worked per Day | hr | 8 | Project Description |
| OE | Operating Efficiency | | 75% | Project Description |

# ASSUMPTIONS

| | | | |
|---|---|---|---|
| STC | Number of Stacked Cells | ea | 3 |
| XPC | Slide Rail Panels per Cell | ea | 2 |
| RPC | Slide Rail Pairs per Cell | ea | 1 |
| SPC | Spreaders per Cell | ea | 1 |
| BLC | Blow Locations per Cell | ea | 6 |
| XEW | Number of End Walers | ea | 4 |
| XNC | Number of Corners | ea | 4 |
| XSW | Number of Side Walers | ea | Equation |
| XCB | Number of Crossmembers | ea | Equation |

## GENERAL EQUATIONS

| | | | |
|---|---|---|---|
| XCC | Number of Corner Cells<br>(XNC * (CD/HC)) rounded up to nearest whole number | ea | Equation<br>12 |
| CCS | Number of Corner Cell Stacks<br>(XNC * (CD/HC))/STC | ea | Equation<br>4 |
| XEC | Number of End Cells<br>(CW/LE)*ET*(CD/HC)-XCC | ea | Equation<br>12 |
| ECS | Number of End Cell Stacks<br>((CW/LE)*ET*(CD/HC)-XCC)/STC | ea | Equation<br>4 |
| XSC | Number of Side Cells<br>(CL-(WC*XCC/ET))/LS*ST*CD/HC | ea | Equation<br>366 |
| SCS | Number of Side Cell Stacks<br>((CL-(WC*XCC/ET))/LS*ST*CD/HC)/STC | ea | Equation<br>122 |
| NSP | Number of Side Barrier Panels<br>(BL/PL)*ST | ea | Equation<br>126 |
| NEP | Number of End Barrier Panels<br>(BW/PL)*ET | ea | Equation<br>6 |
| XCB | Number of Crossmembers<br>(CL/LS) | ea | Equation<br>67 |
| XSW | Number of Side Walers<br>(2*CL/4*LS) | ea | Equation<br>34 |

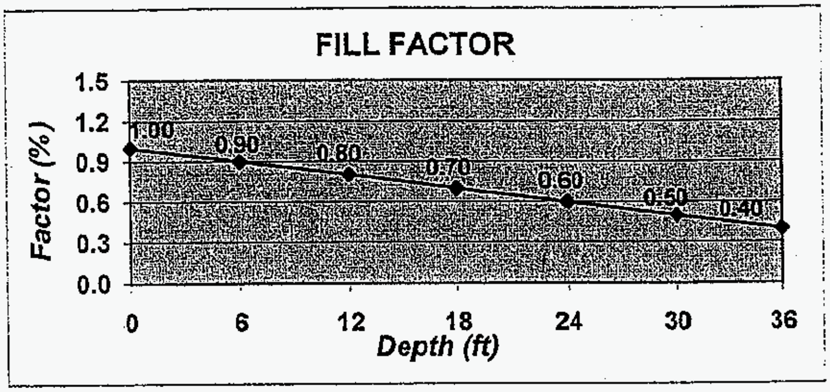
# OPERATION #1:
# EXCAVATE TRENCH & INSTALL SHORING

## DEFINITIONS & INPUT DATA

| | | Unit of Measure | Value | Source |
|---|---|---|---|---|
| LD | Lift Depth | ft | 6 | Definition |
| BST | Bucket Swing Time | sec | 4.5 | Test Data |
| BET | Bucket Empty Time | sec | 2.57 | Test Data |
| TPRP | Time to Place Slide Rail Pair & Spreader Assy | min | 10.25 | Test Data |
| TPPA | Time to Place Panels | min | 3 | Test Data |
| TMP | Time to Move Panel | min | 5 | Test Data |
| TARP | Time to Assemble Slide Rail Pair & Spreader | min | 4 | Test Data |
| TMRP | Time to Move Rail Pair & Spreader Assy | min | 5 | |
| TPB | Time per Blow | sec | 5 | Eng Estimate |
| TIW | Time to Install Waler | min | 30 | Eng Estimate |
| TMW | Time to Move Waler | min | 5 | Eng Estimate |
| TICM | Time to Install Side Trench Cross Beam | min | 30 | Eng Estimate |
| TMCM | Time to Move Cross Beam | min | 5 | Eng Estimate |
| BFF | Bucket Fill Factor | % | Chart#1 | Test Data |
| BFT | Bucket Fill Time | sec | Chart #2,3 &4 | Test Data |
| PPB | Ave Penetration/Blow | in. | Chart #5 | Test Data |

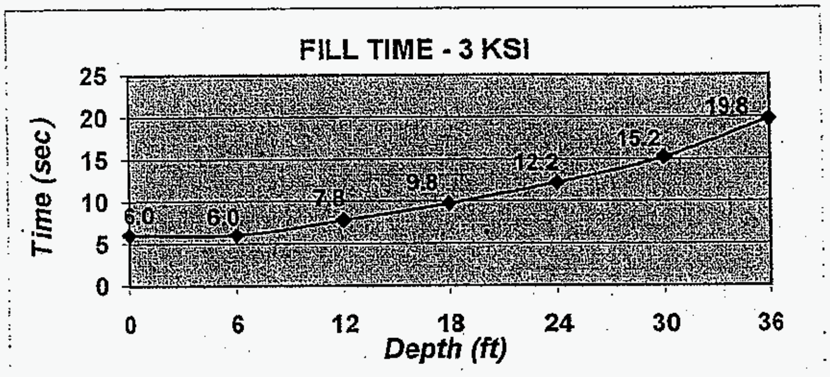
## Chart #1

| Ave Fill Factor (FF) | |
|---|---|
| Factor (%) | Depth (ft) |
| 1.00 | 0 |
| 0.95 | 6 |
| 0.85 | 12 |
| 0.75 | 18 |
| 0.65 | 24 |
| 0.55 | 30 |
| 0.45 | 36 |




## Chart #2

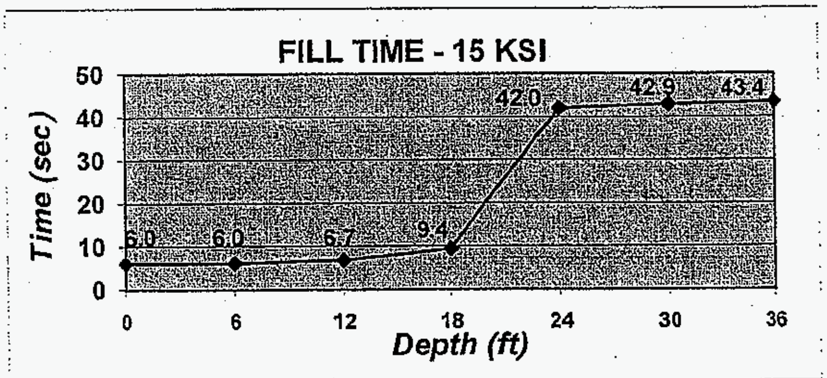
| Fill Time (FT) 3 ksi | |
|---|---|
| Sec | Depth (ft) |
| 6.0 | 0 |
| 6.0 | 6 |
| 7.8 | 12 |
| 9.8 | 18 |
| 12.2 | 24 |
| 15.2 | 30 |
| 19.8 | 36 |




## Chart #3

| Fill time (FT) 15 ksi | |
|---|---|
| Sec | Depth (ft) |
| 6.0 | 0 |
| 6.0 | 6 |
| 6.7 | 12 |
| 9.4 | 18 |
| 42.0 | 24 |
| 42.9 | 30 |
| 43.4 | 36 |

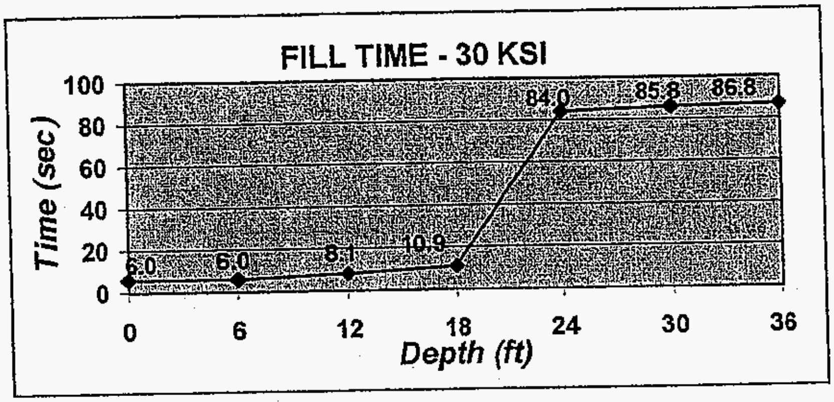
*(Hydraulic hammer used from 15 to 35 ft)*



## Chart #4

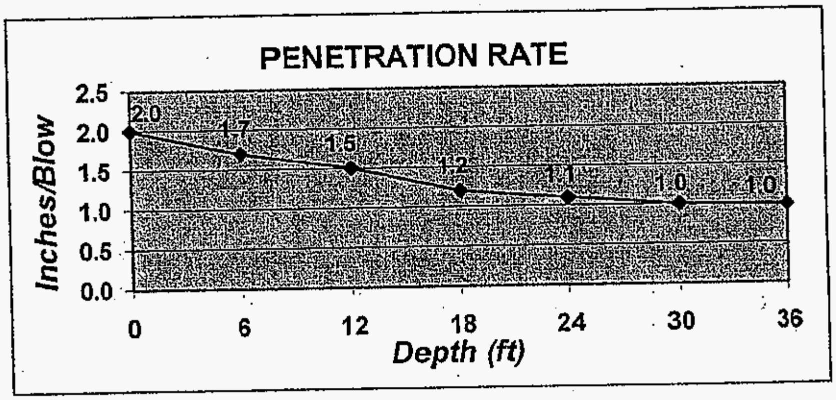
| Fill Time (FT) 30 ksi | |
|---|---|
| Sec. | Depth (ft) |
| 6.0 | 0 |
| 6.0 | 6 |
| 8.1 | 12 |
| 10.9 | 18 |
| 84.0 | 24 |
| 85.8 | 30 |
| 86.8 | 36 |

*(Hydraulic hammer used from 15 to 35 ft)*




## Chart #5

| Penetration Rate (PPB) | |
|---|---|
| In/Blow | Depth |
| 2 | 0 |
| 1.7 | 6 |
| 1.5 | 12 |
| 1.2 | 18 |
| 1.1 | 24 |
| 1 | 30 |
| 0.98 | 36 |



# EQUATIONS

## Excavate Trench:

| | | | |
|---|---|---|---|
| SCXT | Side Cell Excavate Time (per lift) | min | ((WS*LS*SF*LD)/(27*BC*BFF))(BFT + 2*BST + BET) |
| SCST | Time to Excavate Side Cell Stack | hrs | Sum(SCXT)/60 |
| ECXT | End Cell Excavate Time (per lift) | min | ((WE*LE*SF*LD)/(27*BC*BFF))(BFT + 2*BST + BET) |
| EC | Time to Excavate End Cell Stack | hrs | Sum(ECXT)/60 |
| CCXT | Corner Cell Excavate Time (per lift) | min | ((WC*LC*SF*LD)/(27*BC*BFF))(BFT + 2*BST + BET) |
| CCST | Time to Excavate Corner Cell Stack | hrs | Sum(CCXT)/60 |
| TEXET | Time to Excavate an End Trench | hrs | [(ECS*ECXT) + (CCS*CCXT)]/ET |
| TEXST | Time to Excavate Both Side Trenches | hrs | (SCS*SCXT) |
| TTEX | Total Time to Excavate Trenches | hrs | (SCS*SCST) + (ECS*ECST) + (CCS*CCST) |

## Assemble Shoring:

| | | | |
|---|---|---|---|
| TAET | Time to Assemble End Trench | hrs | (((XCC+XEC)*(RPC+SPC)/ET)*(TARP))/60 |
| TAST | Time to Assemble Side Trenches | hrs | (SC*(RPC+SPC)*(TARP))/60 |
| TTAS | Total Time to Assemble Trenches | hrs | (ET*TAET) + TAST |

## Place Shoring:

| | | | |
|---|---|---|---|
| TPET | Time to Move/Place End Trench Shoring | hr | (((XEC + XCC)/2)*(PC(TPPA + TMP) + RPC*(TMRP + TPET)))/60 |
| TPST | Time to Move/Place Side Trench Shoring | hr | (SC*(((PC)*(TPPA+TMP))+(RPC*(TMRP+TPRP))))/60 |
| TTPS | Total Time to Move & Place Shoring | hr | (ET*TPET) + TPST |

## Push Shoring:

| | | | |
|---|---|---|---|
| TPUET | Time to Push an End Trench | hrs | ((((ECS + CCS)/ET)(BLC*TPB)/60)*PPBc)/60 |
| TPUST | Time to Push a Side Trench. | hrs | ((((SCS)(BLC)TPB)/60)*PPBc)/60 |
| TTPU | Total Time to Push Shoring | hrs | (ET*TPUET) + TPUST |
| | | | *Note: PPBc from Chart #5* |

## Install Walers:

| | | | |
|---|---|---|---|
| TIEW | Time to Install End Trench Walers | hrs | (XEW*(TIW+TMW))/60 |
| TISW | Time to Install Side Trench Walers | hrs | ((XSW)(TIW+TMW))/60 |
| TTIW | Total Time to Install Walers | hrs | (ET*TIEW) + TISW |

## Install Cross Beams:

| | | | |
|---|---|---|---|
| TICB | Time to Install Cross Beams | hrs | ((XCB)(TICM + TMCM))/60 |

## Excavate Trench & Install Shoring:

| | | | |
|---|---|---|---|
| ESAR | Excavate/Shoring Advance Rate | hrs | CL/(TTEX+TTPS+TTPU+TTIW)*OE |

# RESULTS @ 15 KSI

## OPERATION #1 - EXCAVATE TRENCHES & INSTALL SHORING

| Excavate End Cell Stack | | | | | | | |
|---|---|---|---|---|---|---|---|
| | *Value* | *0-6 ft* | *6-12 ft* | *12-18 ft* | *18-24 ft* | *24-30 ft* | *30-36 ft* |
| Cell Width | WE | 16 | 16 | 16 | 16 | 16 | 16 |
| Cell Length | LE | 16 | 16 | 16 | 16 | 16 | 16 |
| Swell Fctr | SF | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 |
| Lift Depth | LD | 6 | 6 | 6 | 6 | 6 | 6 |
| Bucket Capa | BC | 3 | 3 | 3 | 3 | 3 | 3 |
| Fill Factor | FF | 0.95 | 0.85 | 0.75 | 0.65 | 0.55 | 0.45 |
| Fill Time | FT | 6.0 | 7.8 | 9.8 | 12.2 | 15.2 | 19.8 |
| Swing Time | BST | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 |
| Empty Time | BET | 2.57 | 2.57 | 2.57 | 2.57 | 2.57 | 2.57 |
| Lift Time (Min) (ECXT) | | 7.3 | 9.0 | 11.2 | 14.4 | 19.3 | 27.5 |

| Excavate Corner Cell Stack | | | | | | | |
|---|---|---|---|---|---|---|---|
| | *Value* | *0-6 ft* | *6-12 ft* | *12-18 ft* | *18-24 ft* | *24-30 ft* | *30-36 ft* |
| Cell Width | WC | 16 | 16 | 16 | 16 | 16 | 16 |
| Cell Length | LC | 16 | 16 | 16 | 16 | 16 | 16 |
| Swell Fctr | S | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 |
| Lift Depth | LD | 6 | 6 | 6 | 6 | 6 | 6 |
| Bucket Capa | B | 3 | 3 | 3 | 3 | 3 | 3 |
| Fill Factor | F | 0.95 | 0.85 | 0.75 | 0.65 | 0.55 | 0.45 |
| Fill Time | FT | 6.0 | 7.8 | 9.8 | 12.2 | 15.2 | 19.8 |
| Swing Time | H | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 |
| Empty Time | E | 2.57 | 2.57 | 2.57 | 2.57 | 2.57 | 2.57 |
| Exc. Time (Min) (CCXT) | | 7.3 | 9.0 | 11.2 | 14.4 | 19.3 | 27.5 |

| Excavate Side Cell Stack | | | | | | | |
|---|---|---|---|---|---|---|---|
| | *Value* | *0-6 ft* | *6-12 ft* | *12-18 ft* | *18-24 ft* | *24-30 ft* | *30-36 ft* |
| Cell Width | WS | 9.453 | 9.453 | 9.453 | 9.453 | 9.453 | 9.453 |
| Cell Length | LS | 16 | 16 | 16 | 16 | 16 | 16 |
| Swell Fctr | S | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 |
| Lift Depth | LD | 6 | 6 | 6 | 6 | 6 | 6 |
| Bucket Capa | B | 3 | 3 | 3 | 3 | 3 | 3 |
| Fill Factor | F | 0.95 | 0.85 | 0.75 | 0.65 | 0.55 | 0.45 |
| Fill Time | FT | 6.0 | 7.8 | 9.8 | 12.2 | 15.2 | 19.8 |
| Swing Time | H | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 |
| Empty Time | E | 2.57 | 2.57 | 2.57 | 2.57 | 2.57 | 2.57 |
| Exc. Time (Min) (SCXT) | | 4.3 | 5.3 | 6.6 | 8.5 | 11.4 | 16.3 |

| | Min | Hr | Qty | Total Hrs |
|---|---|---|---|---|
| Time to Excavate a Side Cell Stack (SCST) | 52.5 | 0.9 | 122 | |
| Total Time to Excavate Side Trenches (TEXST) | | | | 106.6 |
| Time to Excavate a End Cell Stack (ECST) | 88.8 | 1.5 | 4 | |
| Time to Excavate a Corner Cell Stack (CCST) | 88.8 | 1.5 | 4 | |
| Time to Excavate End Trenches (TEXET) | | | | 5.9 |
| Total Time to Excavate Trenches (TTEX) | | | | 112.6 |

| | Min | Hr | Qty | Total Hrs |
|---|---|---|---|---|
| Time to Assemble End Trench (TAET) | 96.0 | 1.6 | 2 | 3.2 |
| Time to Assemble Side Trench (TAST) | 2928.0 | 48.8 | 2 | 97.6 |
| Total Time To Assemble Shoring (TTAS) | | | | 100.8 |

| | Min | Hr | Qty | Total Hrs |
|---|---|---|---|---|
| Time to Place End Trench (TPET) | 375.0 | 6.3 | 2 | 12.5 |
| Place Side Trench (TPST) | 11437.5 | 190.6 | 2 | 381.3 |
| Total Time To Place Shoring (TTPS) | | | | 393.8 |

| Push Times | Min | Hr | Qty | Total Hrs |
|---|---|---|---|---|
| Time to Push End Trench (TPUET) | 180.6 | 3.0 | 2 | 12.0 |
| time to Push Side Trench (TPUST) | 5509.5 | 91.8 | 2 | 183.6 |
| Total Time for Pushing Shoring (TTPU) | | | | 195.7 |

| Install Walers | Min | Hr | | Total Hrs |
|---|---|---|---|---|
| Time to Install End Trench Walers (TIEW) | 140.0 | 2.3 | | 4.7 |
| Time to Install Side Trench Walers (TISW) | 1190.0 | 19.8 | | 19.8 |
| Total Time to Install Walers (TTIW) | | | | 24.5 |

| Install Cross Beams | Min | Hr | | Total Hrs |
|---|---|---|---|---|
| Total Time to Install Cross Beams TICB) | 2345.0 | 39.1 | | 39.1 |

**SUMMARY OF TRENCH EXCAVATION & SHORING SYSTEM INSTALLATION**

*Note: Concurrent activities not included in Construction Days*

| | Critical Path Item | Hrs | Days 1 Crew | Days 2 Crews |
|---|---|---|---|---|
| Excavate Trenches (TTEX) | * | 112.6 | 14.1 | 7.0 |
| Assemble Shoring (TTAS) | | | | |
| Place Shoring (TTPS) | * | 393.8 | 49.2 | 24.6 |
| Push Shoring (TTPU) | * | 195.7 | 24.5 | 12.2 |
| Install Walers (TTIW) | * | 24.5 | 3.1 | 1.5 |
| Install Cross Beams (TICB) | | | | |
| Total Time @100% Efficient (ESAR) | | 726.5 | 90.8 | 45.4 |
| Total Time @75% Efficient (ESAR) | | 968.7 | 121.1 | 60.5 |

# RESULTS @ 15 KSI

## OPERATION #1 - EXCAVATE TRENCHES & INSTALL SHORING

| Excavate End Cell Stack | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Value | 0-6 ft | 6-12 ft | 12-18 ft | 18-24 ft | 24-30 ft | 30-36 ft |
| Cell Width | WE | 16 | 16 | 16 | 16 | 16 | 16 |
| Cell Length | LE | 16 | 16 | 16 | 16 | 16 | 16 |
| Swell Fctr | SF | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 |
| Lift Depth | LD | 6 | 6 | 6 | 6 | 6 | 6 |
| Bucket Capa | BC | 3 | 3 | 3 | 3 | 3 | 3 |
| Fill Factor | FF | 0.95 | 0.85 | 0.75 | 0.65 | 0.55 | 0.45 |
| Fill Time | FT | 6.0 | 6.7 | 9.4 | 42.0 | 42.9 | 43.4 |
| Swing Time | BST | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 |
| Empty Time | BET | 2.57 | 2.57 | 2.57 | 2.57 | 2.57 | 2.57 |
| Lift Time (Min) (ECXT) | | 7.3 | 8.5 | 11.1 | 32.6 | 39.1 | 48.3 |

| Excavate Corner Cell Stack | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Value | 0-6 ft | 6-12 ft | 12-18 ft | 18-24 ft | 24-30 ft | 30-36 ft |
| Cell Width | WC | 16 | 16 | 16 | 16 | 16 | 16 |
| Cell Length | LC | 16 | 16 | 16 | 16 | 16 | 16 |
| Swell Fctr | S | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 |
| Lift Depth | LD | 6 | 6 | 6 | 6 | 6 | 6 |
| Bucket Capa | B | 3 | 3 | 3 | 3 | 3 | 3 |
| Fill Factor | F | 0.95 | 0.85 | 0.75 | 0.65 | 0.55 | 0.45 |
| Fill Time | FT | 6.0 | 6.7 | 9.4 | 42.0 | 42.9 | 43.4 |
| Swing Time | H | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 |
| Empty Time | E | 2.57 | 2.57 | 2.57 | 2.57 | 2.57 | 2.57 |
| Exc. Time (Min) (CCXT) | | 7.3 | 8.5 | 11.1 | 32.6 | 39.1 | 48.3 |

| Excavate Side Cell Stack | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Value | 0-6 ft | 6-12 ft | 12-18 ft | 18-24 ft | 24-30 ft | 30-36 ft |
| Cell Width | WS | 9.453 | 9.453 | 9.453 | 9.453 | 9.453 | 9.453 |
| Cell Length | LS | 16 | 16 | 16 | 16 | 16 | 16 |
| Swell Fctr | S | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 |
| Lift Depth | LD | 6 | 6 | 6 | 6 | 6 | 6 |
| Bucket Capa | B | 3 | 3 | 3 | 3 | 3 | 3 |
| Fill Factor | F | 0.95 | 0.85 | 0.75 | 0.65 | 0.55 | 0.45 |
| Fill Time | FT | 6.0 | 6.7 | 9.4 | 42.0 | 42.9 | 43.4 |
| Swing Time | H | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 |
| Empty Time | E | 2.57 | 2.57 | 2.57 | 2.57 | 2.57 | 2.57 |
| Exc. Time (Min) (SCXT) | | 4.3 | 5.0 | 6.5 | 19.2 | 23.1 | 28.5 |

| | Min | Hr | Qty | Total Hrs |
|---|---|---|---|---|
| Time to Excavate a Side Cell Stack (SCST) | 86.7 | 1.4 | 122 | |
| Total Time to Excavate Side Trenches (TEXST) | | | | 176.4 |
| Time to Excavate a End Cell Stack (ECST) | 146.8 | 2.4 | 4 | |
| Time to Excavate a Corner Cell Stack (CCST) | 146.8 | 2.4 | 4 | |
| Time to Excavate End Trenches (TEXET) | | | | 9.8 |
| Total Time to Excavate Trenches (TTEX) | | | | 186.2 |

| | Min | Hr | Qty | Total Hrs |
|---|---|---|---|---|
| Time to Assemble End Trench (TAET) | 96.0 | 1.6 | 2 | 6.4 |
| Time to Assemble Side Trench (TAST) | 2928.0 | 48.8 | 2 | 97.6 |
| Total Time To Assemble Shoring (TTAS) | | | | 104.0 |

| | Min | Hr | Qty | Total Hrs |
|---|---|---|---|---|
| Time to Place End Trench (TPET) | 375.0 | 6.3 | 2 | 12.5 |
| Place Side Trench (TPST) | 11437.5 | 190.6 | 2 | 381.3 |
| Total Time To Place Shoring (TTPS) | | | | 393.8 |

| Push Times | Min | Hr | Qty | Total Hrs |
|---|---|---|---|---|
| Time to Push End Trench (TPUET) | 180.6 | 3.0 | 2 | 12.0 |
| time to Push Side Trench (TPUST) | 5509.5 | 91.8 | 2 | 183.6 |
| Total Time for Pushing Shoring (TTPU) | | | | 195.7 |

| Install Walers | Min | Hr | | Total Hrs |
|---|---|---|---|---|
| Time to Install End Trench Walers (TIEW) | 140.0 | 2.3 | | 4.7 |
| Time to Install Side Trench Walers (TISW) | 1190.0 | 19.8 | | 19.8 |
| Total Time to Install Walers (TTIW) | | | | 24.5 |

| Install Cross Beams | Min | Hr | | Total Hrs |
|---|---|---|---|---|
| Total Time to Install Cross Beams TICB) | 2345.0 | 39.1 | | 39.1 |

**SUMMARY OF TRENCH EXCAVATION & SHORING SYSTEM INSTALLATION**

*Note: Concurrent activities not included in Construction Days*

| | Critical Path Item | Hrs | Days 1 Crew | Days 2 Crews |
|---|---|---|---|---|
| Excavate Trenches (TTEX) | * | 186.2 | 23.3 | 11.6 |
| Assemble Shoring (TTAS) | | | | |
| Place Shoring (TTPS) | * | 393.8 | 49.2 | 24.6 |
| Push Shoring (TTPU) | * | 195.7 | 24.5 | 12.2 |
| Install Walers (TTIW) | * | 24.5 | 3.1 | 1.5 |
| Install Cross Beams (TICB) | | | | |
| Total Time @100% Efficient (ESAR) | | 800.1 | 100.0 | 50.0 |
| Total Time @75% Efficient (ESAR) | | 1066.8 | 133.4 | 66.7 |

# RESULTS @ 30 KSI

## OPERATION #1 - EXCAVATE TRENCHES & INSTALL SHORING

| Excavate End Cell Stack | | | | | | | |
|---|---|---|---|---|---|---|---|
| | *Value* | *0-6 ft* | *6-12 ft* | *12-18 ft* | *18-24 ft* | *24-30 ft* | *30-36 ft* |
| Cell Width | WE | 16 | 16 | 16 | 16 | 16 | 16 |
| Cell Length | LE | 16 | 16 | 16 | 16 | 16 | 16 |
| Swell Fctr | SF | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 |
| Lift Depth | LD | 6 | 6 | 6 | 6 | 6 | 6 |
| Bucket Capa | BC | 3 | 3 | 3 | 3 | 3 | 3 |
| Fill Factor | FF | 0.95 | 0.85 | 0.75 | 0.65 | 0.55 | 0.45 |
| Fill Time | FT | 6.0 | 8.1 | 10.9 | 84.0 | 85.8 | 86.8 |
| Swing Time | BST | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 |
| Empty Time | BET | 2.57 | 2.57 | 2.57 | 2.57 | 2.57 | 2.57 |
| Lift Time (Min) (ECXT) | | 7.3 | 9.1 | 11.9 | 58.1 | 69.9 | 86.4 |

| Excavate Corner Cell Stack | | | | | | | |
|---|---|---|---|---|---|---|---|
| | *Value* | *0-6 ft* | *6-12 ft* | *12-18 ft* | *18-24 ft* | *24-30 ft* | *30-36 ft* |
| Cell Width | WC | 16 | 16 | 16 | 16 | 16 | 16 |
| Cell Length | LC | 16 | 16 | 16 | 16 | 16 | 16 |
| Swell Fctr | S | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 |
| Lift Depth | LD | 6 | 6 | 6 | 6 | 6 | 6 |
| Bucket Capa | B | 3 | 3 | 3 | 3 | 3 | 3 |
| Fill Factor | F | 0.95 | 0.85 | 0.75 | 0.65 | 0.55 | 0.45 |
| Fill Time | FT | 6.0 | 8.1 | 10.9 | 84.0 | 85.8 | 86.8 |
| Swing Time | H | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 |
| Empty Time | E | 2.57 | 2.57 | 2.57 | 2.57 | 2.57 | 2.57 |
| Exc Time (Min) (CCXT) | | 7.3 | 9.1 | 11.9 | 58.1 | 69.9 | 86.4 |

| Excavate Side Cell Stack | | | | | | | |
|---|---|---|---|---|---|---|---|
| | *Value* | *0-6 ft* | *6-12 ft* | *12-18 ft* | *18-24 ft* | *24-30 ft* | *30-36 ft* |
| Cell Width | WS | 9.453 | 9.453 | 9.453 | 9.453 | 9.453 | 9.453 |
| Cell Length | LS | 16 | 16 | 16 | 16 | 16 | 16 |
| Swell Fctr | S | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 |
| Lift Depth | LD | 6 | 6 | 6 | 6 | 6 | 6 |
| Bucket Capa | B | 3 | 3 | 3 | 3 | 3 | 3 |
| Fill Factor | F | 0.95 | 0.85 | 0.75 | 0.65 | 0.55 | 0.45 |
| Fill Time | FT | 6.0 | 8.1 | 10.9 | 84.0 | 85.8 | 86.8 |
| Swing Time | H | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 |
| Empty Time | E | 2.57 | 2.57 | 2.57 | 2.57 | 2.57 | 2.57 |
| Exc. Time (Min) (SCXT) | | 4.3 | 5.4 | 7.0 | 34.3 | 41.3 | 51.0 |



RAHCO International

| | Min | Hr | Qty | Total Hrs |
|---|---|---|---|---|
| Time to Excavate a Side Cell Stack (SCST) | 143.4 | 2.4 | 122 | |
| Total Time to Excavate Side Trenches (TEXST) | | | | 291.5 |
| Time to Excavate a End Cell Stack (ECST) | 242.7 | 4.0 | 4 | |
| Time to Excavate a Corner Cell Stack (CCST) | 242.7 | 4.0 | 4 | |
| Time to Excavate End Trenches (TEXET) | | | | 16.2 |
| Total Time to Excavate Trenches (TTEX) | | | | 307.7 |

| | Min | Hr | Qty | Total Hrs |
|---|---|---|---|---|
| Time to Assemble End Trench (TAET) | 96.0 | 1.6 | 2 | 6.4 |
| Time to Assemble Side Trench (TAST) | 2928.0 | 48.8 | 2 | 97.6 |
| Total Time To Assemble Shoring (TTAS) | | | | 104.0 |

| | Min | Hr | Qty | Total Hrs |
|---|---|---|---|---|
| Time to Place End Trench (TPET) | 375.0 | 6.3 | 2 | 12.5 |
| Place Side Trench (TPST) | 11437.5 | 190.6 | 2 | 381.3 |
| Total Time To Place Shoring (TTPS) | | | | 393.8 |

| Push Times | Min | Hr | Qty | Total Hrs |
|---|---|---|---|---|
| Time to Push End Trench (TPUET) | 180.6 | 3.0 | 2 | 12.0 |
| time to Push Side Trench (TPUST) | 5509.5 | 91.8 | 2 | 183.6 |
| Total Time for Pushing Shoring (TTPU) | | | | 195.7 |

| Install Walers | Min | Hr | | Total Hrs |
|---|---|---|---|---|
| Time to Install End Trench Walers (TIEW) | 140.0 | 2.3 | | 4.7 |
| Time to Install Side Trench Walers (TISW) | 1190.0 | 19.8 | | 19.8 |
| Total Time to Install Walers (TTIW) | | | | 24.5 |

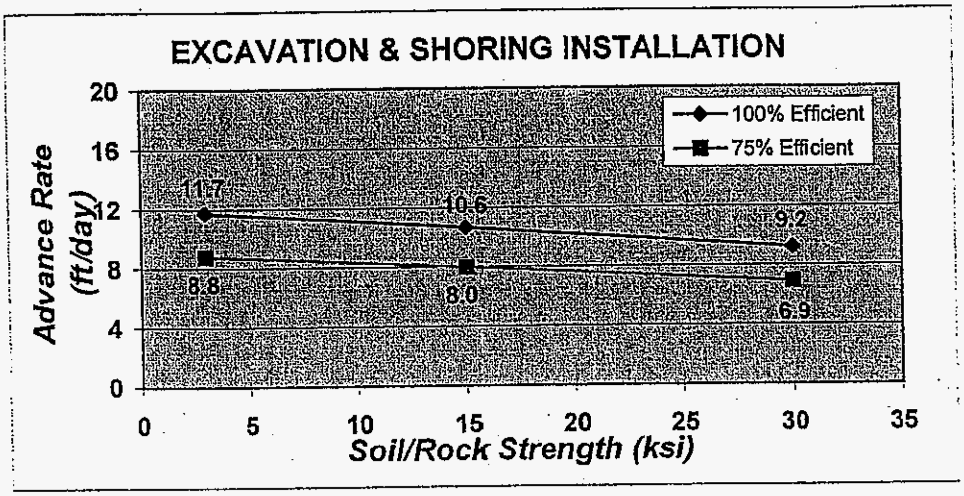
| Install Cross Beams | Min | Hr | | Total Hrs |
|---|---|---|---|---|
| Total Time to Install Cross Beams TICB) | 2345.0 | 39.1 | | 39.1 |

**SUMMARY OF TRENCH EXCAVATION & SHORING SYSTEM INSTALLATION**

*Note: Concurrent activities not included in Construction Days*

| | Critical Path Item | Hrs | Days 1 Crew | Days 2 Crews |
|---|---|---|---|---|
| Excavate Trenches (TTEX) | * | 307.7 | 38.5 | 19.2 |
| Assemble Shoring (TTAS) | | | | |
| Place Shoring (TTPS) | * | 393.8 | 49.2 | 24.6 |
| Push Shoring (TTPU) | * | 195.7 | 24.5 | 12.2 |
| Install Walers (TTIW) | * | 24.5 | 3.1 | 1.5 |
| Install Cross Beams (TICB) | | | | |
| Total Time @100% Efficient (ESAR) | | 921.7 | 115.2 | 57.6 |
| Total Time @75% Efficient (ESAR) | | 1228.9 | 153.6 | 76.8 |

| Advance Rates | | |
|---|---|---|
| ksi | 100% | 75% |
| 3 | 11.7 | 8.8 |
| 15 | 10.6 | 8.0 |
| 30 | 9.2 | 6.9 |



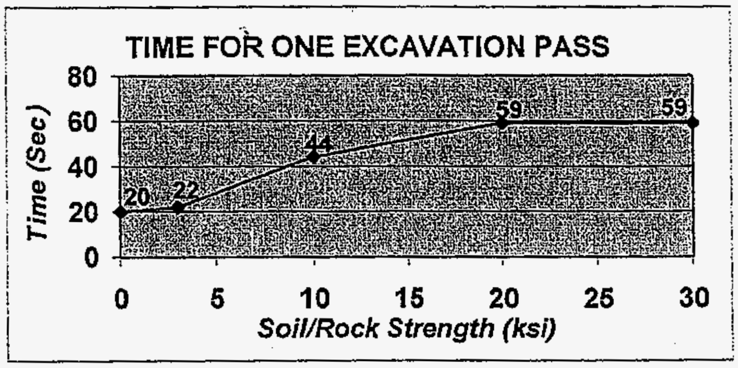
# OPERATION #2: CONSTRUCT HORIZONTAL BARRIER

## DEFINITIONS & INPUT DATA

| | | Unit of Measure | Value | Source |
|---|---|---|---|---|
| Cycle | Distance Traveled | in | 24 | Input |
| TAR | Time to Retract Alignment Jack | sec | 20.71 | Test Data |
| TPBM | Time to Position Block Magazine | sec | 300 | Test Data |
| TPP | Time to Position Poly Magazine | sec | 300 | Eng Estimate |
| TAE | Time to Engage Alignment Jack | sec | 4.1 | Test Data |
| TRR | Time to Retract Both Index Pins | sec | 58 | Test Data |
| TMIP | Time to Move Index Pins Forward | sec | 346 | Test Data |
| TRP | Time to Re-Insert Index Pins | sec | 58 | Test Data |
| TIRC | Time to Insert Robo Cylinder | sec | 2 | Test Data |
| TLSB | Time to Lift Stack Blocks | sec | 25 | Test Data |
| TIB | Time to Insert Block | sec | 24 | Test Data |
| TRBP | Time to Retract Block Pusher | sec | 24 | Test Data |
| TLRSB | Time to Lower Stack Blocks | sec | 25 | Test Data |
| TRRC | Time to Retract Robo Cylinder | sec | 2 | Test Data |
| XB | Number of Blocks | ea | 11 | Input |
| TIP | Insertion Time for Polyliner | sec | 45 | Test Data |
| TSP | Shearing Time for Polyliner | sec | 2 | Test Data |
| TPSCU | Time to Place Construction Unit | hr | 6 | Test Data |
| TEXc | Time for One Excavation Pass | sec | Chart 6 | |
| Tic | Time for One Index | sec | Chart 7 | |
| PDc | Penetration Depth | in. | Chart 8 | |
| CMSc | Cutterhead Maximum Speed | fpm | Chart 9 | |
| Tcycle | Time to Complete One Cycle | hr | Calc'd | |
| TE | Time to Excavate & Index | sec | Calc'd | |
| TRL | Time to Reposition Rail Lock | sec | Calc'd | |
| TB | Time to Insert Blocks | sec | Calc'd | Test Data |
| TP | Time to Insert Polyliner | min | Calc'd | |

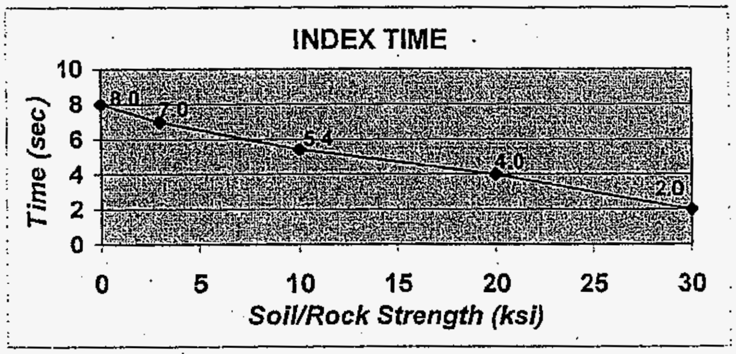
## Chart #7

| One Excavation Pass (TEX) | |
|---|---|
| ksi | sec |
| 3 | 22 |
| 10 | 44 |
| 20 | 59 |
| 30 | 59 |



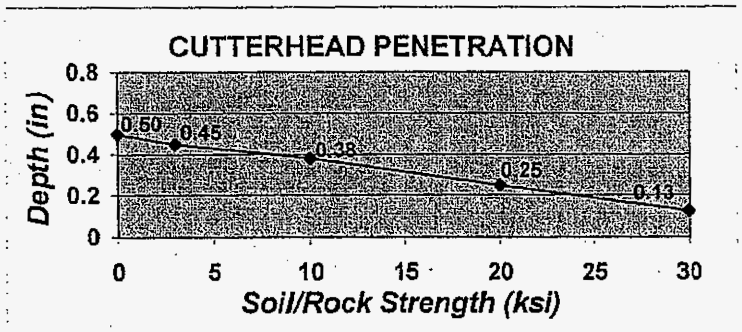

## Chart #8

| Index Time (TI) | |
|---|---|
| ksi | sec |
| 3 | 7 |
| 10 | 5.4 |
| 20 | 4 |
| 30 | 2 |



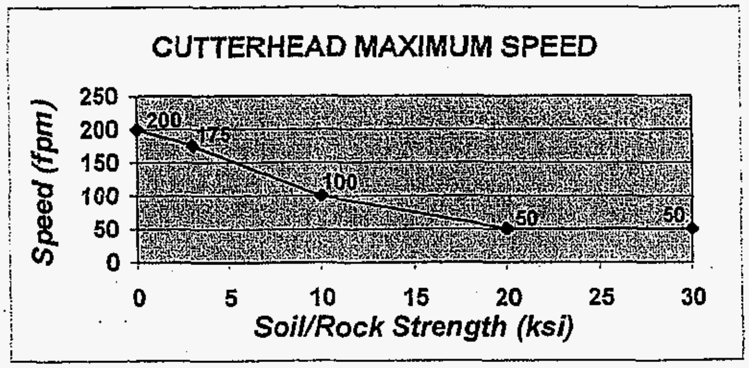

## Chart #9

| Penetration Depth (PD) | |
|---|---|
| ksi | in |
| 0 | 0.5 |
| 3 | 0.45 |
| 10 | 0.38 |
| 20 | 0.25 |
| 30 | 0.125 |



## Chart #10

| Cutterhead Speed (CS) | |
|---|---|
| *ksi* | *fpm* |
| 0 | 200 |
| 3 | 175 |
| 10 | 100 |
| 20 | 50 |
| 30 | 50 |



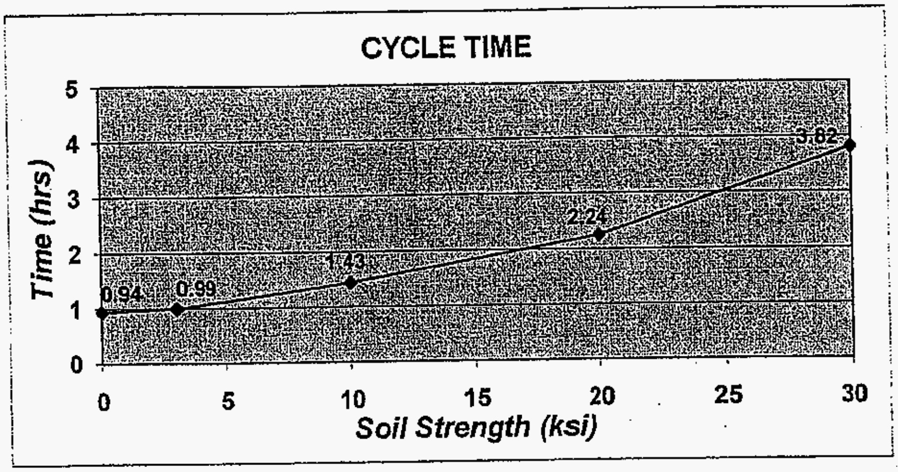

### EQUATIONS

| | | | |
|---|---|---|---|
| Tcycle | Time to Complete One Cycle | hr | TE + TRL + TAR + TBP + TB + TPP + TP + TAE |
| TE | Time to Excavate and Index | sec | TEXc + Tic |
| TRL | Time to Reposition Rail Lock | sec | TRR + TMIP + TRP |
| TB | Time to Insert Blocks | sec | (TIRC+ TLSB + TIB + TRBP + TLRSB + TRRC) * XB |
| TIP | Time to Insert Polyliner | sec | TIP + TSP |
| TTHB | Total Time to Install Horizontal Barrier | hr | BL/2*Tcycle |
| HBAR | Horizontal Barrier Advance Rate | ft/day | (WD/Tcycle)*2*OE |

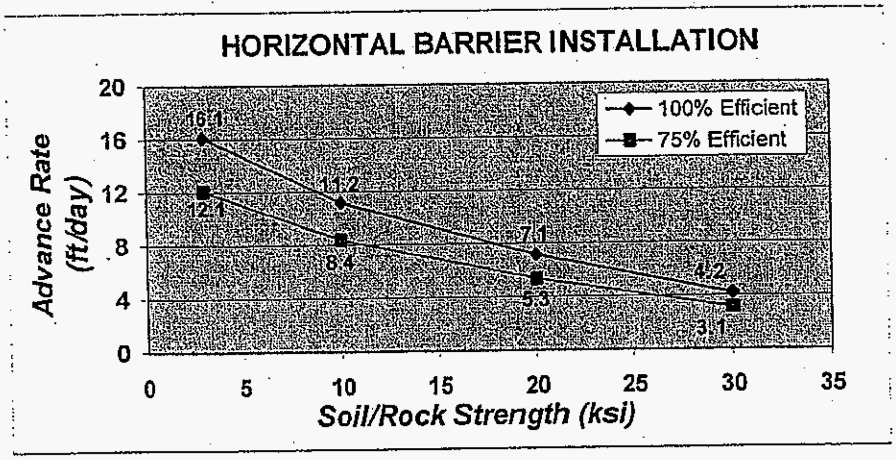
### RESULTS

| Soil Strength | Penetration Depth | # Passes per Cycle | Cutterhead Speed | TEXc (sec) | Ti (sec) | TE(sec) |
|---|---|---|---|---|---|---|
| 0 | 0.5 | 48.0 | 200 | 20 | 8 | 28 |
| 3 | 0.45 | 53.3 | 175 | 22 | 7 | 29 |
| 10 | 0.38 | 63.2 | 100 | 44 | 5.4 | 49.4 |
| 20 | 0.25 | 96.0 | 50 | 59 | 4 | 63 |
| 30 | 0.125 | 192.0 | 50 | 59 | 2 | 61 |

| Calculate Cycle Times | | | | | |
|---|---|---|---|---|---|
| ksi | 0 | 3 | 10 | 20 | 30 |
| Time to Excavate & Index (TE) | 1344 | 1546 | 3120 | 6048 | 11712 |
| Time to Reposition Rail Lock (TRL) | 462 | 462 | 462 | 462 | 462 |
| Time to Retract Alignment Jack (TAR) | 20.71 | 20.71 | 20.71 | 20.71 | 20.71 |
| Time to Position Block Magazine (TPBM) | 300 | 300 | 300 | 300 | 300 |
| Time to Insert Blocks (TB) | 1122 | 1122 | 1122 | 1122 | 1122 |
| Time to Position Poly Magazine (TPP) | 75 | 75 | 75 | 75 | 75 |
| Time to Insert Poly Liner (TIP) | 45 | 45 | 45 | 45 | 45 |
| Time to Engage Alignment Jack (TAE) | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 |
| Total (sec) | 3373 | 3575 | 5149 | 8077 | 13741 |
| Total (min) | 56 | 60 | 86 | 135 | 229 |
| Tcycle Total (hr) | 0.94 | 0.99 | 1.43 | 2.24 | 3.82 |
| Time to Install Horizontal Barrier (TTHB) | 469.4 | 497.5 | 716.5 | 1124.0 | 1912.3 |




| Advance Rates | | |
|---|---|---|
| ksi | 100% | 75% |
| 3 | 16.1 | 12.1 |
| 10 | 11.2 | 8.4 |
| 20 | 7.1 | 5.3 |
| 30 | 4.2 | 3.1 |






RAHCO International

# *OPERATION #3: INSTALL VERTICAL BARRIER*

## DEFINITIONS AND INPUT DATA

| | | *Unit of Measure* | *Value* | *Source* |
|---|---|---|---|---|
| TVBP | Time to Install Vertical Barrier Panel | min | 276 | Eng Estimate |
| IVSTB | Time to Install Vertical Side Trench Barrier | hr | Calc'd | |
| IVETB | Time to Install End Trench Barrier | hr | Calc'd | |

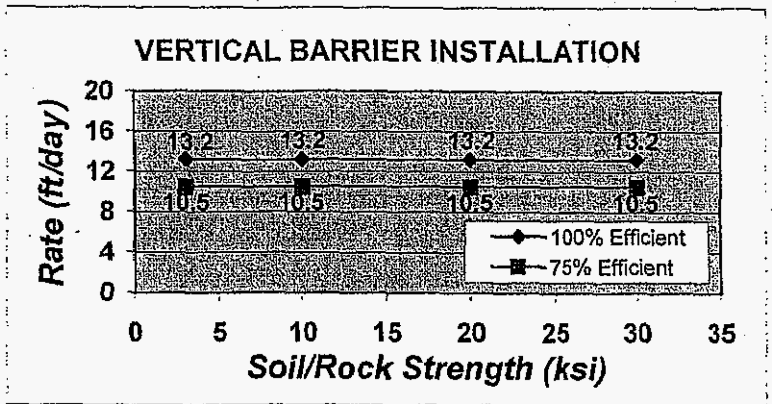
## EQUATIONS

| | | | |
|---|---|---|---|
| IVSTB | Install Vertical Side Trench Barrier | hr | (TVBP * NSP)/60 |
| IVETB | Install Vertical End Trench Barrier | hr | (TVBP * NEP)/60 |
| VBAR | Vertical Barrier Advance Rate | ft/day | ((BL*WD)/(IVSTB + IVETB))*OE |

## RESULTS

| | Qty | TVBP | Min | Hr | Days | Advance Rate |
|---|---|---|---|---|---|---|
| Install End Trench Barriers (IVETB) | 6 | 276 | 1656 | 27.6 | | |
| Install Side Trench Barriers (IVSTB) | 126 | 276 | 34776 | 579.6 | | |
| Total Time @ 100% Efficient (VBAR) | | | | 607.2 | 75.9 | 13.2 |
| Total Time @ 75% Efficient (VBAR) | | | | 809.6 | 101.2 | 10.5 |

| Advance Rate | | |
|---|---|---|
| ksi | 100% | 75% |
| 3 | 13.2 | 10.5 |
| 10 | 13.2 | 10.5 |
| 20 | 13.2 | 10.5 |
| 30 | 13.2 | 10.5 |






RAHCO International

# *OPERATION #4: REMOVE SHORING & BACKFILL TRENCH*

## DEFINITIONS AND INPUT DATA

| | | *Unit of Measure* | *Value* | *Source* |
|---|---|---|---|---|
| TRSR | Time to Remove Slide Rail Pair | min | 8 | Eng Est |
| TRPN | Time to Remove Panels | min | 5 | Eng Est |
| TBSC | Time to Backfill Side Cell | min | 67 | Eng Est |
| TBEC | Time to Backfill End Cell | min | 80 | Eng Est |
| TBCC | Time to Backfill Corner Cell | min | 67 | Eng Est |
| TDSL | Time to Disassemble Slide Rail Pair | min | 4 | Eng Est |
| TRWA | Time to Remove Waler | min | 30 | Eng Est |
| TRCM | Time to Remove Crossmember | min | 30 | Eng Est |
| TRBE | Time to Remove End Cell Shoring & Backfill | min | Calc | |
| TRBC | Time to Remove Corner Cell Shoring & Backfill | min | Calc | |
| TRBS | Time to Remove Side Cell Shoring & Backfill | min | Calc | |
| TRST | Time to Remove Shoring & Backfill Side Trenches | hr | Calc | |
| TRET | Time to Remove Shoring & Backfill End Trenches | hr | Calc | |
| RBAR | Shoring Removal/Backfill Advance Rate | min | Calc | |
| TTRB | Total Time for Removal and Backfill | min | Calc | |

## EQUATIONS

| | | | |
|---|---|---|---|
| TRBE | Time to Remove End Cell Shoring & Backfill | min | (XPC*TRPN) + (RPC*TRSR) + (XPC*TDSL) + TBEC |
| TRBC | Time to Remove Corner Cell Shoring & Backfill | min | (XPC*TRPN) + (RPC*TRSR) + (XPC*TDSL) + TBCC |
| TRBS | Time to Remove Side Cell Shoring & Backfill | min | (XPC*TRPN) + (RPC*TRSR) + (XPC*TDSL) + TBSC |
| TRST | Time to Remove Shoring & Backfill Side Trenches | hr | ((XSC*TRBS) + (XCB*TRCM))/60 |
| TRET | Time to Remove Shoring & Backfill End Trenches | hr | ((XEW*TRWA) + (XEC*TRBE) + (XCC*TRBC))/60 |
| TTRB | Total Time for Removal & Backfill | hr | TRET + TRST |
| RBAR | Shoring Removal/Backfill Advance Rate | ft/day | (WD*CL)/TTRB*OE |

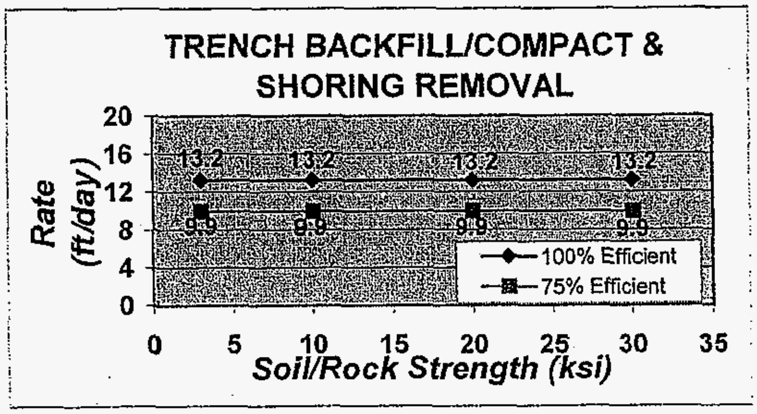


RAHCO International

## RESULTS

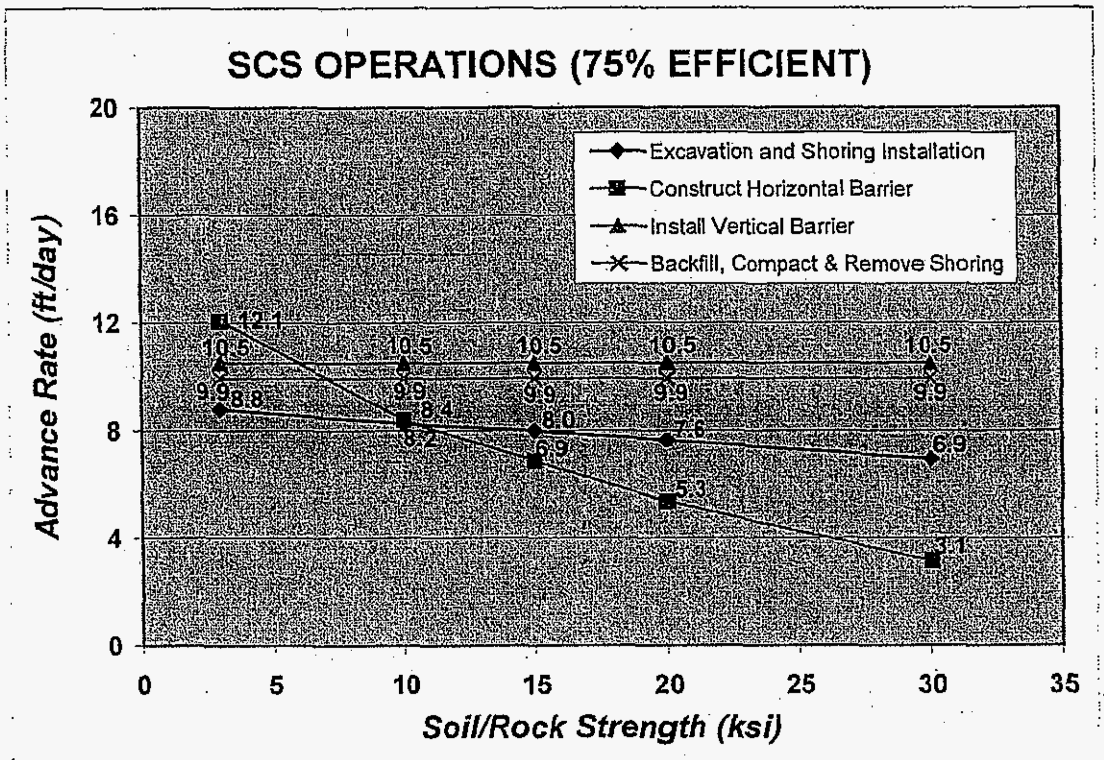
| | Min | Hr | Days | Advance Rate |
|---|---|---|---|---|
| Time to Remove & Backfill End Trench (TRET) | 2508 | 41.8 | | |
| Time to Remove & Backfill Side Trench (TRST) | 36048 | 600.8 | | |
| Total Time @ 100% Efficient (RBAR) | | 642.6 | 80.3 | 13.2 |
| Total Time @ 75% Efficient (RBAR) | | 856.8 | 107.1 | 9.9 |

| Advance Rate | | |
|---|---|---|
| ksi | 100% | 75% |
| 3 | 13.2 | 9.9 |
| 10 | 13.2 | 9.9 |
| 20 | 13.2 | 9.9 |
| 30 | 13.2 | 9.9 |



## SCS OPERATIONS
## SUMMARY @ 75% EFFICIENT

| ksi | 3 | 10 | 15 | 20 | 30 |
|---|---|---|---|---|---|
| Operation #1: Excavate Trench & Install Shoring | 8.8 | 8.2 | 8.0 | 7.6 | 6.9 |
| Operation #2: Construct Horizontal Barrier | 12.1 | 8.4 | 6.9 | 5.3 | 3.1 |
| Operation #3: Install Vertical Barrier | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 |
| Operation #4: Backfill, Compact & Remove Shoring | 9.9 | 9.9 | 9.9 | 9.9 | 9.9 |



# CRITICAL PATH ANALYSIS

## DEFINITIONS AND INPUT DATA

| | | Unit of Measure | Value | Source |
|---|---|---|---|---|
| TSCU | Time to Place or Remove SCU | hr | 6 | Eng Est |
| CPES | Critical Path - Excavate End Trench/ Install Shoring | hr | Calc'd | |
| CPSS | Critical Path Time to Excavate Side Trench/Install Shoring | hr | Calc'd | |
| CPEB | Critical Path Time to Install Vertical Barrier | hr | Calc'd | |
| CPSB | Critical Path Time to Install Side Barriers | hr | Calc'd | |
| CPHB | Critical Path Time to Install Horizontal Barrier | hr | Calc'd | |
| CPBE | Critical Path Time to Backfill & Remove End Shoring | hr | Calc'd | |
| CPBS | Critical Path Time to Backfill & Remove Side Shoring | hr | Calc'd | |

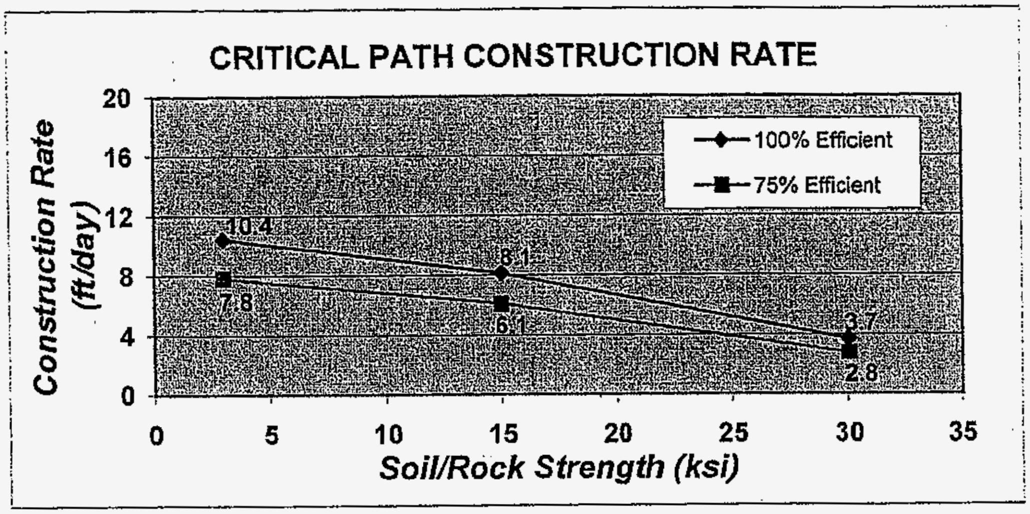
## EQUATIONS

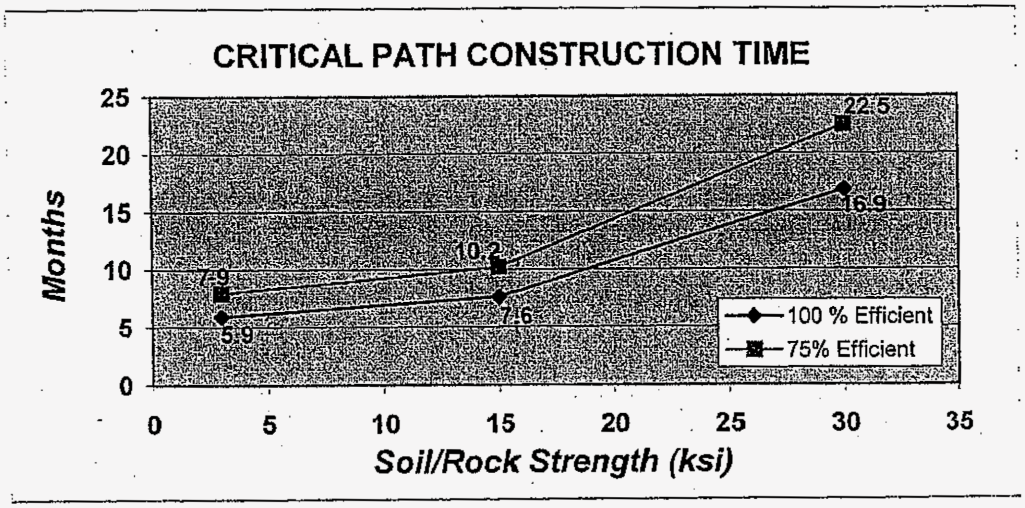
| | | | |
|---|---|---|---|
| CPES | (CP) Excavate End Trench & Install Shoring | hr | (TEXET/ET) + (TPET/ET) + (TPUET/ET) + (TIEW/ET) |
| CPSS | (CP) Excavate Side Trench & Install Shoring | hr | TEXST + TPST + TPUST + TISW |
| CPEB | (CP) Install Vertical End Barrier | hr | IVETB/ET |
| CPSB | (CP) Install Vertical Side Barriers | hr | IVSTB |
| CPHB | (CP) Construct Horizontal Barrier | hr | TTHB |
| CPBE | (CP) Backfill & Remove End Shoring | hr | TRET/ET |
| CPBS | (CP) Backfill & Remove Side Shoring | hr | TRST |
| TTCP | Total Time in Critical Path | days | SUM(CP Activities)/8 |
| CPCR | Critical Path Construction Rate | ft/day | (BL/TTCP)*OE |

## RESULTS

| Critical Path Analysis @ 100% Efficient | | | | | | |
|---|---|---|---|---|---|---|
| CP=Critical Path hrs | 3 | | 15 | | 30 | |
| Excavate End Trench & Install Shoring (CPES) | 17.6 | CP | 19.5 | CP | 22.7 | CP |
| Place Slot Construction Unit (TSCU) | 6.0 | | 6.0 | CP | 6.0 | |
| Install Vertical End Barrier (CPEB) | 13.8 | | 13.8 | | 13.8 | CP |
| Backfill & Remove End Shoring (CPBE) | 20.9 | | 20.9 | | 20.9 | CP |
| Excavate Side Trench & Install Shoring (CPSS) | 691.4 | CP | 761.1 | | 876.3 | CP |
| Construct Horizontal Barrier (CPHB) | 497.5 | | 920.3 | CP | 1912.3 | |
| Install Vertical Side Barriers (CPSB) | 579.6 | | 579.6 | | 579.6 | CP |
| Backfill & Remove Side Shoring (CPBS) | 600.8 | | 600.8 | | 600.8 | CP |
| Excavate End Trench & Install Shoring (CPES) | 17.6 | CP | 19.5 | | 22.7 | CP |
| Remove Slot Construction Unit (TSCU) | 6.0 | CP | 6.0 | CP | 6.0 | CP |
| Install Vertical End Barrier (CPEB) | 13.8 | CP | 13.8 | CP | 13.8 | CP |
| Backfill & Remove End Shoring (CPBE) | 20.9 | CP | 20.9 | CP | 20.9 | CP |
| Critical Path Elapsed Time (Work Days) hrs | 767.2 | | 986.5 | | 2177.5 | |
| Critical Path Elapsed Time (Work Days) days | 95.9 | | 123.3 | | 272.2 | |
| Critical Path Elapsed Time (Work Days) months | 4.4 | | 5.6 | | 12.4 | |
| Overall Construction Time months | 5.9 | | 7.6 | | 16.9 | |
| Construction Rate (ft/day) | 10.4 | | 8.1 | | 3.7 | |
| Total Crews | 4 | | 3 | | 2 | |

| Critical Path Analysis @ 75% Efficient | | | |
|---|---|---|---|
| ksi | 3 | 15 | 30 |
| Critical Path Elapsed Time (Work Days) hrs | 1023 | 1315 | 2903 |
| Critical Path Elapsed Time (Work Days) days | 127.9 | 164.4 | 362.9 |
| Critical Path Elapsed Time (Work Days) months | 5.8 | 7.5 | 16.5 |
| Overall Construction Time months | 7.9 | 10.2 | 22.5 |
| Construction Rate (ft/day) | 7.8 | 6.1 | 2.8 |
| Total Crews | 4 | 3 | 2 |


CRITICAL PATH CONSTRUCTION RATE
Construction Rate (ft/day)
Soil/Rock Strength (ksi)
100% Efficient
75% Efficient
10.4
8.1
3.7
7.8
6.1
2.8
0
4
8
12
16
20
0
5
10
15
20
25
30
35


CRITICAL PATH CONSTRUCTION TIME
Months
Soil/Rock Strength (ksi)
100 % Efficient
75% Efficient
22.5
16.9
10.2
7.6
7.9
5.9
0
5
10
15
20
25
0
5
10
15
20
25
30
35

# APPENDIX 2
# SCS COST ANALYSIS

# SCS COST ANALYSIS

**Prepared by Jalene Greer**
Revision 2 March 28, 2003

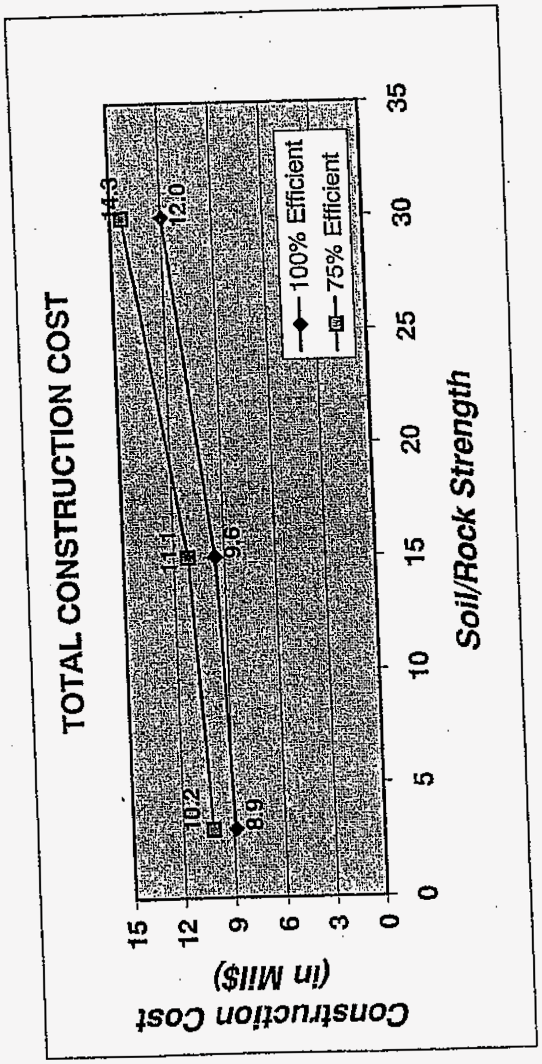
* Summary sheets show 100% and 75% efficiency rates
* Material/Equipment costs are exclusive of local taxes
* Estimates are exclusive of travel costs/per diem

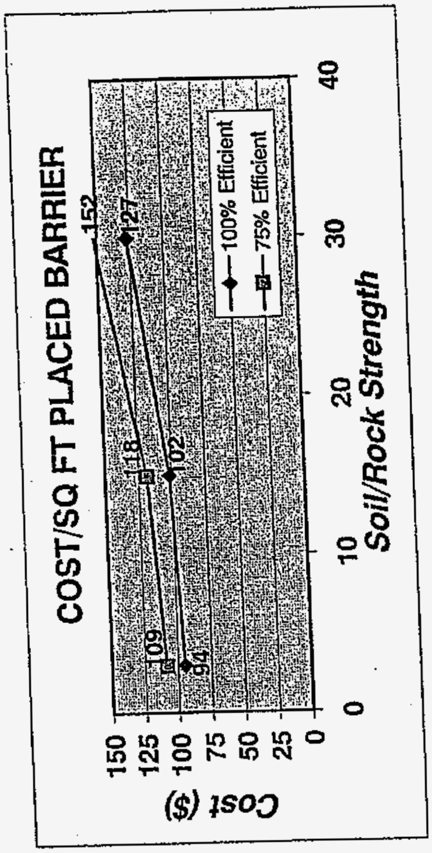
# COST ANALYSIS SUMMARY

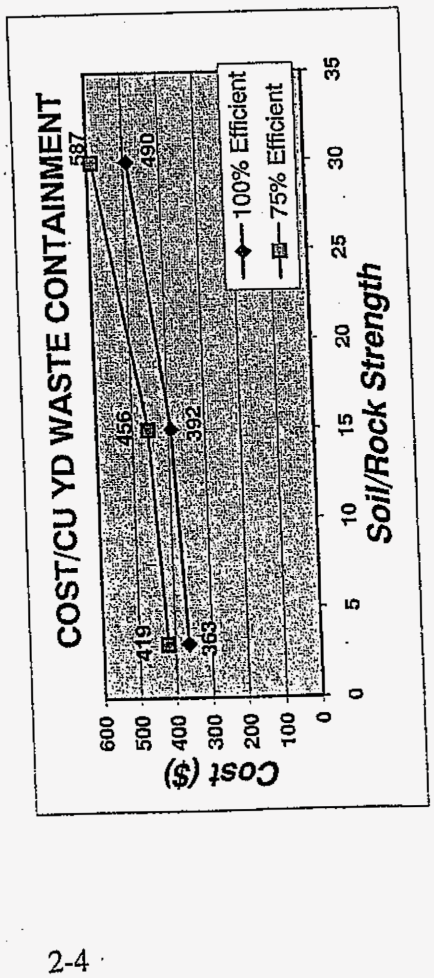
| | 100% Efficient (ksi) | | | 75% Efficient | | |
|---|---|---|---|---|---|---|
| | 3 | 15 | 30 | 3 | 15 | 30 |
| ***Subsurface Containment Barrier*** | | | | | | |
| Mobilization | $ 100,000 | $ 100,000 | $ 100,000 | $ 100,000 | $ 100,000 | $ 100,000 |
| Labor | 1,064,687 | 1,204,397 | 1,984,615 | 1,419,583 | 1,605,863 | 2,646,153 |
| Materials | 1,691,099 | 1,711,099 | 1,707,859 | 1,691,099 | 1,711,099 | 1,707,859 |
| Equipment | 1,970,846 | 2,319,269 | 3,360,497 | 2,627,794 | 3,092,358 | 4,480,663 |
| Demobilization | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 | 100,000 |
| Contingency @ 10% | 492,663 | 543,476 | 725,297 | 593,848 | 660,932 | 903,468 |
| Home Office @ 3% | 159,579 | 176,347 | 236,348 | 192,970 | 215,108 | 295,144 |
| SG&A @ 15% | 662,128 | 727,529 | 919,500 | 780,857 | 866,924 | 1,123,070 |
| Profit @ 10% | 338,522 | 386,662 | 534,164 | 429,547 | 493,532 | 690,235 |
| | $ 6,579,523 | $ 7,268,779 | $ 9,668,280 | $ 7,935,697 | $ 8,845,816 | $ 12,046,591 |
| ***RCRA Cover*** | $ 286,200 | $ 286,200 | $ 286,200 | $ 286,200 | $ 286,200 | $ 286,200 |
| ***Long Term Monitoring*** | $ 2,000,000 | $ 2,000,000 | $ 2,000,000 | $ 2,000,000 | $ 2,000,000 | $ 2,000,000 |
| **Total Construction Cost** | $ 8,865,723 | $ 9,554,979 | $ 11,954,480 | $ 10,221,897 | $ 11,132,016 | $ 14,332,791 |
| **Cost in Million$** | 8.9 | 9.6 | 12.0 | 10.2 | 11.1 | 14.3 |
| **Cost/Cu Yd of Waste Containment** | 363 | 392 | 490 | 419 | 456 | 587 |
| **Cost/Sq Ft of Placed Barrier** | 94 | 102 | 127 | 109 | 118 | 152 |



RAHCO International






RAHCO International

# COST ANALYSIS (3 ksi)

| | 100% Efficient | 75% Efficient | Source |
|---|---|---|---|
| ***Subsurface Containment Barrier (SCB)*** | | | |
| Mobilization | $ 100,000 | $ 100,000 | Eng Est |
| Labor | 1,064,687 | 1,419,583 | See Detail |
| Materials | 1,691,099 | 1,691,099 | See Detail |
| Equipment | 1,970,846 | 2,627,794 | See Detail |
| Demobilization | 100,000 | 100,000 | Eng Est |
| Contingency @10% | 492,663 | 593,848 | Industry Std |
| Home Office @ 3% | 159,579 | 192,969.71 | Industry Std |
| SG&A @ 15% | 662,128 | 780,856.52 | Industry Std |
| Profit @10% | 338,522 | 429,546.81 | Industry Std |
| ***Subtotal SCB*** | $ 6,579,523 | $ 7,935,697 | |
| ***RCRA Cover*** | $ 286,200 | $ 286,200 | Vendor |
| ***Long Term Monitoring*** | $ 2,000,000 | $ 2,000,000 | Eng Est |
| | $ 8,865,723 | $ 10,221,897 | |
| **Cost in Million$** | 8.9 | 10.2 | |
| **Cost/Cu Yd of Waste Containment** | 363 | 419 | 24,400 cu yd |
| **Cost/Sq Ft of Placed Barrier** | 94 | 109 | 90,400 sf |

## SCS LABOR COST - 3 ksi - 100% Efficient

*Labor Hours* 767

| POSITION | QTY | FT / PT | HOURS | RATE/HR | LABOR $ | SOURCE |
|---|---|---|---|---|---|---|
| Construction Superintendent | 1 | FT | 927 | $ 51.32 | $ 47,584 | Eng Est |
| Crew Foreman | 4 | FT | 927 | $ 51.32 | 190,338 | Eng Est |
| Quality Assurance | 1 | FT | 927 | $ 49.70 | 46,082 | Eng Est |
| Safety Specialist | 1 | PT 50% | 544 | $ 49.70 | 27,017 | Eng Est |
| E/H Specialist | 1 | PT 50% | 544 | $ 35.00 | 19,026 | Eng Est |
| Project Engineer | 1 | FT | 927 | $ 47.36 | 43,913 | Eng Est |
| Administrative Assistant | 1 | FT | 927 | $ 33.69 | 31,238 | Eng Est |
| Maintenance Crew | 2 | FT | 927 | $ 39.19 | 72,675 | Eng Est |
| **OPERATION #1 = EXCAVATE TRENCHES AND INSTALL SHORING EQUIPMENT** | | | | | | |
| Operators | 3 | FT | 767 | $ 39.19 | $ 90,201 | Eng Est |
| Laborers | 4 | FT | 767 | $ 25.00 | 76,721 | Eng Est |
| Survey Crew | 2 | FT | 767 | $ 35.00 | 53,705 | Eng Est |
| **OPERATION #2 = INSTALL HORIZONTAL BARRIER** | | | | | | |
| Operators | 3 | FT | 767 | $ 39.19 | $ 90,201 | Eng Est |
| Temporary Operators | 2 | PT (4 days) | 32 | $ 39.19 | 2,508 | Eng Est |
| Laborers | 2 | FT | 767 | $ 25.00 | 38,360 | Eng Est |
| **OPERATION #3 = INSTALL VERTICAL BARRIER** | | | | | | |
| Operators | 2 | FT | 767 | $ 39.19 | $ 60,134 | Eng Est |
| Inspectors | 1 | FT | 767 | $ 49.70 | 38,130 | Eng Est |
| Laborers | 2 | FT | 767 | $ 25.00 | 38,360 | Eng Est |
| **OPERATION #4 = BACKFILL & REMOVE SHORING** | | | | | | |
| Operator | 2 | FT | 767 | $ 39.19 | $ 60,134 | Eng Est |
| Laborers | 2 | PT | 767 | $ 25.00 | 38,360 | Eng Est |
| ***TOTAL # PERSONNEL*** | 37 | | | **TOTAL** | $ 1,064,687 | |



RAHCO International.

## SCS MATERIAL COST - 3 ksi - 100% Efficient

| | QTY | UNIT | UNIT $ | TOTAL | SOURCE |
|---|---|---|---|---|---|
| **Barrier Items** | | | | | |
| Cement Blocks | 5,787 | Ea | $ 100 | $ 578,700 | Vendor |
| Poly Rolls | 132 | Roll | 540 | 71,280 | Vendor |
| Horizontal Vertical Joint | 63 | Roll | 357 | 22,468 | Vendor |
| Vertical Joint | 47 | Roll | 76.58 | 3,602 | Vendor |
| Vertical Barrier Poly Panels 16' X 29' | 133 | Ea | 1,400 | 186,200 | Vendor |
| Vertical Barrier Frames (Steel) | 133 | Ea | 4,500 | 598,500 | Eng Est |
| Bentonite | 307 | Ton | 164 | 50,348 | Vendor |
| **Miscellaneous Construction Items** | | | | | |
| Temporary Utilities | | | | | |
| Operating Supplies | | | | | |
| Weather Protection | | | | | |
| Personal Protection Equipment | | | | | |
| Decontamination Equipment/Supplies | | | | | |
| Material Handling/Storage | | | | | |
| Field Sampling/Test/Monitor Equipment | | | | | |
| Borrow Materials | | | | | |
| Soil Stabilization | | | | | |
| Erosion Control | | | | | |
| Fence & Gates | | | | | |
| Landscaping | | | | | |
| Pumps | | | | | |
| **Total Miscellaneous Construction Items** | | | | 180,000 | Eng Est |
| | | | **Total** | **$ 1,691,099** | |



RAHCO International

# SCS EQUIPMENT COST - 3 ksi - 100% Efficient

**OPERATION #1 = EXCAVATE TRENCHES AND INSTALL SHORING EQUIPMENT**

| | | |
|---|---|---|
| Excavator | 1 | Continuous |
| Front End Loader | 1 | Continuous |
| Flat Bed Truck | 1 | Continuous |

**OPERATION #2 = INSTALL HORIZONTAL BARRIER**

| | | |
|---|---|---|
| SCU/PCU | 1 | Continuous |
| Cranes | 2 | 4 Days |
| Mobile Crane | 1 | Continuous |
| Flat Bed Truck | 1 | Continuous |
| Diesel Generator | 2 | Continuous |

**OPERATION #3 = INSTALL VERTICAL BARRIER**

| | | |
|---|---|---|
| Mobile Crane | 1 | Continuous |
| Flat Bed Truck | 1 | Continuous |

**OPERATION #4 = BACKFILL & REMOVE SHORING**

| | | |
|---|---|---|
| Excavator/Compactor | 1 | Continuous |
| Front End Loader | 1 | Continuous |

**Total # Days: 126**

| ITEM | QTY | DURATION | RATE | UNIT | # DAYS | COST | SOURCE |
|---|---|---|---|---|---|---|---|
| Excavator/Compactor | 2 | Continuous | $ 1,195 | Day | 126 | $ 300,904 | Vendor |
| Excavator Attachments | 2 | Continuous | 546 | Day | 126 | 137,484 | Vendor |
| Shoring | 1 | Continuous | 300,000 | Lot | 126 | 300,000 | Eng Est |
| Support Rails | 8 | Continuous | 7,799 | Ea | 126 | 62,390 | Vendor |
| Front End Loader | 2 | Continuous | 343 | Day | 126 | 86,368 | Vendor |
| Flat Bed Truck (W/Crane) | 3 | Continuous | 200 | Day | 126 | 75,541 | Vendor |
| SCU/PCU * | 1 | Continuous | 6,349 | Day | 126 | 799,347 | Vendor |
| Crane | 2 | 4 Days | 1,000 | Day | 4 | 8,000 | Vendor |
| Mobile Crane | 2 | Continuous | 533 | Day | 126 | 134,211 | Vendor |
| Diesel Generator | 2 | Continuous | 117 | Day | 126 | 29,461 | Vendor |
| Personnel Vehicles | 3 | Continuous | 55 | Day | 126 | 20,774 | Vendor |
| Maintenance Truck | 1 | Continuous | 55 | Day | 126 | 6,925 | Vendor |
| Fuel Truck | 1 | Continuous | 75 | Day | 126 | 9,443 | Vendor |
| | | | | | **Total** | $ 1,970,846 | |

* SCU/PCU is expected to be used at a site for multiple trenches. This figure represents 10 ea 1000 foot trenches with maintenace costs in between trenches.

# COST ANALYSIS (15 ksi)

| | 100% Efficient | 75% Efficient | Source |
|---|---|---|---|
| ***Subsurface Containment Barrier (SCB)*** | | | |
| Mobilization | $ 100,000 | $ 100,000 | Eng Est |
| Labor | 1,204,397 | 1,605,863 | See Detail |
| Materials | 1,711,099 | 1,711,099 | See Detail |
| Equipment | 2,319,269 | 3,092,358 | See Detail |
| Demobilization | 100,000 | 100,000 | Eng Est |
| Contingency @10% | 543,476 | 660,932 | Industry Std |
| Home Office @ 3% | 176,347 | 215,107.57 | Industry Std |
| SG&A @ 15% | 727,529 | 866,924.47 | Industry Std |
| Profit @10% | 386,662 | 493,532.24 | Industry Std |
| ***Subtotal SCB*** | $ 7,268,779 | $ 8,845,816 | |
| ***RCRA Cover*** | $ 286,200 | $ 286,200 | Vendor |
| ***Long Term Monitoring*** | $ 2,000,000 | $ 2,000,000 | Eng Est |
| | $ 9,554,979 | $ 11,132,016 | |
| **Cost in Million$** | 10 | 11.1 | |
| **Cost/Cu Yd of Waste Containment** | 392 | 456 | 24,400 cu yd |
| **Cost/Sq Ft of Placed Barrier** | 102 | 118 | 90,400 sf |

## SCS LABOR COST - 15 ksi - 100% Efficient

*Labor Hours* 986

| POSITION | QTY | FT / PT | HOURS | RATE/HR | LABOR $ | SOURCE |
|---|---|---|---|---|---|---|
| Construction Superintendent | 1 | FT | 986 | $ 51.32 | $ 50,626 | Eng Est |
| Crew Foreman | 3 | FT | 986 | $ 51.32 | 151,879 | Eng Est |
| Quality Assurance | 1 | FT | 986 | $ 49.70 | 49,028 | Eng Est |
| Safety Specialist | 1 | PT 50% | 493 | $ 49.70 | 24,514 | Eng Est |
| E/H Specialist | 1 | PT 50% | 493 | $ 35.00 | 17,263 | Eng Est |
| Project Engineer | 1 | FT | 986 | $ 47.36 | 46,720 | Eng Est |
| Administrative Assistant | 1 | FT | 986 | $ 33.69 | 33,235 | Eng Est |
| Maintenance Crew | 2 | FT | 986 | $ 39.19 | 77,320 | Eng Est |
| **OPERATION #1 = EXCAVATE TRENCHES AND INSTALL SHORING EQUIPMENT** | | | | | | |
| Operators | 3 | FT | 986 | $ 39.19 | $ 115,981 | Eng Est |
| Laborers | 4 | FT | 986 | $ 25.00 | 98,648 | Eng Est |
| Survey Crew | 2 | FT | 986 | $ 35.00 | 69,054 | Eng Est |
| **OPERATION #2 = SLOT CONSTRUCTION** | | | | | | |
| Operators | 3 | FT | 986 | $ 39.19 | $ 115,981 | Eng Est |
| Temporary Operators | 2 | PT (4 days) | 32 | $ 39.19 | 2,508 | Eng Est |
| Laborers | 2 | FT | 986 | $ 25.00 | 49,324 | Eng Est |
| **OPERATION #3 = VERTICAL BARRIER** | | | | | | |
| Operators | 2 | FT | 986 | $ 39.19 | $ 77,320 | Eng Est |
| Inspectors | 1 | FT | 986 | $ 49.70 | 49,028 | Eng Est |
| Laborers | 2 | FT | 986 | $ 25.00 | 49,324 | Eng Est |
| **OPERATION #4 = BACKFILL/COMPACT AND REMOVE** | | | | | | |
| Operator | 2 | FT | 986 | $ 39.19 | $ 77,320 | Eng Est |
| Laborers | 2 | PT | 986 | $ 25.00 | 49,324 | Eng Est |
| *TOTAL # PERSONNEL:* | 36 | | | **TOTAL** | $ 1,204,397 | |



RAHCO International

## SCS MATERIAL COST - 15 ksi - 100% Efficient

| | QTY | UNIT | UNIT $ | TOTAL | SOURCE |
|---|---|---|---|---|---|
| **Barrier Items** | | | | | |
| Cement Blocks | 5,787 | Ea | $ 100 | $ 578,700 | Vendor |
| Poly Rolls | 132 | Roll | 540 | 71,280 | Vendor |
| Horizontal Vertical Joint | 63 | Roll | 357 | 22,468 | Vendor |
| Vertical Joint Material | 47 | Roll | 76.58 | 3,602 | Vendor |
| Vertical Barrier Poly Panels 16' X 29' | 133 | Ea | 1,400 | 186,200 | Vendor |
| Vertical Barrier Frames (Steel) | 133 | Ea | 4,500 | 598,500 | Eng Est |
| Bentonite | 307 | Ton | 164 | 50,348 | Vendor |
| | | | | | |
| **Miscellaneous Construction Items** | | | | | |
| Temporary Utilities | | | | | |
| Operating Supplies | | | | | |
| Weather Protection | | | | | |
| Personal Protection Equipment | | | | | |
| Decontamination Equipment/Supplies | | | | | |
| Material Handling/Storage | | | | | |
| Field Sampling/Test/Monitor Equipment | | | | | |
| Borrow Materials | | | | | |
| Soil Stabilization | | | | | |
| Erosion Control | | | | | |
| Fence & Gates | | | | | |
| Landscaping | | | | | |
| Pumps | | | | | |
| **Total Miscellaneous Construction Items** | | | | 200,000 | Eng Est |
| | | | **Total** | **$ 1,711,099** | |

# SCS EQUIPMENT COST - 15 ksi - 100% Efficient

**OPERATION #1 = EXCAVATE TRENCHES AND INSTALL SHORING EQUIPMENT**

| | | |
|---|---|---|
| Excavator | 1 | Continuous |
| Front End Loader | 1 | Continuous |
| Flat Bed Truck | 1 | Continuous |

**OPERATION #2 = INSTALL HORIZONTAL BARRIER**

| | | |
|---|---|---|
| SCU/PCU | 1 | Continuous |
| Cranes | 2 | 4 Days |
| Mobile Crane | 1 | Continuous |
| Flat Bed Truck | 1 | Continuous |
| Diesel Generator | 2 | Continuous |

**Total # Days: 153**

**OPERATION #3 = INSTALL VERTICAL BARRIER**

| | | |
|---|---|---|
| Mobile Crane | 1 | Continuous |
| Flat Bed Truck | 1 | Continuous |

**OPERATION #4 = BACKFILL & REMOVE SHORING**

| | | |
|---|---|---|
| Excavator/Compactor | 1 | Continuous |
| Front End Loader | 1 | Continuous |

| ITEM | QTY | DURATION | RATE | UNIT | # DAYS | COST | SOURCE |
|---|---|---|---|---|---|---|---|
| Excavator/Compactor | 2 | Continuous | $ 1,195 | Day | 153 | $ 366,411 | Vendor |
| Excavator Attachments | 2 | Continuous | 546 | Day | 153 | 167,415 | Vendor |
| Shoring | 1 | Continuous | 300,000 | Lot | 153 | 300,000 | Eng Est |
| Support Rails | 8 | Continuous | 7,799 | Ea | 153 | 62,390 | Vendor |
| Front End Loader | 2 | Continuous | 343 | Day | 153 | 105,171 | Vendor |
| Flat Bed Truck (W/Crane) | 3 | Continuous | 200 | Day | 153 | 91,986 | Vendor |
| SCU/PCU | 1 | Continuous | 6,349 | Day | 153 | 973,366 | Vendor |
| Crane | 2 | 4 Days | 1,000 | Day | 4 | 8,000 | Vendor |
| Mobile Crane | 2 | Continuous | 533 | Day | 153 | 163,429 | Vendor |
| Diesel Generator | 2 | Continuous | 117 | Day | 153 | 35,875 | Vendor |
| Personnel Vehicles | 3 | Continuous | 55 | Day | 153 | 25,296 | Vendor |
| Maintenance Truck | 1 | Continuous | 55 | Day | 153 | 8,432 | Vendor |
| Fuel Truck | 1 | Continuous | 75 | Day | 153 | 11,498 | Vendor |
| | | | | | **Total** | $ 2,319,269 | |

# COST ANALYSIS (30 ksi)

| | 100% Efficient | 75% Efficient | Source |
|---|---|---|---|
| ***Subsurface Containment Barrier (SCB)*** | | | |
| Mobilization | $ 100,000 | $ 100,000 | Eng Est |
| Labor | 1,984,615 | 2,646,153 | See Detail |
| Materials | 1,707,859 | 1,707,859 | See Detail |
| Equipment | 3,360,497 | 4,480,663 | See Detail |
| Demobilization | 100,000 | 100,000 | Eng Est |
| Contingency @10% | 725,297 | 903,468 | Industry Std |
| Home Office @ 3% | 236,348 | 295,144 | Industry Std |
| SG&A @ 15% | 919,500 | 1,123,070 | Industry Std |
| Profit @10% | 534,164 | 690,235 | Industry Std |
| ***Subtotal SCB*** | $ 9,668,280 | $ 12,046,591 | |
| ***RCRA Cover*** | $ 286,200 | $ 286,200 | Vendor |
| ***Long Term Monitoring*** | $ 2,000,000 | $ 2,000,000 | Eng Est |
| | $ 11,954,480 | $ 14,332,791 | |
| **Cost in Million$** | 12 | 14.3 | |
| **Cost/Cu Yd of Waste Containment** | 490 | 587 | 24,400 cu yd |
| **Cost/Sq Ft of Placed Barrier** | 127 | 152 | 90,400 sf |



RAHCO International

## SCS LABOR COST - 30 ksi - 100% Efficient

*Labor Hours* 2177

| POSITION | QTY | FT / PT | HOURS | RATE/HR | LABOR $ | SOURCE |
|---|---|---|---|---|---|---|
| Construction Superintendent | 1 | FT | 2177 | $ 51.32 | $ 111,748 | Eng Est |
| Crew Foreman | 2 | FT | 2177 | 51.32 | 223,495 | Eng Est |
| Quality Assurance | 1 | FT | 2177 | 49.70 | 108,220 | Eng Est |
| Safety Specialist | 1 | PT 50% | 1089 | 49.70 | 54,110 | Eng Est |
| E/H Specialist | 1 | PT 50% | 1089 | 35.00 | 38,106 | Eng Est |
| Project Engineer | 1 | FT | 2177 | 47.36 | 103,125 | Eng Est |
| Administrative Assistant | 1 | FT | 2177 | 33.69 | 73,359 | Eng Est |
| Maintenance Crew | 2 | FT | 2177 | 39.19 | 170,670 | Eng Est |
| **OPERATION #1 = EXCAVATE TRENCHES AND INSTALL SHORING EQUIPMENT** | | | | | | |
| Operators | 3 | FT | 2177 | $ 39.19 | $ 256,005 | Eng Est |
| Laborers | 4 | FT | 2177 | 25.00 | 217,747 | Eng Est |
| Survey Crew | 2 | FT | 2177 | 35.00 | 152,423 | Eng Est |
| **OPERATION #2 = SLOT CONSTRUCTION** | | | | | | |
| Operators | 3 | FT | 2177 | $ 39.19 | $ 256,005 | Eng Est |
| Temporary Operators | 2 | PT (4 days) | 32 | 39.19 | 2,508 | Eng Est |
| Laborers | 2 | FT | 2177 | 25.00 | 108,873 | Eng Est |
| **OPERATION #3 = VERTICAL BARRIER** | | | | | | |
| Operators | 0 | FT | 2177 | $ 39.19 | $ - | Eng Est |
| Inspectors | 1 | FT | 2177 | 49.70 | 108,220 | Eng Est |
| | | | | | | Eng Est |
| **OPERATION #4 = BACKFILL/COMPACT AND REMOVE** | | | | | | |
| Operator | 0 | FT | 2177 | $ 39.19 | $ - | Eng Est |
| Laborers | 0 | PT | 2177 | 25.00 | - | Eng Est |
| ***TOTAL # PERSONNEL*** | 27 | | | **TOTAL** | **$ 1,984,615** | |



RAHCO International

## SCS MATERIAL COST- 30 ksi - 100% Efficient

| | QTY | UNIT | UNIT $ | TOTAL | SOURCE |
|---|---|---|---|---|---|
| **Barrier Items** | | | | | |
| Cement Blocks | 5,787 | Ea | $ 100 | $ 578,700 | Vendor |
| Poly Rolls | 126 | Rolls | 540 | 68,040 | Vendor |
| Horizontal Vertical Joint | 63 | Roll | 357 | 22,468 | Vendor |
| Vertical Joint | 47 | Roll | 76.58 | 3,602 | Vendor |
| Vertical Barrier Poly Panels 16' X 29' | 133 | Ea | 1,400 | 186,200 | Vendor |
| Vertical Barrier Frames (Steel) | 133 | Ea | 4,500 | 598,500 | Eng Est |
| Bentonite | 307 | Ton | 164 | 50,348 | Vendor |
| **Miscellaneous Construction Items** | | | | | |
| Temporary Utilities | | | | | |
| Operating Supplies | | | | | |
| Weather Protection | | | | | |
| Personal Protection Equipment | | | | | |
| Decontamination Equipment/Supplies | | | | | |
| Material Handling/Storage | | | | | |
| Field Sampling/Test/Monitor Equipment | | | | | |
| Borrow Materials | | | | | |
| Soil Stabilization | | | | | |
| Erosion Control | | | | | |
| Fence & Gates | | | | | |
| Landscaping | | | | | |
| Pumps | | | | | |
| **Total Miscellaneous Construction Items** | | | | 200,000 | Eng Est |
| | | | **Total** | $ 1,707,859 | |



RAHCO International

# SCS EQUIPMENT COST - 30 ksi - 100% Efficient

**OPERATION #1 = EXCAVATE TRENCHES AND INSTALL SHORING EQUIPMENT**

| | | |
|---|---|---|
| Excavator | 1 | Continuous |
| Front End Loader | 1 | Continuous |
| Flat Bed Truck | 1 | Continuous |

**OPERATION #2 = INSTALL HORIZONTAL BARRIER**

| | | |
|---|---|---|
| SCU/PCU | 1 | Continuous |
| Cranes | 2 | 4 Days |
| Mobile Crane | 1 | Continuous |
| Flat Bed Truck | 1 | Continuous |
| Diesel Generator | 2 | Continuous |

**Construction Days:** 302

**OPERATION #3 = INSTALL VERTICAL BARRIER**

| | | |
|---|---|---|
| Mobile Crane | 0 | Continuous |
| Flat Bed Truck | 0 | See Operation #1 |

**OPERATION #4 = BACKFILL & REMOVE SHORING**

| | | |
|---|---|---|
| Excavator/Compactor | 0 | See Operation #1 |
| Front End Loader | 0 | See Operation #1 |

| ITEM | QTY | DURATION | RATE | UNIT | # DAYS | COST | SOURCE |
|---|---|---|---|---|---|---|---|
| Excavator/Compactor | 1 | Continuous | $ 1,195 | Day | 302 | $ 361,109 | Vendor |
| Excavator Attachments | 1 | Continuous | 546 | Day | 302 | 164,992 | Vendor |
| Shoring | 1 | Continuous | 300,000 | Lot | 302 | 300,000 | Eng Est |
| Support Rails | 8 | Continuous | 7,799 | Ea | 302 | 62,390 | Vendor |
| Front End Loader | 1 | Continuous | 343 | Day | 302 | 103,649 | Vendor |
| Flat Bed Truck (W/Crane) | 2 | Continuous | 200 | Day | 302 | 120,873 | Vendor |
| SCU/PCU | 1 | Continuous | 6,349 | Day | 302 | 1,918,564 | Vendor |
| Crane | 2 | 4 Days | 1,000 | Day | 4 | 8,000 | Vendor |
| Mobile Crane | 1 | Continuous | 533 | Day | 302 | 161,064 | Vendor |
| Diesel Generator | 2 | Continuous | 117 | Day | 302 | 70,711 | Vendor |
| Personnel Vehicles | 3 | Continuous | 55 | Day | 302 | 49,860 | Vendor |
| Maintenance Truck | 1 | Continuous | 55 | Day | 302 | 16,620 | Vendor |
| Fuel Truck | 1 | Continuous | 75 | Day | 302 | 22,664 | Vendor |
| | | | | | **Total** | $ 3,360,497 | |