Missouri University of Science and Technology
Scholars' Mine

International Conference on Case Histories in Geotechnical Engineering

(1993) - Third International Conference on Case Histories in Geotechnical Engineering

02 Jun 1993, 2:30 pm - 5:00 pm

SMW Wall for Seepage Control in Levee Reconstruction

D. S. Yang
S.M.W. SEIKO, Inc., Hayward, California

U. Luscher
Woodward-Clyde Consultants, Oakland, California

I. Kimoto
Kajima Engineering & Construction, Inc., Pasadena, California

S. Takeshima
S.M.W. SEIKO, Inc., Hayward, California

Follow this and additional works at: https://scholarsmine.mst.edu/icchge

Part of the Geotechnical Engineering Commons

Recommended Citation

Yang, D. S.; Luscher, U.; Kimoto, I.; and Takeshima, S., "SMW Wall for Seepage Control in Levee Reconstruction" (1993). *International Conference on Case Histories in Geotechnical Engineering*. 28.
https://scholarsmine.mst.edu/icchge/3icchge/3icchge-session02/28

This Article - Conference proceedings is brought to you for free and open access by Scholars' Mine. It has been accepted for inclusion in International Conference on Case Histories in Geotechnical Engineering by an authorized administrator of Scholars' Mine. This work is protected by U. S. Copyright Law. Unauthorized use including reproduction for redistribution requires the permission of the copyright holder. For more information, please contact scholarsmine@mst.edu.

Proceedings: Third International Conference on Case Histories in Geotechnical Engineering, St. Louis, Missouri, June 1-4, 1993, Paper No. 2.41

SMW Wall for Seepage Control in Levee Reconstruction

D. S. Yang
Senior Manager, Engineering, S.M.W. SEIKO, INC., Hayward, California

I. Kimoto
Project Manager, Kajima Engineering & Construction, Inc., Pasadena, California

U. Luscher
Vice President, Woodward-Clyde Consultants, Oakland, California

S. Takeshima
Vice President, S.M.W. SEIKO, INC., Hayward, California

SYNOPSIS: An SMW wall was installed as a cutoff wall for seepage control during high floods in a narrow levee constructed in the early 1900's using sandy soils. After part of the wall was installed, difficulties were encountered in evaluating the permeability of the as-built cutoff wall according to the project specifications. Methods used to evaluate the permeability of the cutoff wall included laboratory tests on bulk samples and core samples and in-situ permeability tests. Significant differences in test results were caused by various sample preparation and handling procedures, sampling disturbance, and different testing methods. The difficulties were resolved by performing a trial mix study and installing a full scale test section that resulted in changed installation, sampling, and testing procedures.

BACKGROUND

In September, 1990, the US Army Corps of Engineers (COE), Sacramento District, started the Phase I installation work for an eleven-mile long slurry cutoff wall in the flood control levee on the east bank of the Sacramento River south of downtown Sacramento, California (Fig. 1). The levee is mainly composed of loose to medium dense clean sands of uniform size interbedded with firm to stiff silts and clays (Fig. 2). The levee is underlain by the original ground which consists of layers of silts, clays and sands. Geotechnical investigations after the high flood of the Sacramento River in 1985 and 1986 concluded that a cutoff wall would be required to control seepage and to prevent sudden levee failure due to piping during flood conditions.

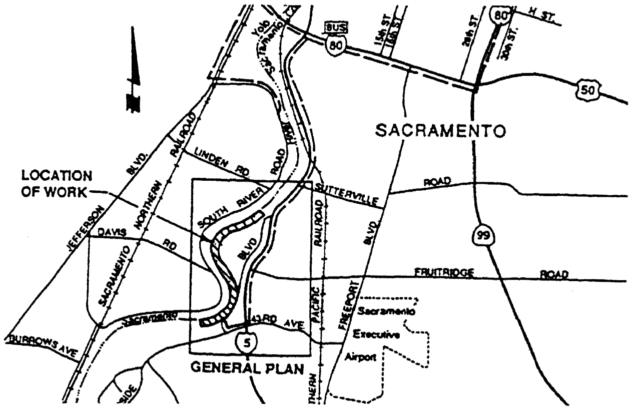


Fig. 1 Site Plan

Significant questions regarding the constructability, environmental impacts and costs of various methods for installing the cutoff wall from the top of a narrow levee arose in the design phase of the work. The Corps of Engineers therefore performed a cutoff wall installation trial of four methods to collect relevant information for use in the cutoff wall design (Foott, 1990). The four methods included: 1) conventional backhoe trench method using cement-bentonite slurry; 2) vertical in-situ soil mixing method using multiple augers to mix cement-bentonite or other slurries with natural soils to form a low permeability material; 3) trencher method using cement-bentonite slurry as backfill, and; 4) vibration beam method in which a wide flange beam section is vibrated into the ground and slurry is injected as the beam is withdrawn (Foott, 1990). The primary levee constraints on the installation method related to the narrow crest of the levees, relatively steep side slopes, limited accesses to the levee crest, and the existence of housing adjacent to the levee. The major installation considerations were the environmental impact, the stability of the levee during construction, transportation of excavated soil and slurry along the levee, production rate, cost, and the attainment of the desired cutoff strength and impermeability.

The trial installation was completed in December, 1989, and the instrumentation, testing, and reporting were completed in January, 1990. Potential construction difficulties of some installation techniques due to levee constraints were addressed. This information was provided to bidders later for use in planning and cost estimating. In developing the cutoff wall specifications, the COE's construction consultant recommended the use of cutoff wall depth and "effective permeability" to specify the cutoff wall requirements. The effective permeability of a wall is a function of both its thickness and its permeability. By specifying an effective permeability, it becomes possible for alternate installation methods of different wall thickness to compete by selecting slurries of appropriate permeability. The consultant also recommended the use of performance specifications to allow for specialty contractors to develop the most cost-effective means of installation to meet both construction requirements on the levee and performance requirements on engineering properties of the cutoff wall.

The specifications for the trial installation required an unconfined compressive strength of 15 to 150 psi and a coefficient of permeability of $1x10^{-6}$ cm/sec or less for the 12-inch wide cutoff walls. For the vibrating beam method, the requirement was $5x10^{-7}$ cm/sec for a 6-inch wide cutoff wall. The majority of the laboratory strength test results met the specified strength requirements. However, the majority of the permeability test results from molded bulk samples, hardened core samples, or packer tests varied between 10^{-5} to 10^{-6} cm/sec.

In 1990, COE decided to start the first two miles of levee modification work (Phase I) as shown on Fig. 1. The bid documents imposed operational constraints, but allowed for various installation techniques to compete. The requirements for the slurry wall were as follows:

Third International Conference on Case Histories in Geotechnical Engineering
Missouri University of Science and Technology
http://ICCHGE1984-2013.mst.edu

Width: 12 inches (minimum)
Depth: Varies (23 to 30 feet)
Permeability: 1×10^{-6} cm/sec (maximum)
Strength (28-day): 15 psi (minimum); 200 psi (maximum)
Upstream Limit: Station 121+50
Downstream Limit: Station 228+20

The specifications required that two bulk samples be taken for every eight hour shift of work at 10 feet and 20 feet depths before the cutoff wall material set up. It also required that undisturbed samples (core samples) be obtained from each of the first 100, 200, and 300 feet of hardened cutoff wall installed and every 1,000 feet thereafter.

Bulk samples are molded test specimens using freshly mixed soil-cement retrieved from the cutoff wall. The specimens are cured in a moist environment for hardening. Core samples are test specimens retrieved from the hardened cutoff wall by conventional rock core samplers or thin-walled samplers.

SMW WORK

In September 1990, the soil mix wall (SMW) technique was accepted for the installation of the cutoff wall from the levee crest. The SMW technique is a soil improvement technology for modifying in-situ soils to construct cutoff walls, excavation support walls, grid walls for liquefaction stabilization, and soilcrete columns for support of vertical foundation loads or shear forces. The technology consists of mixing soils in-situ with a slurry consisting of cement, bentonite, or other additives using multiple shaft augers to form column, panel, wall or lattice forms. The soil mixing is carried out in-situ inside the bore holes made by 22 to 34 inch diameter multiple shaft augers. The slurry is premixed in an automatic mixing plant and supplied from the tips of the hollow-stemmed augers for slurry mixing. The engineering properties of the walls produced vary from low strength and low permeable soil-bentonite slurry walls to high strength and low permeable soil-cement walls.

At the Sacramento Levee, a three-auger machine was used for the majority of the cutoff wall installation and a five-auger machine was used in 1990 for a small section of the levee where the width of the levee crest was more than 25 feet. The multiple auger machine with 22-inch diameter overlapping augers produces column panels with a minimum width of 12 inches and an average width of 20 inches. Cross sections of the SMW cutoff wall and the levee are shown in Fig. 3.

The installation equipment consists of a SMW machine for soil mixing, an automatic slurry plant for slurry production and delivery, and a backhoe for overflow control during cutoff wall installation. A sketch of the equipment on top of the levee is shown in Fig. 4.

EVALUATION OF CUTOFF WALL

The initial installation of the SMW cutoff wall started in September, 1990 after the approval of a laboratory trial mix with a seven-day strength test result of 40 psi and a coefficient of permeability of 8.8×10^{-7} cm/sec. The cement and bentonite contents of the mix were increased in October due to marginal strength test results and permeability test results higher than the maximum permeability requirement. Further testing on both bulk samples and core samples indicated satisfactory strength, however, the permeabilities of the soil-cement samples continued to be higher than 1×10^{-6} cm/sec. The results of permeability tests on soil-cement samples from the cutoff wall between Station 228+20 and Station 156+30 are summarized in Fig. 5. Due to non-passing permeability test results, construction was suspended in November and December, 1990 for development of remedial solutions.

At this stage, it became clear that the bulk samples did not receive adequate care during sampling and transportation resulting in inferior bulk samples. Disturbance of core samples during sampling and transportation also were believed to have contributed to the higher permeability test results. It was also considered that the mix designs used did not provide a sufficient safety margin to compensate for sample disturbances. Consequently the following actions were taken:

1. Development of quality control measures for bulk sampling and permeability testing of soil-cement.
2. Performance of in-situ permeability testing of the existing wall between Stations 228+20 and 156+30.
3. Use of a more conservative mix design for installation of the cutoff wall in the new area from Station 156+30 toward Station 121+50. Construction was resumed based on the passing permeability test results on samples obtained in a field trial mix.

The in-situ permeability test was performed to evaluate the in-situ permeability of the as-built cutoff wall. The test plan incorporated input from both COE and the contractor. The set up of in-situ permeability testing is shown on Fig. 6. The test holes were drilled with a 3-wing drag bit using clean water as drilling fluid. After drilling, the test holes were flushed with clean water until cuttings and fines were removed. A close up view of the inside surface of a bore hole is shown on Fig. 7. The rough surface was caused by scraping of gravels in the hardened soil-cement mixture during the drilling of the bore hole. After drilling, the test holes were filled with clean water for saturation of the soil-cement column. Water was constantly added to the test hole. Water drawdown data were recorded and plotted to make sure that the water flow inside the soil-cement column had reached a steady state condition before performing packer tests. The

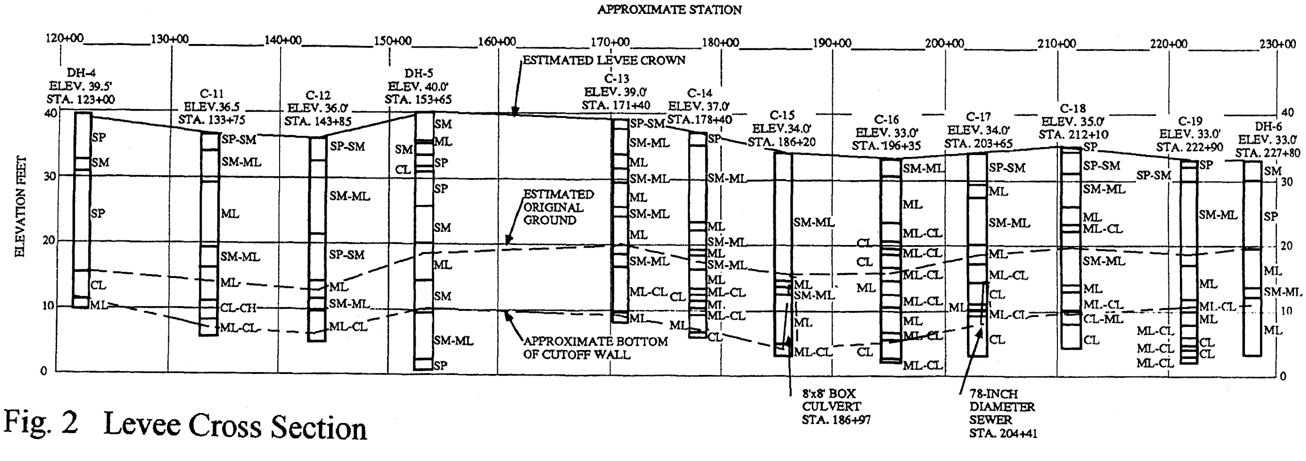


Fig. 2 Levee Cross Section

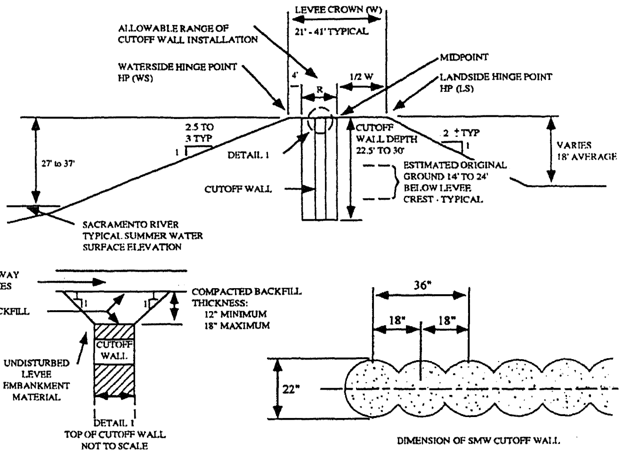


Fig. 3 Cross Sections of Cutoff Wall & Levee

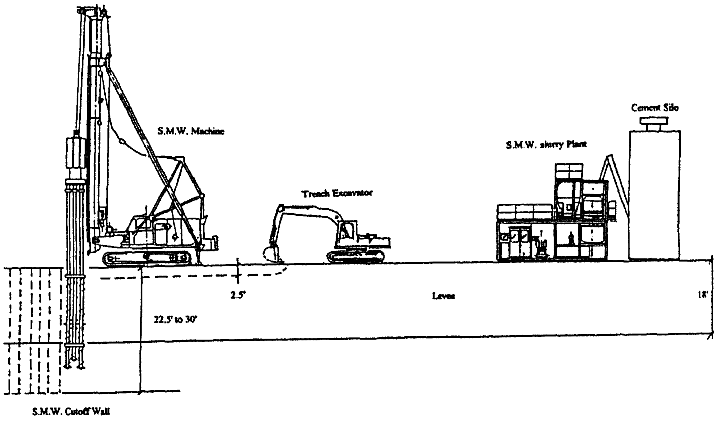


Fig. 4 SMW Equipment Positioning

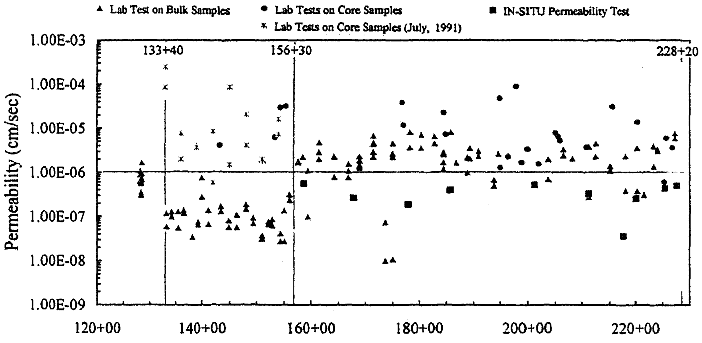


Fig. 5 Permeability Test Results

depth of bore holes varied from 10 to 24 feet and the packer was located at an elevation such that the lower 4-foot section of the bore hole and soil-cement column were tested for in-situ permeability. The testing depth was selected to provide permeability characteristics of the cutoff wall at depths varying from 6 to 24 feet where the performance of the cutoff wall would be most critical during a high flood. A total of ten packer tests were performed with the pressure head in the test zone maintained at levels higher than the design flood. The test data were analyzed using flow nets shown in Fig. 8. The effective permeabilities of the existing cutoff wall based on Packer Tests are presented in Fig. 9 and Fig 5.

Difficulties in performing packer tests inside the soil-cement column included: 1) drilling the bore hole inside the soil-cement column; 2) minimizing the erosion of the bore hole during drilling and flushing; and 3) providing a good seal between the packer and the rough inside surface of the boring as shown in Fig. 7. Items 1 and 2 were resolved by selection of drilling equipment and a skillful operator and quality control during the operation. Sealing was provided through the selection of a more flexible packer and the use of silicon grease over the surface of the packer to minimize leaks along the interface between the packer and the wall of the test hole. Leaks during the packer test would result in a higher permeability reading than the true value under the testing conditions in use. Therefore bore hole permeability tests were performed to obtain supplemental data. The results of these comparative tests are presented in Fig. 9. The comparison of these two data sets indicates that the packers provided effective seals during the in-situ packer testing.

While the in-situ permeability testing on the existing cutoff wall between Stations 228+20 and 156+30 was going on, installation of the cutoff wall from Station 156+30 continued and stopped at Station 133+40 on February 20, 1991. The laboratory permeability tests results of both bulk samples and core samples are presented in Fig. 5. Although the permeability results of the bulk samples were well below $1x10^{-6}$ cm/sec, the permeability of four core samples in this wall section were higher than $1x10^{-6}$ cm/sec.

To evaluate the discrepancy of permeability testing results between bulk samples and core samples obtained between Station 156+30 and 133+40, a core sampling and testing program was performed in June and July of 1991. Core samples were obtained in sixteen locations using a Pitcher Sampler. The sixteen permeability test results are also shown in Fig. 5 and additionally as ranges in Fig. 11. The coefficient of permeability of the core samples were approximately one to two orders higher than those of bulk samples and spread widely between $5.9x10^{-7}$ to $2.5x10^{-4}$ cm/sec. Based on the observations during previous core sampling and testing it was considered that sample disturbance was probably the main cause of the high permeability test results. Therefore, the core sampling and testing program was carefully observed. Items which were believed to affect the permeability test results are as follows.

1. Thin Wall Tubes:

   The cutting edges of thin wall tubes were frequently deformed, damaged or dented after sampling.

2. Soil-Cement Samples Before Testing

   - very rough and loose surface zones (Fig. 10)
   - horizontal cracks (Fig. 10)
   - a series of disc type cracking
   - vertical lines of scratches or gouges created by gravels or damaged edges of thin wall tubes

3. Soil-Cement Samples After Testing

   - loose surface zone

Third International Conference on Case Histories in Geotechnical Engineering
Missouri University of Science and Technology
http://ICCHGE1984-2013.mst.edu

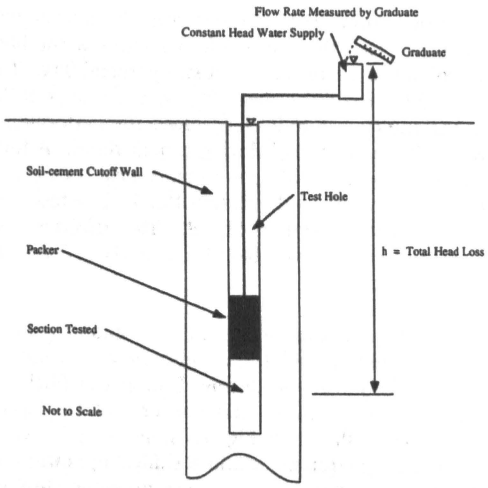


Fig. 6 In-Situ Permeability Test Setup

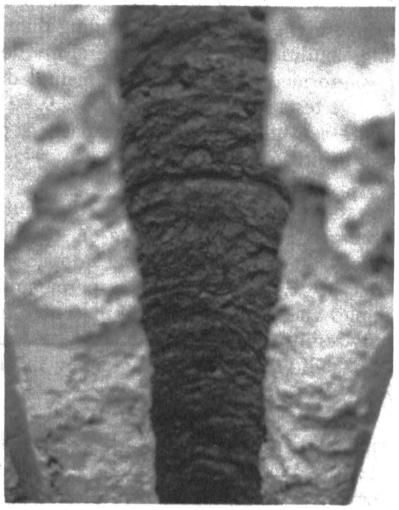
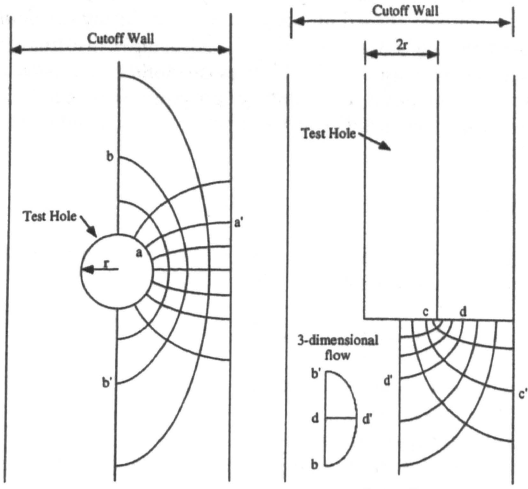


Fig. 7 Drilled Bore Hole



2 - dimensional lateral flow

Bottom Flow

Fig. 8 Flow Nets for In-Situ Permeability Tests

- vertical cracks
- cracks near surface zones

For comparison of permeability testing results obtained by using different samples and testing methods, all testing data were plotted in Fig. 5. Interpretation of the discrepancy of testing results are summarized as follows:

1. Inferior quality of bulk samples: The molded bulk samples were not handled and transported adequately. The bulk samples were retrieved immediately after wall installation and molded using 2-inch diameter plastic or brass tubes. The samples were then transported off the site in approximately one to two hours. No adequate shock cushioning was provided during transportation. The samples were frequently carried to other project sites before being placed in the moisture room for curing. From Station 156+30 to Station 133+40, the bulk sampling and handling procedures were improved in addition to the use of a more conservative mix proportion on soil-cement. These two measures resulted in the satisfactory test results shown in Fig. 5 and Fig 11.

2. Disturbed core samples: Like naturally occurring weakly cemented sand and silt, the hardened soil-cement produced in sandy and silty soils within the specified strength range of 15 to 200 psi is very sensitive to sampling disturbance. The penetration of thin wall tubes into the soil-cement wall during sampling and the extrusion of samples out of the tube in the laboratory both induce stresses significant enough to change the permeability characteristics of the soil-cement, especially in the annular zone near the sample side surfaces. The samples were in worse condition when gravel existed in the samples. The same data sets in Fig. 5 were reorganized according to mix design and are presented in Fig. 11. Due to a more conservative mix design and improved sample preparation and handling procedures, the permeability of the soil-cement bulk samples from Station 156+30 to Station 133+40 ranged from the 10^{-7} range to the high 10^{-8} range cm/sec. However, the permeability data of the core samples fell in the same range as before and showed no significant influence from the changes in the mix design. The disturbance of the core samples was so severe that the data were inadequate to represent the true performance of the in-situ cutoff wall.

3. Effective Confining Pressure for Laboratory Permeability Tests.

   For flexible wall permeability tests in triaxial type cells, the confining pressure is used to create a good contact between the membrane and the side surface of the test specimen, to prevent the migration of water between the sample-membrane interface during the permeability test. For a relatively compressible material like clayey soils and samples with smooth side surfaces, an effective confining pressure of 10 psi as specified might be sufficient. However, for relatively incompressible soil-cement samples, especially core samples which developed a rough and loose side surface during sampling, 20 to 40 psi effective confining pressure is needed to minimize migration of water between the sample-membrane interface during permeability tests.

   As shown on Fig. 12, permeability values converged at 20 psi for bulk samples with a relatively smooth surface, and higher confining pressures of 40 psi did not affect the permeability values. For bulk samples with rough surfaces, the permeability values converge at 40 psi effective confining pressure. Similar observations were reported by Ito and Otsuka (1981). It was concluded that, the rougher sample surface is, the

Third International Conference on Case Histories in Geotechnical Engineering
Missouri University of Science and Technology
http://ICCHGE1984-2013.mst.edu

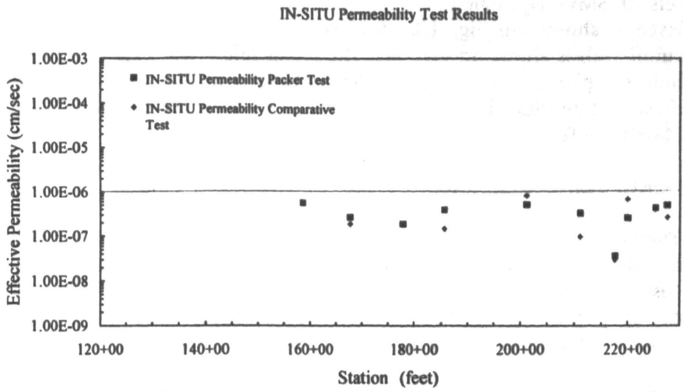


Fig. 9 In-Situ Permeability Test Results

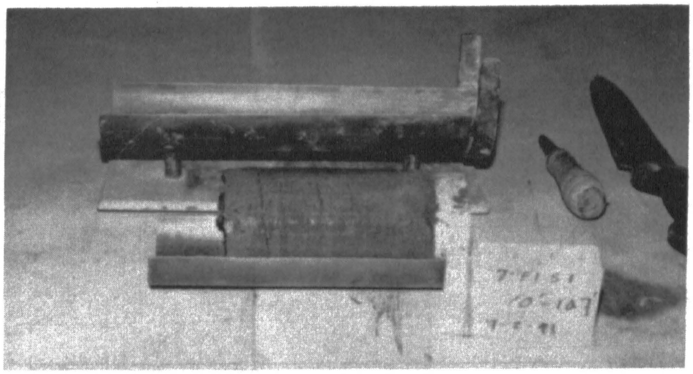


Fig. 10 Horizontal Cracks in Core Sample

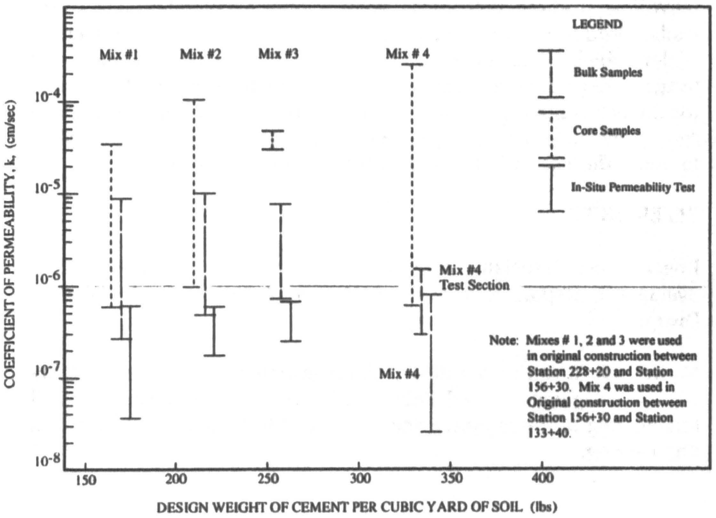


Fig. 11 Permeability Versus Mix Design

Symbol	Mix #	Station	Depth (ft)	Curing Age (days)	Type of Mold	Side Surface	Initial Void Ratio (e)	Void Ratio e1 σ = 10 psi	Void Ratio e2 σ = 20 psi	Void Ratio e3 σ = 40 psi
○	3	159+40	20	7	metal	relatively rough	1.610	1.598	1.593	–
△	3	161+40	20	7	metal	relatively rough	1.299	1.283	1.264	1.220
●	4	128+23	10	7	plastic	relatively smooth	1.217	1.213	1.208	1.119
×	4	128+23	20	7	plastic	relatively smooth	1.341	1.335	1.332	1.325
▲	4	128+36	10	7	plastic	relatively smooth	1.341	1.338	1.330	1.321
⋇	4	128+50	10	14	plastic	relatively smooth	1.552	1.242	1.540	1.531
□	4	128+50	20	7	plastic	relatively smooth	1.341	1.334	1.327	–

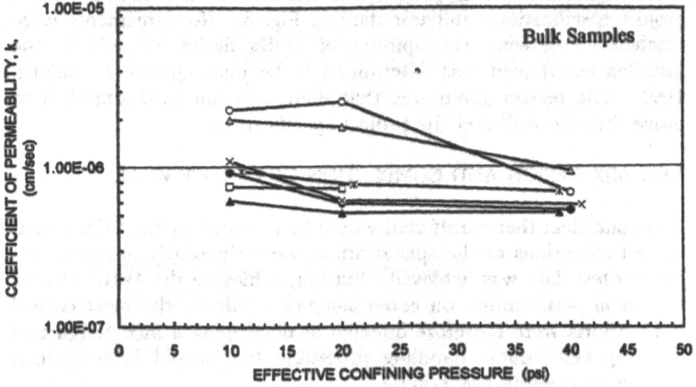


Fig. 12 Effect of Containing Pressure on Permeability

Fig. 13 View of SMW Work on Levee

Fig. 14 Exposed SMW Columns

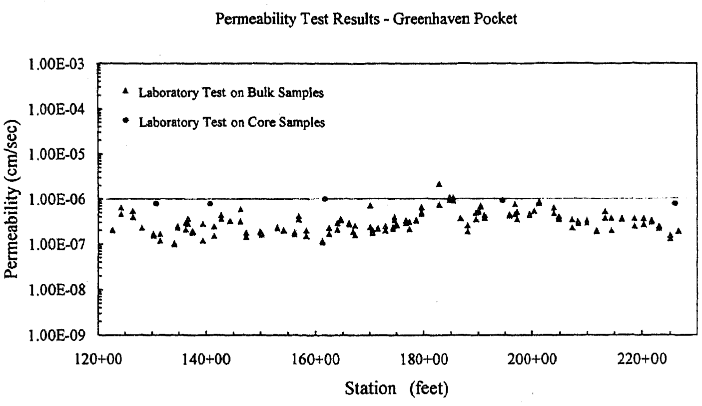


Fig. 15 Accepted Permeability Results

higher effective confining pressure is required to prevent flow between the sample and the membrane.

Parties involved in this project had different interpretations of the project specifications and test data in Fig. 5. No agreements were reached. Following the opinion of COE's design consultant, the installed cutoff wall was determined to be unacceptable in August, 1991. The reason given was that there was not sufficient data to prove that the wall met the project specifications.

NEW MIX DESIGN AND COMPLETION OF CUTOFF WALL

It became clear that cutoff wall would be accepted by the COE only if all test conditions of the specifications were rigorously followed and passing test data was achieved. Further, achieving the 1×10^{-6} cm/sec maximum permeability on cored samples would be the most critical test. Efforts were therefore directed at developing a mix design and a coring and sample handling procedure that would have optimal chances of meeting this criteria.

According to the project documents, conventional rock core samplers or thin-walled samplers were considered to be acceptable for sampling the hardened cutoff wall material. The rock core technique was considered for taking core samples but was ruled out since the gravelly soil-cement with unconfined compressive strength between 15 and 200 psi would be severely disturbed during core sampling. The efforts were, therefore, concentrated on developing a type of soil-cement that would satisfy both strength and permeability requirements in bulk samples and could also be core sampled after hardening without significant disturbance so that satisfactory permeability test results on core samples would be obtained.

A laboratory trial mix program was carried out in October, 1991 to study more than twenty trial mixes using various materials including cement, fly ashes, bentonite, and natural clays. Following the laboratory study, a full scale test program was performed in December, 1991 on the levee to study the sampling characteristics of four mix designs selected from the laboratory trial mix program. The bulk samples of these four trial mixes all provided soil-cement with the strength and permeability required by the project specifications. Even though installed by the same equipment and soil mixing procedures, the four types of soil-cement wall showed different sampling characteristics when sampled with thin wall tubes using a Pitcher Sampler. The mix design with the best passing rate for permeability tests on core samples was selected for full production.

The full production of cutoff wall reconstruction commenced in January, 1992 and was completed at the end of February using two sets of SMW equipment. A view of cutoff wall installation on the levee is shown on Fig. 13. A close up view of the exposed SMW cutoff wall is shown in Fig. 14. The permeability test data from both bulk samples and core samples are presented in Fig. 15. Based on these test results, the SMW cutoff wall was accepted by the COE in March, 1992.

CONCLUDING REMARKS

The evaluation of the in-situ performance of a cutoff wall is complex and the consequence of the test results not being accepted can be very costly. It is crucial that the project team has a clear understanding of the properties of various cutoff wall materials in order to produce reasonable criteria for acceptance of the cutoff wall.

For soil-cement cutoff walls like the SMW wall, core sampling is difficult and probably misleading due to sampling disturbance if test results are not used with caution. Further research and development on undisturbed sampling techniques are needed to obtain representative low strength soil-cement samples from deep soil-cement cutoff walls. Until a reliable and cost effective undisturbed sampling method is developed for hardened soil-cement, bulk samples obtained and tested under stringent quality control should be used in routine tests for quality control purposes. Correlations between bulk sample test results and in-situ performance of cutoff walls should be established to allow the use of bulk samples for routine quality control.

REFERENCES

Roger Foott Associates (1990), "Levee Seepage Cutoff Wall Test Evaluation, Report to U.S. Army, Corps of Engineers, Sacramento District.

M. Ito and Y. Ohtsuka (1981), "Experimental Study on Permeability Tests for Cement Treated Soils", 16th Research Conference on Soil Engineering of the Japanese Society of Soil Mechanics and Foundation Engineering.