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PERFORMANCE EVALUATION OF CEMENT-BENTONITE SLURRY WALL MIX DESIGN

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ABSTRACT

A cement-bentonite (CB) slurry cut-off wall is a variation of the slurry wall process that is used to create an underground barrier to stop the lateral flow of groundwater and other fluids. Because of the relative simplicity of the construction process, the CB technique might be chosen over other types of slurry cut-off walls in situations with poor access or poor subsoil conditions. The characteristics and engineering properties of CB slurry are generally not well understood and are poorly documented. This paper documents a case study where enough testing was done to draw significant conclusions.

The principal findings of this study were the moderate increase in strength and decrease in permeability which results when fly ash is added to cement-bentonite. In addition, sampling and testing techniques were found to

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have little effect on cement-bentonite permeability. Due to the complexity of the cement-bentonite sealing mechanism, only long term permeability tests were found to be appropriate for evaluating cement-bentonite permeability.

INTRODUCTION

Slurry cut-off walls have been in use in the USA for about forty years to control the lateral migration of groundwater and other fluids. The slurry wall system uses bentonite slurry (similar to drilling mud) to facilitate the excavation of a vertical-walled slot or trench into the ground. This slot is subsequently backfilled with various materials, depending on the application. The most popular type of cut-off wall is the soil-bentonite (SB) variety where the trench is backfilled with a blended mass of soil and bentonite. At least 90% of the installations of slurry cut-off walls in the USA are SB walls. The cement-bentonite (CB) wall is a variation of the process in which cement is added to the slurry, so that, after the excavation process, the slurry sets up without a separate backfilling operation. This paper concentrates on the CB technique and particularly the permeability of various mix designs and the procedures for testing the mixes.

CEMENT-BENTONITE TECHNIQUE

The CB slurry is typically prepared in a remote plant (Fig. 1); bentonite and water are blended together and the cement added just prior to pumping the material to the trench. Trenching is done with a backhoe (Fig. 2) or other suitable equipment. After a period of about 12 hours, the CB slurry sets (Fig. 3). The result is a non-structural cut-off wall that, even when it is fully set, acts like a stiff clay and can be dug with a hand shovel.

The CB technique has some advantages that make it the technique of choice on certain sites. They are:

- The backfill mix is a controlled material whose properties may be more homogeneous and more consistent than soil bentonite.

- The technique is not dependent on the quality of soil excavated from the trench, since it is not reused. This is helpful on sites where the soil profile contains rubble, refuse or other unusable material.

- Since there is no separate backfilling operation, it is much easier to install CB through areas of tight access such as the tops of dikes, between buildings, etc.

- The panels may be joined together with previous work by simply reexcavating the end of the set-up panel. This enables a simple construction procedure on sites where, due to maintenance of traffic or other considerations, the trench must be installed in discontinuous sections.

There are several disadvantages to the CB technique, however, that have led to its limited use when compared to the SB technique:

- Due to the addition of cement to the backfill blend, the cost of CB will be more than a comparable SB project, unless one of the technical advantages listed above presents a significant economic benefit.

- Cement bentonite mixes, in most cases, yield

permeabilities in the range of 10^{-6} cm/sec, whereas soil bentonite can usually be mixed in the range of 10^{-7} - 10^{-8} cm/sec.

- Because of the high water content of the set mix (typically 100 to 300%) and the relative susceptibility of both cement and bentonite to various types of degradation by water-borne contaminates, CB walls are not always the best choice for sites that have contaminated groundwater. Leachate compatibility tests may be run to confirm this on a case by case basis.

APPLICATIONS

The CB technique was developed in Europe in the late 1960's and continues to be used there almost exclusively instead of soil-bentonite. The first American application was in 1973 for a cut-off under a dam in the southeastern US. Since that time, there have been many projects, some quite large. Perhaps the most dramatic was the work done at Braidwood Nuclear Power Station in the mid 1970's. The plant site was dewatered by a mile long,

thirty foot deep CB wall. Subsequently, the cooling lake for the plant was isolated by miles of slurry wall, up to 120 ft. deep.

Since the early projects, a better understanding of CB properties and advantages has begun to evolve, and most applications are now more appropriately engineered. There had been, for example, the notion that CB is "stronger" and more resistant to loads than SB. In fact, opposite can be true. CB is generally stronger in unconfined compression tests, but SB is usually stronger and less compressive when consolidated and tested under triaxial conditions. The result of the new understanding of CB has been a more appropriate use of the product.

Currently, the most typical applications are those where difficult access is involved (Fig. 4) and the CB represents an economic advantage over SB by eliminating the backfill mixing operation. Examples are situations where the cut-off wall passes through plant sites with buildings close by, and along the narrow tops of containment dikes. There have not been a large number of environmental applications, for the reasons stated earlier. The major exception is tank farm containments for underground spills

of petroleum products (Fig. 5). Oil and gas usually have no deleterious effect on the CB material and the tough access conditions around most tank farms make the CB method economically attractive. Sometimes it is possible to key the wall into the lowest seasonal water table and literally skim the floating product off the groundwater surface.

It is worth noting that the first Superfund project ever constructed, at Stroudsburg, PA, used a CB wall as a containment. In retrospect this application may have been somewhat inappropriate; all subsequent superfund slurry wall containments have used the SB technique.

MIX DESIGN CONSIDERATIONS

The rational determination of ingredients for cement-bentonite requires a knowledge of the material properties, their interactions, and an understanding of mixing technology. To this must be added an appreciation of slurry workability, recognition of project specifics, and experience. Most of what is known about CB comes from previous experience, much of it with proprietary mixtures and mixing techniques.

The basic component of cement-bentonite slurry is the bentonite-water mixture. Specifically engineered cement-bentonites are generally created by changing the cement content or by adding other ingredients to the bentonite-water slurry.

The final properties of cement-bentonite are a function of the initial mix proportions, curing time, soil conditions, and sampling and testing methods. Some commonly specified mix proportions are given in Table 1. More exotic mixtures may contain fly ash and set retarders. In general, cement-bentonite mixtures for slurry trenching are specified by performance criteria.

The performance limits of cement-bentonite are defined by the following major restraints.

- The slurry must be pumpable and allow excavating equipment to penetrate it easily for extended periods. High cement and/or bentonite proportions and fly ash can increase slurry viscosity. Set retarders can decrease viscosity.

- The slurry must set within a definable period. Too little cement or too much fly ash can impede the set. Set retarders may extend the fluid state, though unpredictably.

- The slurry properties must be controllable and regular within limits. Fly ash is generally of irregular quality and may adversely affect slurry viscosity without the use of set retarders.

- A continuous, low permeability barrier must result. Too little bentonite can result in higher than expected permeabilities. A higher solids content generally leads to lower permeabilities.

- The set slurry should be strong enough to resist hydraulic and earth pressures, yet flexible enough to resist cracking and earth movements. Too much cement or fly ash can result in a material which is stronger, yet subject to brittle failure at low strains.

The mixture of materials used in cement-bentonite slurries is known to meet the above criteria depending upon mix proportions. Any significant change in the proportion of one ingredient can affect the entire mixture in ways which may make the product unusable either in the liquid or solid state.

SAMPLING AND TESTING TECHNIQUES

During a recent project in southern California, three separate design mixtures were used to construct five cement-bentonite groundwater barriers. Four well-known, independent testing laboratories were employed to perform various tests on the field-mixed cement bentonite. Samples of the cement-bentonite were obtained from the trench while still fluid. Other samples were cored from the set-up wall using thin tube samplers months after construction. In all, over 100 permeability measurements were made and 15 unconfined compression tests performed.

Fluid samples of cement-bentonite slurry were gathered from the mid-depth of the trench at the completion of each panel. The still-fluid samples were poured into 3 inch diameter plastic tubes of two lengths, one foot and 3

feet. The samples were capped, sealed, and allowed to set undisturbed on site for 3 days in a climate-controlled construction trailer.

Due to the long time lapse between construction and final cure, it may be desirable to somehow artificially accelerate the cure of the slurry in order to monitor performance of the installation. Some of the one foot samples were artificially cured in a 65^{o}C water bath for 5 days. The samples were extruded, trimmed to a workable length and tested in a triaxial permeability apparatus for a period of three days including time for consolidation. The 3 ft. samples were allowed to cure at room temperature for at least 28 days and tested in a triaxial permeability apparatus for a period of seven days to eight weeks.

A comparison of the results is presented in Fig. 6. The quick cure method did not produce an acceptable agreement with the naturally cured samples. The average ratio of permeability of the artificially cured samples to the naturally cured samples is about 5. This discrepancy could be due to other factors beyond cure conditions. In order to ascertain the source of this discrepancy, a comparison was made to evaluate the effect of the sampling and testing techniques on permeability.

The results of the comparison between the different sampling techniques are shown in Fig. 7. No obvious or persistent differences are evident; however, there is a slight tendency for the undisturbed samples to give slightly lower permeabilities. In situ cure conditions, consolidation stresses, and water loss through the trench walls may have contributed to this trend.

A separate comparison was made to evaluate various testing parameters on cement-bentonite permeability. The factors evaluated were sample size, permeant, test method, consolidation stress. The results are presented in Fig. 8. Again, testing effects are rather insignificant with increased consolidation pressures giving the most noticeable effect.

DESIGN MIX PERFORMANCE

Unconfined compressive strength tests were performed to evaluate the strength of the three cement-bentonite mixtures. The results of these tests are presented in Fig. 9 along with design curves from previous work by others. In all cases, the strengths were somewhat higher than would have been expected. It is assumed that

samples of the cured cement-bentonite with and without fly ash. Results are presented in Fig. 11. The most obvious similarity in the mixes is that they apparently achieve their low permeability after some time and with continued flow. It appears that the mechanism controlling permeability may be pore plugging and/or consolidation. Particle migration was frequently observed in the laboratory by the presence of minute particles which flowed out of the sample during testing. Although repeated efforts were made to clear the test apparatus of these particles, it was apparent that particle migration within the sample during permeation contributed to an eventual lowering of the samples' permeability.

The effect of this phenomenon in the field is unknown. One would surmise that as long as free water is available, cementing and bonding continues within the barrier leading to an eventual decrease in available flow channels and an accompanying drop in permeability.

CONCLUSIONS

The results of a large number of tests on field samples of cement-bentonite slurry walls results in the

following conclusions:

1. Artificially accelerating the cure of cement-bentonite leads to conservative permeability test results.

2. Cement-bentonite is relatively insensitive to laboratory test conditions. Effective confining stress is the most important variable of those investigated.

3. The addition of fly ash to cement-bentonite was shown to moderately increase strength and reduce average permeabilities.

4. Pore plugging by particle migration may be an important mechanism of cement-bentonite impermeability and was observed during long term permeability tests.

Additional research and more documented case studies are still needed to assist the engineering community in fully understanding cement-bentonite mixes.

TABLE 1: Common Cement-Bentonite Specifications

Cement/Water (%)	16-35
Bentonite/Water (%)	3-6
Viscosity (Marsh Funnel Seconds)	35-90
Unit Weight (gm/cc)	$\geq$1.15
Unconfined Compressive Strength (psi)	$\geq$5
Strain at Failure (%)	$\geq$15
Hydraulic Conductivity (cm/sec)	$\leq 5 \times 10^{-6}$
Curing Time (days)	$\geq$28

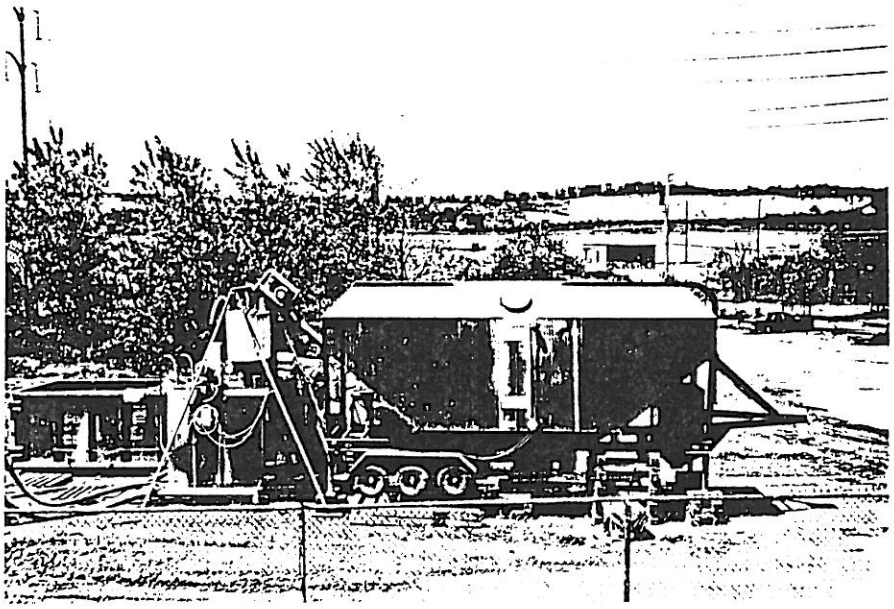


FIGURE 1 - CB SLURRY MIXING PLANT

FIGURE 2 - TRENCHING UNDER CB SLURRY

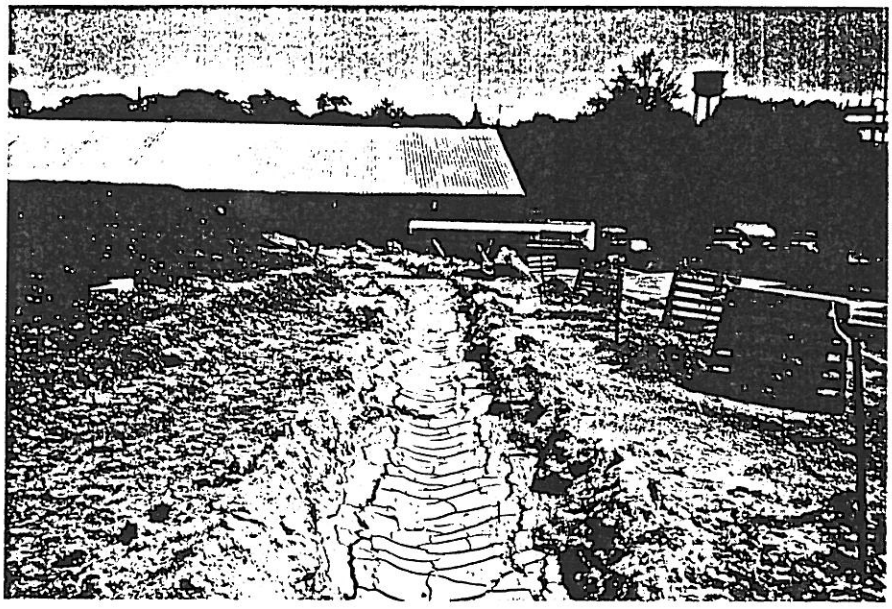


FIGURE 3 - SET-UP CB SLURRY

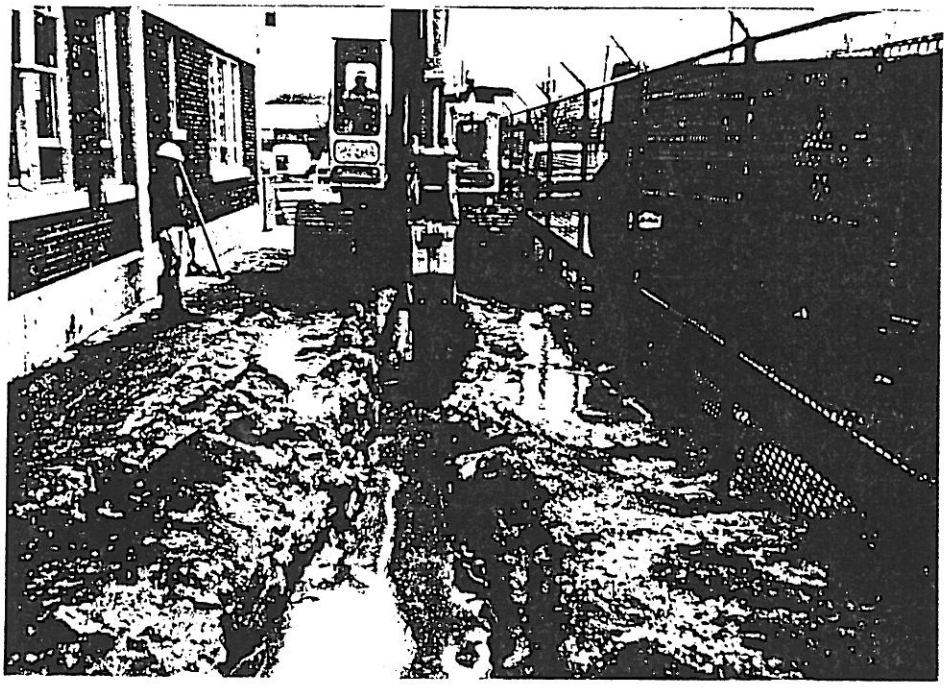
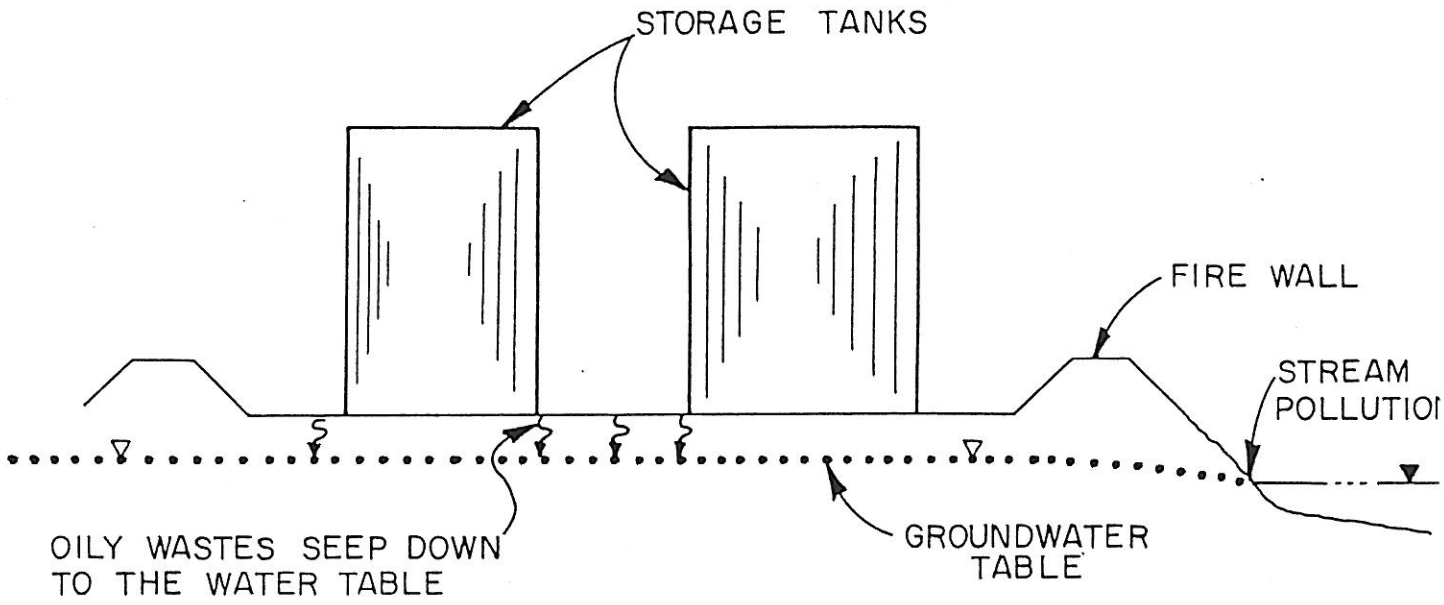
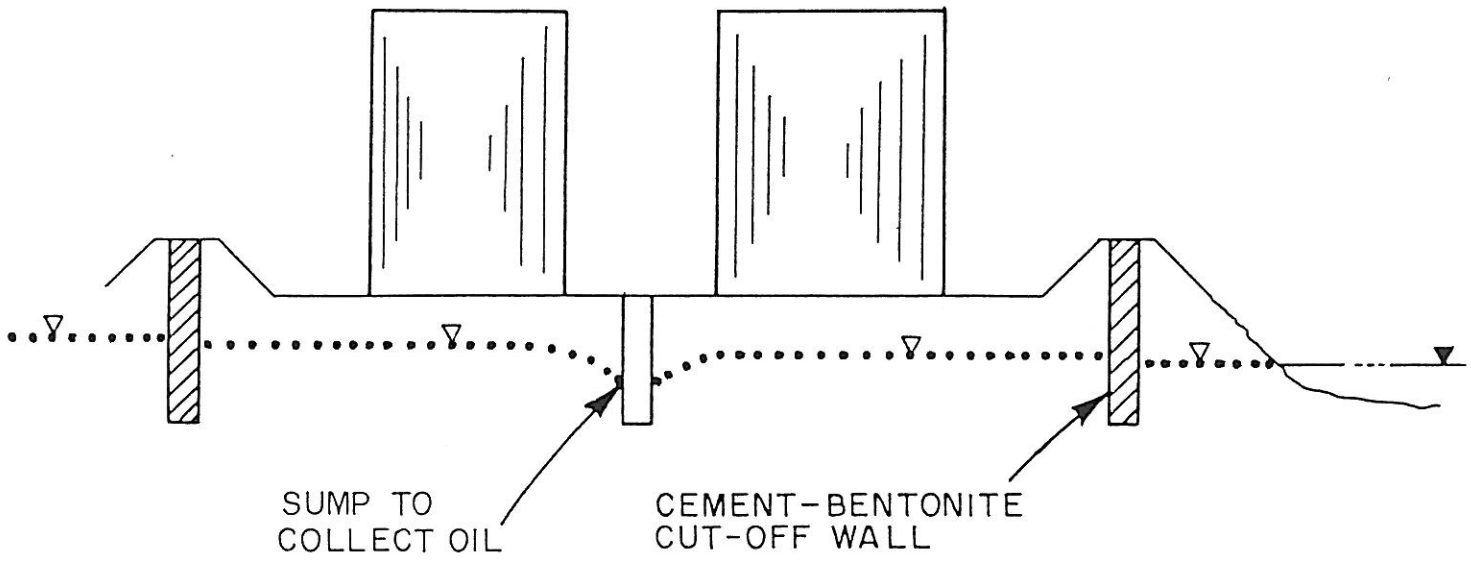


FIGURE 4 - CB WORK IN AREA OF TIGHT ACCESS



BEFORE CONTAINMENT



AFTER CONTAINMENT

FIG. 5 SCHEMATIC OF TYPICAL APPLICATION OIL-POLLUTED GROUNDWATER

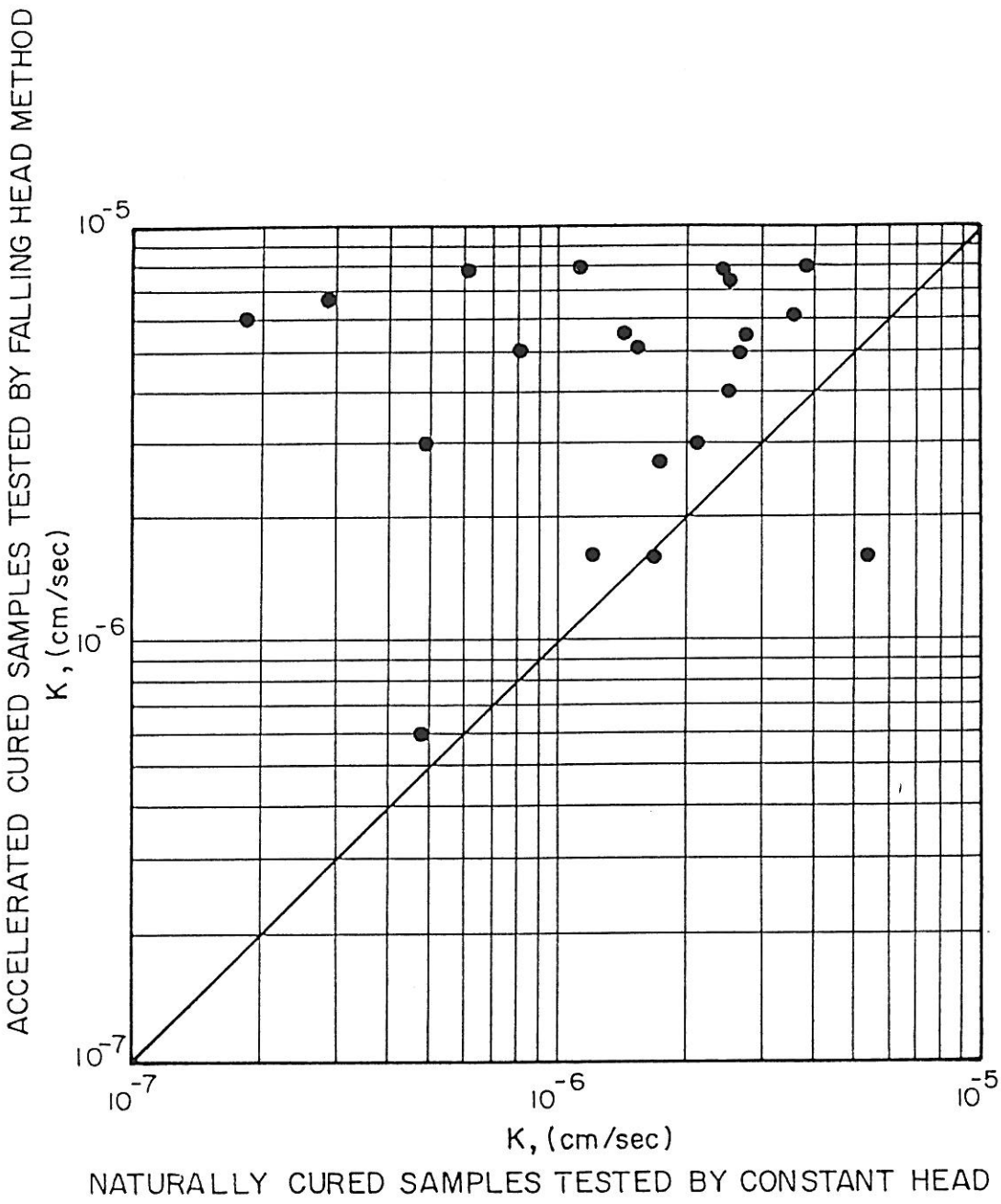


FIG. 6 INFLUENCE OF CURING AND TESTING CONDITIONS ON THE PERMEABILITY OF CEMENT-BENTONITE SAMPLES

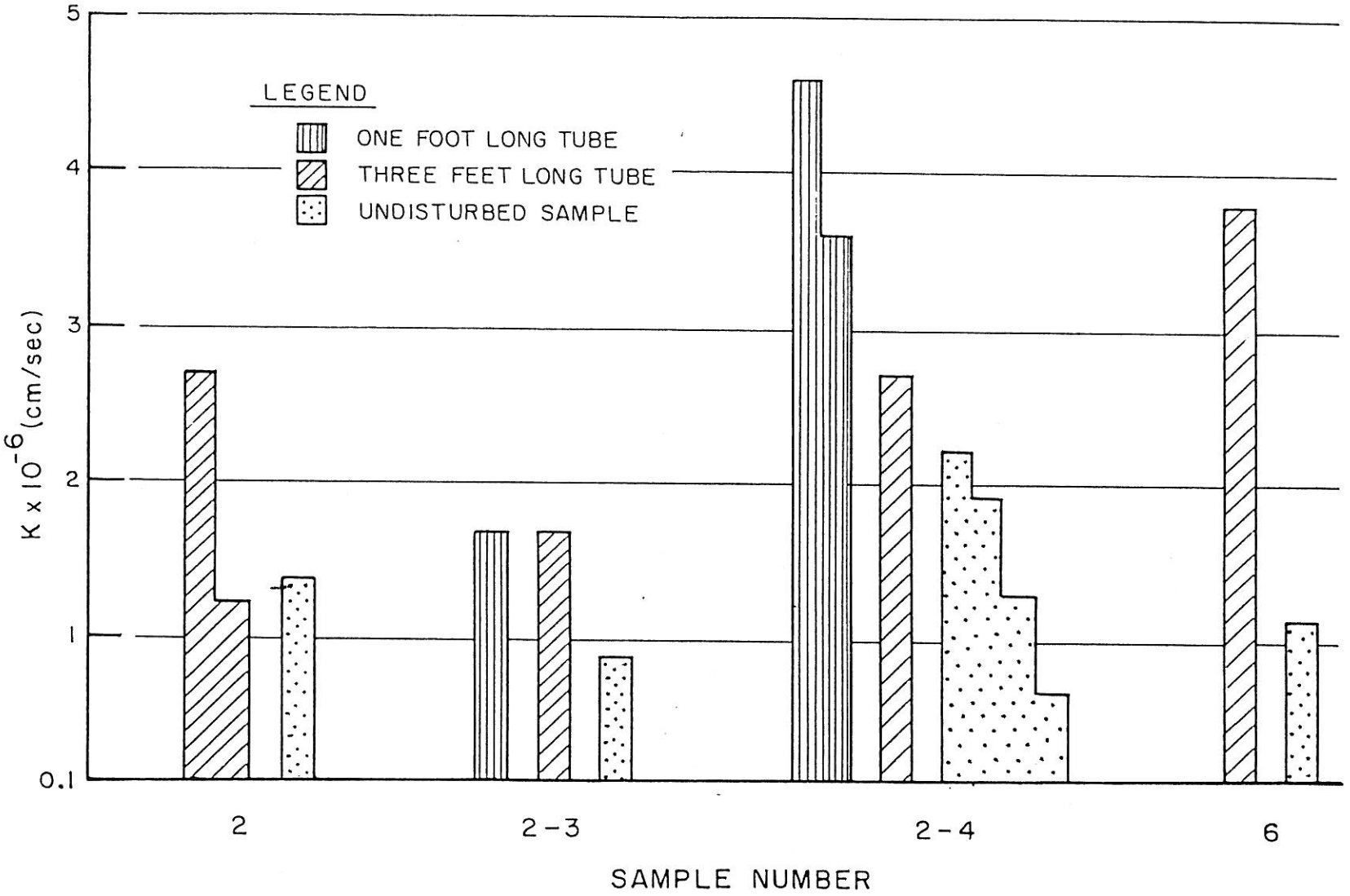


FIG. 7 PERMEABILITY RESULTS FROM VARIOUS SAMPLING TECHNIQUES

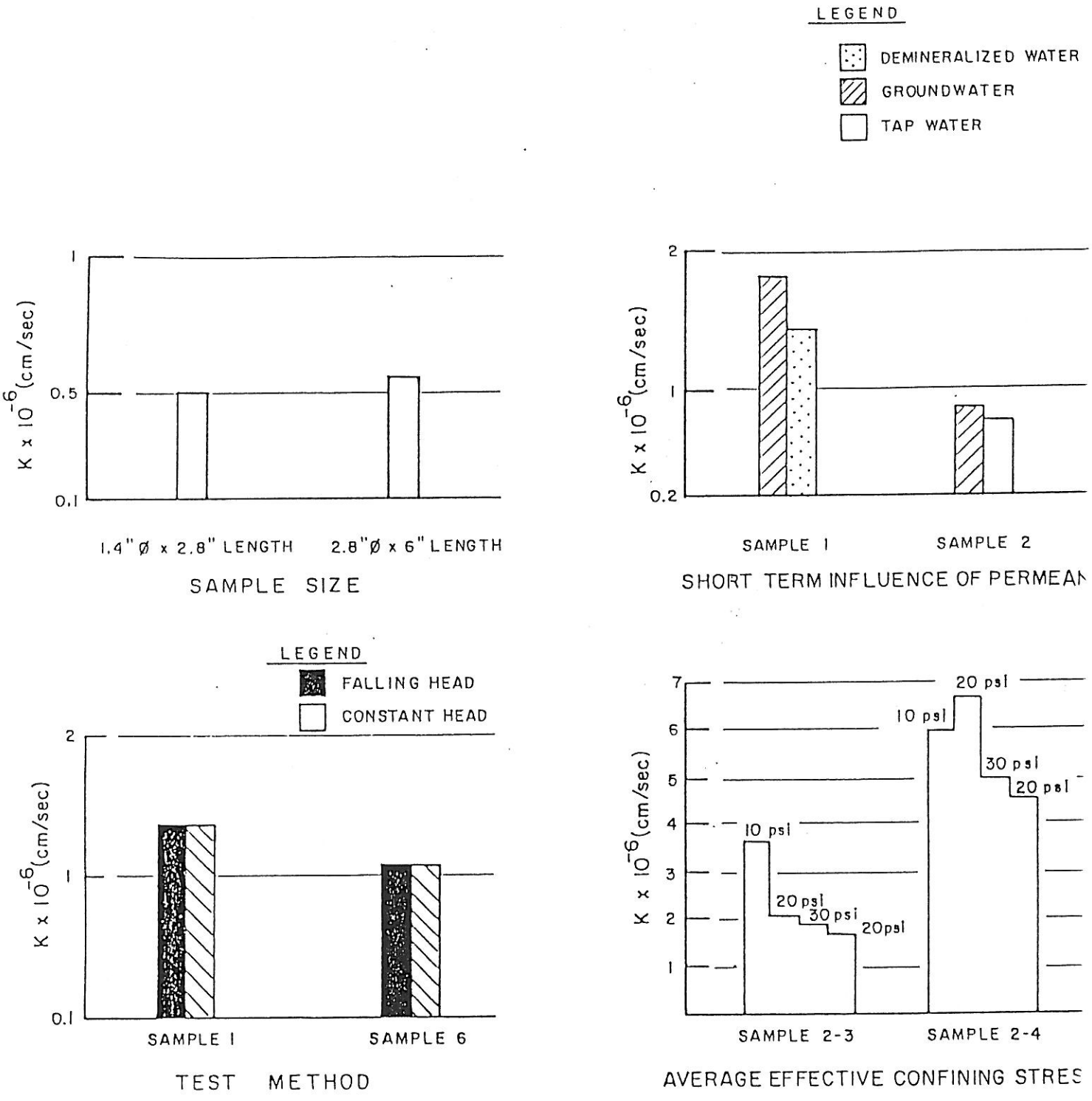


FIG. 8 PERMEABILITY RESULTS USING VARIOUS TESTIN(TECHNIQUES

(ALL VALUES OF HYDRAULIC CONDUCTIVITY OBTAINED AFTER 3-5 DAYS OF FLOW)

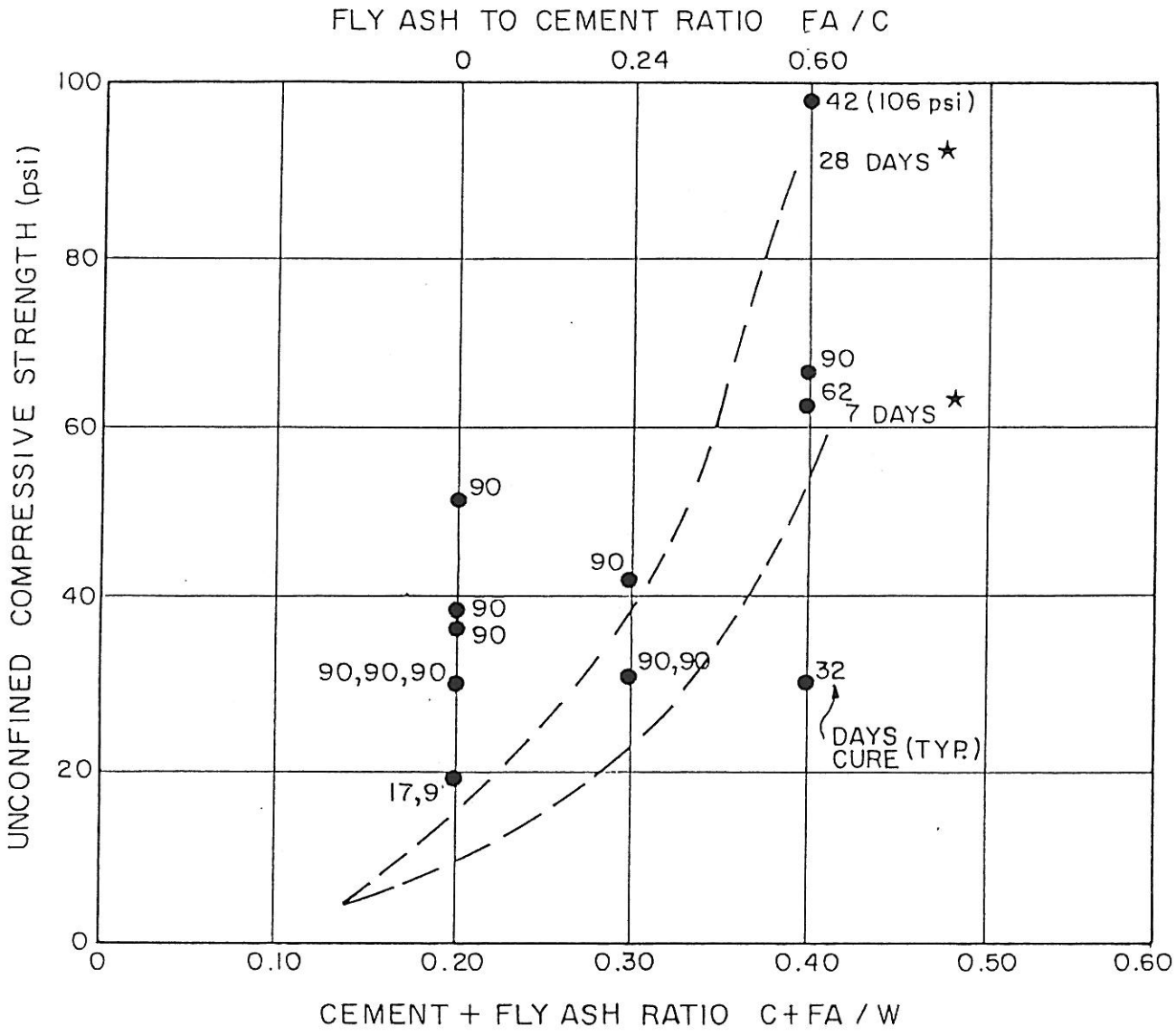


FIG. 9 INFLUENCE OF CEMENT AND FLY ASH PROPORTION ON COMPRESSIVE STRENGTH OF CEMENT – BENTONITE AFTER VARIOUS CURING PERIODS

★ AFTER MILLET, RICHARD A., AND PEREZ, J.Y., "CURRENT USA PRACTICES: SLURRY WALL SPECIFICATIONS," JOURNAL OF GEOTECHNICAL ENGINEERING DIVISION, ASCE, VOL. 107, NO. GT8, AUGUST 1981.

	C / W	FA / C
MIX 1	0.20	0.00
MIX 2	0.20	0.24
MIX 3	0.25	0.60

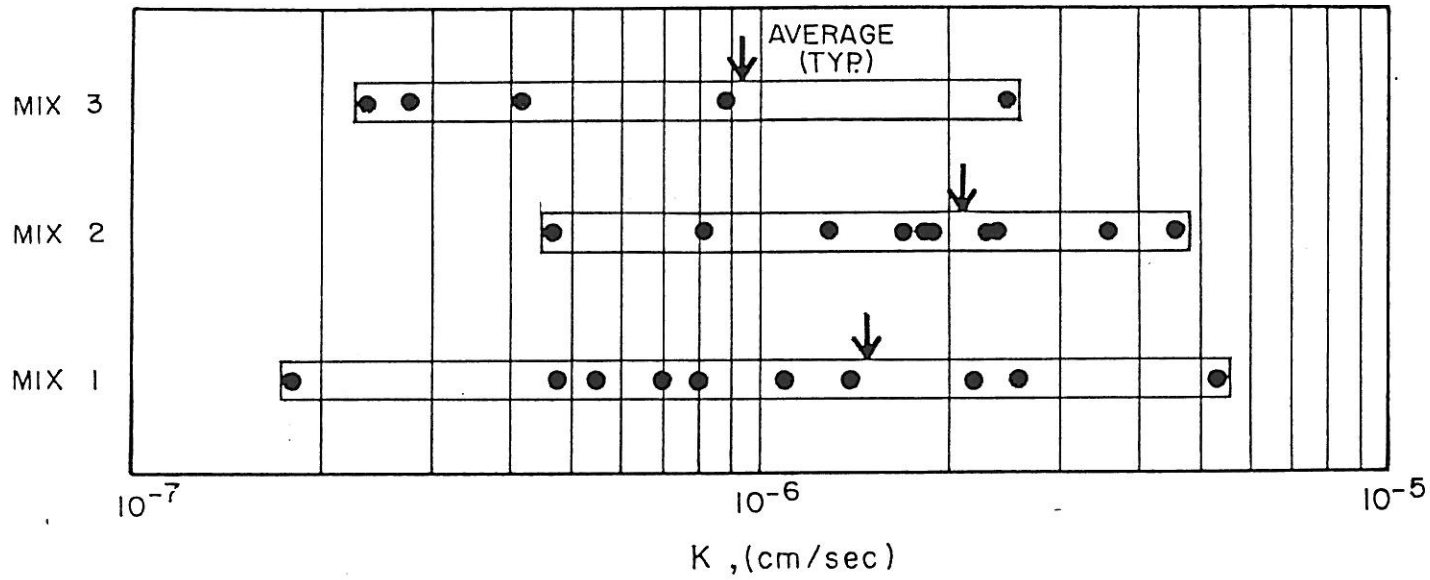


FIG. 10 PERMEABILITIES OF VARIOUS CEMENT-BENTONITE MIXTURES

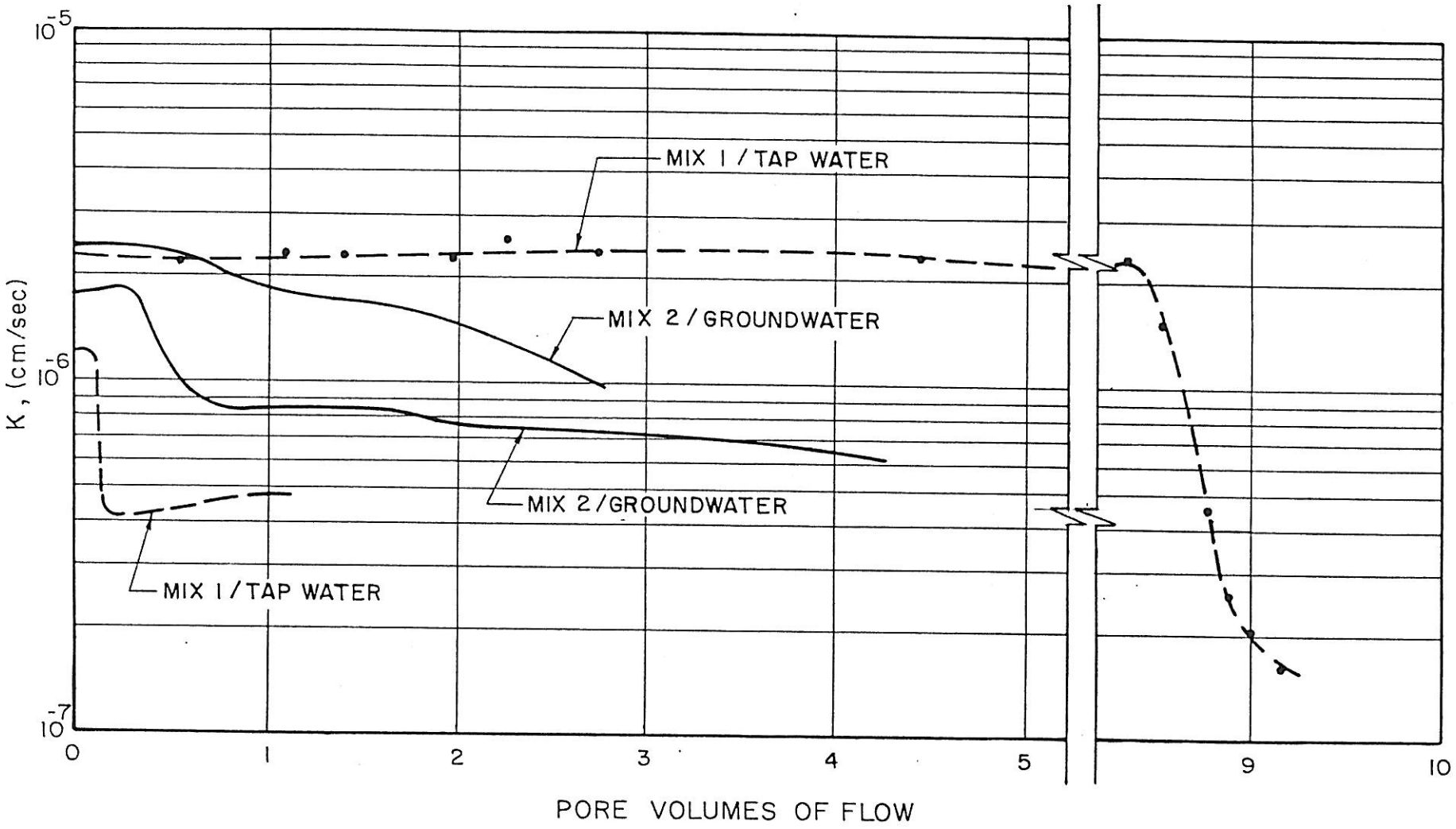


FIG. 11 RESULTS OF LONG TERM PERMEABILITY TESTS ON UNDISTURBED SAMPLES OF CEMENT-BENTONITE (MIX NO. / PERMEANT)