A STUDY OF PERMEABILITY CONTROL WITH ASPHALT EMULSIONS

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I N T R O D U C T I O N

Statement of the Problem

The control of soil permeability has been an engineering problem dating as far back as the Roman Empire. Then they sought to control it in canals and aqueducts for rural and urban use. Today some of the problem areas are dams, highway embankments, building foundations, and sewage lagoons. This study deals specifically with the aspects of the latter problem area. The methods employed have been treatment with bentonite and installation of plastic linings. The bentonite has not proved to control the permeability accurately and the plastic linings present problems in construction and economic feasibility.

Purpose of the Study

The purpose of this study was to investigate the usage of asphalt emulsions to accurately control permeability. The asphalt used was a slow curing anionic emulsion. The soil studied was a river valley silt which is commonly the soil underlying lagoons in Kansas. A value of 0.25 inches/day was sought. This value was adopted because it is that set by the Enviormental Protection Agency and Kansas Public Health as the maximum permeability rate for low standing sewage lagoons. Any value lower than this results in an increased size of the lagoon and consequently a much higher cost.

Scope of the Study

The scope of this study included a literature review of permeability control with asphalt emulsions and the characteristics of asphalt emulsions. Very little has been published in this area and the author found practically no literature concerning permeability control with asphalt emulsions, but ample literature concerning asphalt emulsions themselves.

The scope also included extensive laboratory experiments to determine the permeability of the soil mixed with varying amounts of asphalt emulsion mixtures. The effect of time on the permeability of the soil-asphalt specimens was studied also.

L I T E R A T U R E
R E V I E W

Asphalt emulsions usually consist of a base asphalt dispersed in water by means of an emulsifier. Emulsions can supply a definite type of asphalt in a very fluid condition to a specified surface. Some of their advantages are low-temperature application, readily adjustable viscosity to greater fluidity, non-flammability, ease of penetration into porous materials, and their excellent wetting (coating) ability. The high fluidity of the emulsion allows easy penetration of the fluid carrying along with it the dispersed particles of asphalt which are deposited on the surface to be coated; Barth(1).

Asphalt emulsions were first used in the United States as early as 1869. A patent then issued to Thomas (12) covered the use of resins, tar residues, and a little natural waste rubber, all emulsified with silicate of soda. The Westmurite pavement appeared in the period of 1900 and 1910. A.W. Dow (7) stated that this surface, made with emulsion intimately mixed with aggregate, gave good performance as a pavement. The first thoroughly tested emulsions were laid in Chicago as reported by Barth (1). Emulsions using local "oil-residues" with rosin soap as emulsifier were successfully employed there as early as 1907. Van Westrum later, as reported by Barth (1), laid a series of excellent pavements in 1909-1910 in Chicago and Whiting, Indiana, of the pre-mixed or cold-laid type.

Since then the predominate use of emulsions has been for road surfaces. Recently other areas are being explored along the lines of agricultural uses such as irrigation ditches, lake beds, and even peanut growing, Draper (8), and grass in sandy soil, Draper (9). In the engineering realm emulsions have been used for soil stabilization and grouting, Gebhart (10), and in this study for permeability control.

Many patents on the uses and manufacturing of emulsions have been issued since 1910, Barth (1). Some prescribed the use of no soap whatever, but merely called for adding sufficient caustic soda solution to the water and stirring the mixture with asphalt, obtaining good brown colored, quite stable emulsions. Many California oil asphalts appeared on the market then and were, and still are, quite easy to emulsify. In the early 1920's considerable Panuco petroleum became available in the United States. Asphalts from these are readily emulsified, and so many emulsions were made from them that they were termed "self-emulsifying". Except for the few exceptions noted, the manufacture of asphalt emulsions of the water dispersable type requires the use of well chosen emulsifying agents.

Characteristics of Asphalt Emulsions

Asphalt emulsions are of two types, those in which the asphalt is dispersed in an external phase, which is the water (O/W); and those in which the water is dispersed in the external phase, which is the asphalt (W/O), according to Barth (1). The former type can be diluted with more water, but not with asphalt. The latter can

be diluted or otherwise made richer in asphalt content, since here asphalt is the external phase, but cannot be diluted with water. Whenever a phase, either asphalt or water, can be added to an emulsion and it mixes well to produce a homogeneous product, that phase is the external phase of the emulsion. All emulsions thus comprise two phases, one of asphalt and the other of water.

A third component is commonly needed to disperse either the asphalt into the water (O/W) or vice versa (W/O). These agents are called dispersing agents of emulsifiers. The chemical nature of the emulsifier most often determines the type of emulsion.

The ability of aqueous of asphalt-in-water emulsions to perform properly is dependent on their prime or most distinguishing characteristic, namely, to deposit the dispersed asphalt as a continuous film on the surface to be coated or impregnated. During application high fluidity coupled with high penetrability of the emulsion places the fluid where the asphalt is required, namely, the aggregate or fiber.

How dispersed asphalt particles form into continuous films will be discussed in relation to the asphalt-in-water (O/W type). This type is commercially the more important of the two types, and the physicochemical aspects of asphalt-in-water emulsions receive greater consideration than do those of the water-in-asphalt type products. One reason is that the stability of the former often is critical, whereas in W/O type the continuous phase asphalt usually is present in large percentages and the dispersed or water phase usually presents no problem of stability or other

considerations.

Since an O/W emulsion was used in this study, this review will be concerned with the asphalt in water emulsions. The dispersed asphalt particles are precipitated from the emulsion immediately or soon after contacting a foreign surface, such as paving stones, fibers, masonry, and the like. The result is the formation of a continuous asphalt film on the surface, at the location where it is required. This physical change or precipitation of dispersed asphalt is termed the "break". The emulsion is said to "break" when the asphalt particle size is disturbed and the dispersed phase agglomerates or precipitates. The initiation of "break" is due to electronegative or electropositive charges present on the surface of the material to be coated, as for instance, on paving aggregate. These charges - predominantly either negative of positive - repel or attract, as the case may be, similar of opposite charges of the asphalt in the emulsion or, more particularly, in the ionizable portion of the emulsifier compound. The water originally present as the dispersing phase evaporates, hastening the formation of the continuous asphalt film. One must be reminded, however, that emulsion systems with water as the external phase also will precipitate the dispersed asphalt by the mere loss of water due to evaporation. The emulsion will "break" above a maximum asphalt content due to the loss of water, which tends to concentrate the asphalt in the emulsion. The "break" varies with the type of emulsifier. Most asphalt-in-water emulsions are unstable at above 70 to 75% asphalt content;

commercial types are generally made in the range of 55 to 65% asphalt content. The emulsifier and any stabilizers used in manufacture will be found in the asphalt film after the emulsion has broken, and these substances may or may not alter the properties of the film compared to the properties of the original asphalt used for dispersion.

Various types of emulsifiers are used in making asphalt emulsions; these materials are surface active. Substances that migrate from the bulk of immiscible liquids or solid liquids and concentrate at their interfaces will decrease the strain or interfacial tension between the immiscible substance. Briefly, the lower the surface tension between the two phases of an emulsion, the easier it is to effect emulsification.

Emulsifiers in their simplest form, such as the typical soaps, consist of molecules containing a hydrocarbon "tail" or chain (also called the lipophillic or nonpolar group) attached to a strongly polar group or "head". The hydrocarbon tail is hydrophobic and is the asphalt-solubilizing portion of the compound. The polar "head" is the surface-active portion, and it secures solubility in water or other polar liquids. This occurs when the emulsifier is thoroughly water-soluble, as with the alkali-metal soaps. When the "head" of polar group in the molecule is composed of the heavymetal elements and borderline elements such as calcium, the emulsifier often will show good asphalt solubility rather than water-solubility (when attached to similar length hydrocarbon chain). Other groups affect water-solubility, of course, such as the sulfate, sulfophosphate, and similar groups, as well as the

halogen elements and nitrogen compounds.

The distinction between the above compounds is based on whether the hydrophillic polar group is located in the electronegative or positive portions of the molecule.

Chemically, emulsifiers are surface-active agents, classified as, (1) anionic, (2) cationic, and (3) non-ionic types. Types (1) and (2) give emulsions where the dispersed phase shows a definite charge; type (3) agents carry no charge, according to Barth (1).

Since the emulsion employed in this thesis is of the anionic type, and due to the length of description necessary to adequately describe cationic and non-ionic emulsions, this review will deal only with anionic emulsions.

As reported by Barth (1), in the anionic types the hydrophobic portion or hydrocarbon chain is found in the negative part of the molecule as well as in the sulfate group.

The emulsifiers for the anionic type of emulsions most often are soaps sufficiently water-soluble or "dispersible" in water, but with the proper degree of balance as to be lipophillic. If the emulsifier is chemically designed and synthesized, consideration also must be given to a balanced molecular structure and proper polarity. Thus we require for the usual type of anionic emulsions three components: (1) the asphalt, (2) the water, and (3) an emulsifier of dual solubility.

The emulsifier should show oil-solubility, which with certain asphalts is an advantage; a pure wetting type of compound is less

of a requirement than is a powerful emulsifying agent.

A large array of substances is used to make the asphalt-in-water type of emulsions. Some of these materials are soaps of fatty acids and oils, such as oleic acid, tall-oil, and its sodium, potassium, and even lime soaps; alkali soaps of naphthenic acids and oxidize fatty acids, as derived from the oxidation of solid parafin wax; metallic soaps of the same derivation, such as the aluminum wax acids and their inverted sodium form, Barth (2); rosin soaps of woodrosin; casein, procein, metallic tannates, and similar materials. The alkali metal salts of the petroleum sulfonates, of various molecular weights and solubilities, are powerful emulsifiers, as reported by Barth(1).

The alkali portion of the above products most often is a sodium or potassium ion; occasionally ammonia is used for certain solubility effects. The price of the compound often is the chief deciding factor in determining which of the various industrial oils listed above will be used. There are innumerable variations in the choice of definite chemical compounds, raw fats, fatty acids, or the like. Asphalt-in-water emulsions are usually considered by the trade to be soap-containing types, or anionic emulsions, as distinct from the cationic types.

In general, asphalt-in-water emulsions contain from 40 to close to 75% of asphalt. Theoretically, the low limit is that of very little asphalt and nearly all water plus emulsifier; on the upper side the emulsion will become unstable with more than 75% asphalt content. This figure is very approximate, and would vary with the

type asphalt used, the percentage of emulsifier, the particle size, the pH value, and whether stabilizers are present.

Soap content may be as low as 0.2% to as high as 3%, depending on the type of product to be made, the need for long periods of storage, etc. In general, the RC (rapid break) emulsions can be made with extremely low soap content (from 0.2% to 0.75% of the emulsion) and still maintain reasonable stability. The MC types (medium break) usually require about 1% solid soap, whereas the SC (slow break) types require 1 to 1½% soap. These are relative values and depend entirely on the asphalt, the hardness of the water, and the chemical composition of the soap compound or emulsifier.

Three Kinds of Asphalt-in-Water Emulsions

The most important property of any emulsion is its stability after the emulsion is made as reported by Barth(1). Will it remain an emulsion? How long will it remain an emulsion? The rate of break (lability) and its storage and mixing stability depend on several factors. The purpose of asphalt-in-water emulsions is to bring to the stone aggregate or other surface to be treated a uniform film of high-quality asphalt that is resilient, durable, and not altered in any way by mechanical or chemical means or different from the asphalt originally used in manufacturing as reported by Bierhalter (4). According to Barth(1), this film is to be supplied to the aggregate as true asphalt fairly soon after the emulsion has been spread or mixed with the aggregate or other surface to be treated. The degree or ease with which these asphalt

in-water emulsions begin to deposit the bulk asphalt from the dispersed condition is called the "break time" or "curing time" of the emulsion. Curing is the term used to define technically the moment when the water has started to evaporate after the first dispersed asphalt particles have agglomerated on the foreign surface, and in coalescing have now formed the binding film of asphalt. During this coalescence, and as the film forms, the external or outside water phase evaporates from the surface. There are three grades of emulsions, depending on how fast the dispersed particles of asphalt will break out or coalesce on application. The three grades are:

1. Fast break or fast cure (rapid curing or rapid setting);
2. Medium break or medium cure (medium curing or medium sitting); and
3. Slow break or slow cure (slow curing or slow setting).

One of the unique properties of asphalt-in-water emulsions is their relative high mobility or fluidity. It is related to the time of break or speed of curing. These products perform well because of their high fluidity and their spreading or penetrating ability over surfaces, fibers, etc., wherein the external or water phase carries the dispersed particles into the ultramicroscopic interstices and capillaries of the treated material, as well as providing good coverage over various surfaces. Subsequently, the dispersed asphalt begins to coalesce into a continuous adhesive film if the emulsion has been made properly.

This "break" must not occur before the emulsion has reached

its service area, nor should the break be delayed beyond a reasonable time after application. A long-delayed break allows the emulsion to be washed away from the surface, such as of felts or aggregates, if the latter come into contact with water. Once the emulsion has broken, the film thus formed is or should be absolutely insoluble in water and completely unaffected by it, by moisture, or by damp air.

These products present a distinct advantage over the road oils or cut-backs in that they may be used at normal temperatures and are seldom applied heated in any form, as are the higher-viscosity grades of cut-backs. Viscosity of the emulsions also is easily adjusted at will by further addition of water should the product be too viscous for certain applications.

Asphalt-in-water (O/W) emulsions are applicable at ambient temperatures, in contrast to the other extreme of bituminous materials, such as the asphalt cements that must be used at elevated temperatures.

One disadvantage emulsions might present is the fact that the emulsifier remains in the asphalt film with either type of emulsion. In the case of the asphalt-in-water type, the kind of soap used often affects the physical, as well as the chemical, properties of the asphalt film after the emulsion has cured. In such cases, the deposited film often is not the desired film of asphalt or is not similar to that of the original material used in the emulsion.

Physicochemical Considerations

The ease of "breaking" (or setting) and the desirability of permanency on storage are most important considerations, as reported by Barth (1). Very often these two properties are diametrically opposed to each other.

If the asphalt particles are dispersed to a very high degree and they are thoroughly stabilized, by whatever means, a slow-break emulsion results that is stable under road mixing and storage conditions. If properly made it will also be stable in storage for the required prolonged period of time.

Conversely, when the asphalt is less finely divided or poorly dispersed we can expect an early coalescence of particles, either during storage and/or on application. This statement applies to rapid-setting (RS) or fast-break types. Medium-type emulsions are intermediate between the slow-break emulsion grades and the RC-type grades in terms of rate of setting of curing. However, regardless of the rate of break (lability), all emulsions are required to be thoroughly stable on storage (stability).

The nature of the asphalt has an important bearing on its emulsifiability, but the particle size of the dispersed asphalt is probably more intimately related to "rate of cure" and stability than any other property. Some asphalts emulsify easily, whereas others of similar grade handle with difficulty, no matter whether low or high percentages of soap are used. Asphalts reasonably low in wax content should be used when possible. Pure paraffin waxes can be emulsified with known powerful emulsifiers, but the

low-cost emulsifiers available for asphalt emulsification usually do not emulsify waxes or asphalts containing wax. Naturally occuring organic acids, such as naphthenic acids present in asphalts in variable quantities, are beneficial for producing emulsions of the asphalt-in-water type. Heavy crudes of naphthenic origin such as heavy Venezuelan, Sicilian, and Mexican oils, furnish asphalts that are easily emulsified, although still requiring the addition of some external soap in most cases. The theory and mechanism of spontaneous or in-situ emulsification is exhaustively treated by Bellanger (3) and Clayton (6).

Breaking Point in Performance

The actual mechanism of the breaking of emulsions in contact with various surfaces and aggregates has received considerable attention, as reported by Barth (1). Break could take place on the surface of the paving aggregates or on other surfaces, due to an increase of the concentration of alkali caused by adsorption, as reported by Klinkman (11). The initiation of break may be due as well, or independently, to mere evaporation and loss of water, producing a deficiency in the proportion of external to internal phases. An abnormal concentration of asphalt results in its precipitation, as reported by Blott and Osborn (5).

The time of break is an important consideration since it determines the class of emulsion to be made, as reported by Barth (1). Rapid-curing emulsions "break" soon after their application, from a few minutes to 3 to 4 hours. They are sensitive to mechanical handling once in contact with a surface; flocculation of the

asphalt results. This grade is therefore made with a low or limited soap with just enough stability, and seldom contains added stabilizers. Slow-curing emulsions, on the other hand, are quite stable, breaking in from 5 to 24 hours, and they withstand considerable mechanical manipulation with dry or damp aggregates before breaking.

Stability on Storage

According to Barth (1), emulsions in storage will when properly made remain stable for long periods of time (3 to 6 months for slow-break types); this is true provided water has not evaporated and there is no possibility of contamination by electrolytes. This statement also assumes the emulsion shows the proper optimum particle size and is not undergoing putrefaction.

Settling of coarser particles (5 to 10μ) in asphalt-in-water emulsions, statistically always present, is termed sedimentations; this may occur with no indication of "break" or rupture of the emulsion. Sedimentation is counteracted to some degree by Brownian movement of asphalt particles of very small size (less than 0.5μ in diameter). Sedimentation can take place in emulsions with coarse particles size - a matter of simple settling of very large particles such as exist in poorly made products. The term sedimentation connotes, generally, a slow separation of coarser particles from a mixture of particles in which the size range is apparently too wide or the percentage of coarse particles is unduly large. Sedimentation of particles in asphalt suspensions is dependent on the force that gravity exerts, especially in dilute solutions. A constant rate of fall of the particles would possibly

follow Stoke's Law:

$$V = \frac{2r^2(S - S')g}{9n}$$

where V = rate of fall of the particle, r = radius of the particles, S = their specific gravity, S' = the specific gravity of the liquid, g = gravitational constant, and n = viscosity of the dispersed medium.

The specific gravity of asphalt particles is about that of the aqueous soap solution, of slightly over 1.0, even including the soap absorbed at the interface, so settling would not be expected to be a very common occurrence. The reversible thickening of asphalt-in-water emulsions in storage is due to a slight agglomeration of particles, where interphase alkalinity is low, and the particles are not sufficiently repellent in close packing; often this is due to a weak electrolyte surrounding them (neutral solution of soap due to very low alkalinity). Sedimentation takes place if particle size is large to begin with, with or without minute disturbances such as storage atmospheric conditions, occlusion of air in the product, change in soap structure due to putrefaction, etc.

The effect of initial particle size on the storage stability (in days) is shown in Figure 1.

The curve is a composite for a Panuco and a Columbian naphthenic-type asphalt, emulsified without and with an emulsifier. White circles denote the Panuco asphalt without the emulsifier and small crossed circles with the emulsifier; the black circles denote Columbian asphalt without the emulsifier, and those with

emulsifier are denoted by dotted circles. A sharp break in stability occurs at a particle diameter of about 3 μ, equivalent to less than 1 month of stability. The critical area of good stability is in the region of about 2.5 μ particle diameter. Properly made emulsions should store satisfactorily for periods of at least 6 months under the conditions already described.

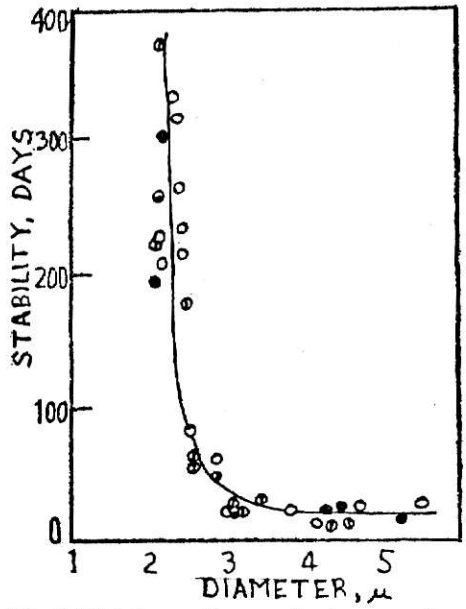


Fig. 1 - Stability of emulsions during storage as a function of particle size.

Sedimentation is first indicated by a slight or decided viscosity increase of the product toward the bottom of the storage tank; it can be removed by gentle mechanical agitation. If sedimentation is constantly recurring within 1 month's time, the product should be milled through a colloid mill or be reformulated. If the emulsion forms scum, the product should be adjusted. Scum formation is due to rapid break of the surface of the emulsion in storage with products of too rapid "break". Evaporation of water

from the surface is the immediate cause. A remedy to prevent scum, also due to too-rapid dehydration, is to exclude air by covering the surface of the product with a layer of petroleum distillate (kerosene).

Storage of Asphalt-in-Water Emulsions

The emulsion should not be stored at freezing temperatures or below as reported by Barth (1). Tropical or desert temperatures in the neighborhood of 145°F. (tank temperatures of 140 to 160°F.) usually do not affect emulsions unless the tank is aerated, producing by dehydration a foamy scum on the surface of the product. Water thus lost by evaporation can be added, or a film of heavy kerosene placed on the surface of the emulsion as a sealant.

Storage of emulsions at 32°F. or below is not good practice, as such temperatures produce ice crystals in the mass, causing coagulation. The water used in manufacture should be as free of salts as possible to avoid difficulties in producing the slow-break types. Sodium soap emulsifiers appear to coagulate more easily at the freezing point of water then do the potash soap emulsifiers.

The Use of Emulsions

According to Barth (1), the paving industry consumes the largest quantity of emulsions, usually of the asphalt-in-water types. "Invert emulsions" also are used in paving, and blown asphalts also can be emulsified.

Most of the water-in-asphalt emulsions are consumed in the

roofing industry and for specialty products. Here one of the main characteristics is plasticity, besides cementing and waterproofing properites, so that a pasty or extrudable product is most often desired. For these engineering applications, the function of water in the emulsion often has been disputed and said to be needless. Incorporated water however, serves to give some plastic flow, if not outright low viscosity; properly made, these products can be applied more easily than without any water in the formulation. There are many of these types that contain so little water, however, that they are not classified as water-in-asphalt emulsions.

The scope and uses of asphalts emulsified in water in the paving industry are:

RS-1. This specification covers an emulsified asphalt for penetration macadam, surface treatment, and tack coats.

RS-2. This specification covers an emulsified asphalt for penetration macadam, surface treatment, and tack coats where a more viscous product is desired.

MS-2. This specification covers an emulsified asphalt for plant mixes with coarse aggragate, substantially all of which is retained on a No. 8 sieve with practically no material passing a No. 200 sieve.

SS-1. This specification covers an emulsified asphalt for fine aggregate mixes in which a substantial quantity of aggregate passes a No. 8 sieve and a portion may pass a No. 200

sieve. It also can be used for slurry seals, dilute tack coats, and mulching purposes.

SS-1h. This specification covers an emulsified asphalt (of low penetration) for fine aggregate mixes and for admixture with soil aggregates in which a portion passes a No. 200 sieve. It also is suitable for light sealcoat applications, with or without sand cover, and for slurry seals.

Emulsions also are used in the roofing industry, waterproofing, and building construction, and several varieties are the basis of a diversified series of asphalt specialties, as reported by Barth (1).

One of the speciality uses of asphalt emulsions as reported by Gebhart (10) has been in the area of grouting. At Morrow Point Dam, located on the Gunnison River near Montrose in west central Colorado, leakage increased around the limits of the cement grout curtain on the left abutment established during dam construction. There was also leakage in excess of 400 gpm (gallons per minute) in the underground power plant drainage tunnel downstream and minor seepage along two prominent shear zones along the rock walls of the power plant excavated chamber.

Cationic asphalt emulsion, triggered with a hydrated lime slurry, was chosen as the first step in plugging the large water channels. To provide a stable curtain and further reduce leakage a cement grout curtain was established in the area after the asphalt grouting.

A rapid curing cationic asphalt emulsion was used and resulted

in a 65% reduction in total leakage into the drainage tunnel. After the cement grouting the power plant tunnel leakage was down to 37 gpm showing a 91% reduction had been attained by the asphalt and the cement grouting.

As to the use of emulsions for control of permeability, very little literature was found. In Venezuela an anionic emulsion was used to seal an irrigation ditch as reported by Draper (8). The ditch, about 30 inches wide, 10 inches deep, and 100 feet long was dug in the dry sand. A weir was installed at each end and a small reservoir of water was formed behind one of them. Water flowed over it and a distance of 25 feet in 30 minutes before disappearing into the sand. At this point, anionic emulsion was injected into the water and allowed to flow into the ditch. Water reached the base of the lower weir one hour and 35 minutes later. A total of 3.2 gallons of emulsion was used to this point. Water overflowed the lower weir two hours and 45 minutes later. A total of 11.8 gallons of emulsion was used over a period of 4 hours and 20 minutes to effect 90 per cent water recovery. No attempt was made for complete recovery.

Other than this the author found no literature dealing with the direct use of asphalt emulsions to control the permeability of soil.

D E S I G N
O F
E X P E R I M E N T

The procedure for the laboratory experiments was carried out in four phases:

(1) Determination of soil properties

(2) Determination of best method for preparing specimens

(3) Testing of specimens for permeability

(4) Time study on effect of permeability

Phase (3) was repeated until the desired permeability was attained reasonably accurately. Each specimen had a minimum of 2 sets of data collected on it, and some as many as 22 sets of data collected on them.

Phase One

The soil used was a river valley soil taken from the site of the new waste treatment plant of Manhattan, Kansas, in 1976.

The soil properties were determined by laboratory experiments and by using information already attained by the Black and Veatch office on the site.

Phase Two

The anionic emulsion as it was received from the plant is much too viscous to mix well with soil. A mixture of 50% emulsion and 50% water was tried, but found to be too viscous. By trial and adjustment a workable mixture was found and adopted for the laboratory

experiments.

The air dry soil was first weighted out into a mixing bowl. Then water was added to bring the soil to optimum moisture. Then the emulsion mixture was added. (It was later found that it was easier to mix the soil and emulsion mixture if the water was added to the emulsion mixture and then added to the soil.) All of this was then thoroughly mixed by hand in a mixing bowl until all particles appeared to be coated with emulsion mixture. This gave the soil-emulsion mixture a uniform darker tone than the soil water mixture. The soil-mixture was then compressed to a specified height and diameter.

Phase Three

After compaction each specimen's weight and height were recorded and used to determine the actual density and per cent of Proctor density. Then the specimens were placed in the permeameters.

The procedure for securing the specimens in the permeameters consisted of careful placing of each specimen on a porous disk placed in each slot of the 3-slot permeameter. Then the cylindrical polethylene tube was placed around it leaving approximately ¼ inch (0.63 cm) of space between the specimen and the tube. This space was then poured full of molten esker wax and thus sealed the specimens on its sides. The top and the bottom of the specimen were left unsealed for the water to travel through. A porous disk was then placed on top of the specimen and the top of the permeameter was fitted carefully into place and evenly

tightened down. In this manner water was allowed to pass through the porous disk on top of the specimen, through the specimen, and out through the bottom porous disk and into the collection beakers. Each specimen was allowed to be saturated over night before any test results were recorded.

Phase Four

When specimen appeared to be approaching the desired permeability, it was studied for time effect. The length of time varied depending on how much the values of permeability differed from the desired value. That is to say that if the values were near the desired value thenthe tests were continued, if not, then the tests were soon discontinued.

Tests Run

A total of 30 differing specimens of soil-emulsion mixtures were prepared and tested for permeability rate. A total of 80 different sets of data was collected on these 30 specimens. The number of sets of data on each specimen was dependent once again on the difference between the permeability rate being obtained and the desired value of permeability. If the values obtained were close to the desired value, then more sets of data were collected for the given specimen. A minimum of 2 sets of data were collected for each individual specimen.

P R E S E N T A T I O N
O F D A T A

The data presented in this section is in three basic forms: data page, tables, and graphs.

The data pages contain information concerning the soil properties as found through laboratory experiments or other sources.

The tables are arranged in such a way that permeabilities are figured and recorded individually for each timed reading for each specimen. Some of the tables have unreliable test data in them. Those which were judged reliable have a check mark by the specimen number. The notes on each table page explain why or why not a set of data is judged reliable. Not every set of data is represented on a graph. Twenty-two specimens have test data recorded herein. The other eight specimens have data recorded in Appendix A. Ten specimen's data are represented on the graphs.

The graphs presented are based on the data from the tables. Graphs 1-6 plot permeability versus time elapsed in minutes. Graph 7 has permeability versus time in days for a specific specimen. Graph 8 has permeability versus per cent asphalt emulsion.

It should be noted that both the graphs and the tables have two different percentages for each specimen. The larger one is the percentage of 80-20 emulsion-water mixture that is in the specimen, and the smaller is the actual percentage of asphalt emulsion in the specimen.

Data Page

The first property determined was the natural water content of the soil. This was done by preparing three different specimens of soil in its original state and placing them in an oven over night. The values prior to and after placement in the oven were recorded and from these values the value of the natural water content was determined to be 2.25%. The values are recorded in Appendix A.

The values for the maximum density (Proctor) and optimum moisture were secured from the Black and Veatch office at the site. These values were maximum Proctor density = 112.1 lb/ft^3, and optimum moisture = 13.2%.

1

SLOT 1

Type Specimen	: 80-20 10% (2.0%)	Density	: 117.42 #/ft³
Area Specimen	: 31.58 cm²	% Proctor	: 92.5 %
Height Specimen:	4.77 cm	Pressure Head:	225 cm
Weight Specimen:	233.90 gm	Comments	:

SLOT 2

Type Specimen	: 80-20 10% (2.0%)	Density	: 118.3 #/ft³
Area Specimen	: 31.68 cm²	% Proctor	: 93.2 %
Height Specimen:	4.77 cm	Pressure Head:	225 cm
Weight Specimen:	285.73 gm	Comments	:

SLOT 3

Type Specimen	: 80-20 8% (1.6%)	Density	: 110.97 #/ft³
Area Specimen	: 31.68 cm²	% Proctor	: 87.4 %
Height Specimen:	5.08 cm	Pressure Head:	225 cm
Weight Specimen:	296.25 gm	Comments	:

SLOT A1

Type Specimen	: 80-20 8% (1.6%)	Density	: 111.57 #/ft³
Area Specimen	: 31.68 cm²	% Proctor	: 87.4 %
Height Specimen:	5.08 cm	Pressure Head:	227 cm
Weight Specimen:	287.77 gm	Comments	: Specimen prepared differently – brae batch mixed; enough taken for sample.

****

TIME → / SPECIMEN	200m	K	195m	K								
1	148cc	0.284	145	0.282								
2	189	0.358	150	0.291								
3	181	0.365	195	0.404								
A1	542	1.090	450	≈								

TIME → / SPECIMEN												
1												
2												
3												
A1												

NOTE: Doubt accuracy; suspect vapor lock and tampering of equipment by someone unknown

2

SLOT 1

Type Specimen : 80-20 2%
Area Specimen : 31.68 cm^2
Height Specimen: 5.08 cm
Weight Specimen: 286.93 gm
Density : 111.24 #/ft^3
% Proctor : 87.6 %
Pressure Head: 225 cm
Comments : Didn't mix too badly ; leaked around the sides

SLOT 2

Type Specimen : 80-20 2.5%
Area Specimen : 31.68 cm^2
Height Specimen: 5.08 cm
Weight Specimen: 286.23 gm
Density : 111.13 #/ft^3
% Proctor : 87.6 %
Pressure Head: 225 cm
Comments : NOT 2.5% Error made & Also leaked around the sides

SLOT 3

Type Specimen : 80-20 1.8%
Area Specimen : 31.68 cm^2
Height Specimen: 5.08 cm
Weight Specimen: 291.63 gm
Density : 113.06 #/ft^3
% Proctor : 89.1 %
Pressure Head: 225 cm
Comments :

SLOT A1

Type Specimen : 80-20 1.8%
Area Specimen : 31.68 cm^2
Height Specimen: 5.08 cm
Weight Specimen: 286.56 gm
Density : 111.09 #/ft^3
% Proctor : 87.5 %
Pressure Head: 227 cm
Comments : Specimen leaked badly around the sides

****

TIME → / SPECIMEN	4-5-76 48m	K	183m	K	50m	K	50m	K	160m	K
1	175cc	1.47	305	1.48	175	1.42	175	1.42	x	x
2	295	2.48	506	2.46	310	2.50	x	x	x	x
3	125	1.05	179	0.87	100	0.81	94	0.76	260	0.656
A1	580	4.87	x	x	x	x	x	x	x	x

TIME → / SPECIMEN	4-6-76 103m	K	68m	K	185m	K	65m	K		K
1	307	1.20	183	1.08	x	x	x	x		
2	x	x	x	x	x	x	x	x		
3	140	0.549	84	0.49	207	0.452	60	0.370		
A1	x	x	x	x	x	x	x	x		

3

SLOT 1

Type Specimen :	11% (2.2%)	Density :	111.55 #/ft³
Area Specimen :	31.68 cm²	% Proctor :	87.9 %
Height Specimen:	5.08 cm	Pressure Head:	245 cm
Weight Specimen:	287.74 gm	Comments :	Tests set up down in old lab for ALL specimens

SLOT 2

Type Specimen :	11% (2.2%)	Density :	111.02 #/ft³
Area Specimen :	31.68 cm²	% Proctor :	87.5 %
Height Specimen:	5.08 cm	Pressure Head:	245 cm
Weight Specimen:	286.33 gm	Comments :	Leaked badly around the sides

SLOT 3

Type Specimen :	12% (2.4%)	Density :	111.30 #/ft³
Area Specimen :	31.68 cm²	% Proctor :	87.7 %
Height Specimen:	5.08 cm	Pressure Head:	245 cm
Weight Specimen:	287.11 gm	Comments :	

****

TIME →	4-28-76								4-29-76	
SPECIMEN	185 m	k	315 m	k	24 m	k	110 m	k	35 m	k
1	191 cc	0.383	325	0.382	50	0.773	235	0.792	160	1.060
2	615	1.230	✕	✕	✕	✕	✕	✕	✕	✕
← 3	186	0.373	300	0.353	44	0.681	80	0.269	35	0.371

TIME →	4-29-76								4-30-76	
SPECIMEN	140 m	k	132 m	k	146 m	k	108 m	k	84 m	k
1	320	0.848	✕	✕	416	1.060	300	1.030	✕	✕
2	✕	✕	✕	✕	✕	✕	✕	✕	✕	✕
← 3	142	0.376	145	0.408	206	0.508	150	0.515	108	0.477

TIME →	4-30-76		5-3-76						5-4-76	
SPECIMEN	222 m	k	200 m	k	240 m	k	155 m	k	155 m	k
1	✕	✕	170	0.324	198	0.306	121	0.289	109	0.261
2	✕	✕	275	0.510	302	0.467	183	0.438	150	0.359
← 3	390	0.652	158	0.293	175	0.271	114	0.273	105	0.251

TIME →	5-4-76				5-5-76					
SPECIMEN	122 m	k	62 m	k	95 m	k	80 m	k	65 m	k
1	88	0.268	45	0.269	250	1.091	231	1.070	195	1.110
2	120	0.364	60	0.359	305	1.330	274	1.270	225	1.170
← 3	85	0.258	42	0.251	220	0.960	207	0.961	173	1.030

TIME →	5-5-76		5-6-76	
SPECIMEN	65 m	k	240 m	k
1	181	1.030	475	0.734
2	206	1.170	458	0.708
← 3	164	0.936	408	0.631

NOTE! Vapor lock discovered for readings from 5-3 thru 5-4-76, ∴ these values are invalid. Suspect paraffin leaking on days 5-5 & 5-6-76

4

SLOT 1

Type Specimen :	10% (2.0%)	Density :	120.98 #/ft³
Area Specimen :	31.68 cm²	% Proctor :	95.3 %
Height Specimen:	5.08 cm	Pressure Head:	240 cm
Weight Specimen:	312.14 gm	Comments :	Prepared new way (i.e.- H_2O & Emulsion Mixture added together)

SLOT 2

Type Specimen :	10 % (2.0%)	Density :	121.31 #/ft³
Area Specimen :	31.68 cm²	% Proctor :	95.6 %
Height Specimen:	5.08 cm	Pressure Head:	240 cm
Weight Specimen:	312.99 gm	Comments :	[See Comments above]

SLOT 3

Type Specimen :	10 % (2.0%)	Density :	120.96 #/ft³
Area Specimen :	31.68 cm²	% Proctor :	95.3 %
Height Specimen:	5.08 cm	Pressure Head:	240 cm
Weight Specimen:	311.95 gm	Comments :	[See Comments above]

****

TIME →	5-13-76									
SPECIMEN	96m'	k	77m'	k	60m'	k	123m'	k	65m'	k
← 1	182	0.718	148	0.728	111	0.700	240	0.739	125	0.728
← 2	197	0.777	169	0.831	122	0.770	264	0.813	140	0.816
← 3	227	0.896	188	0.925	131	0.827	286	0.881	143	0.833

TIME →	5-14-76									
SPECIMEN	68m'	k	120m'	k	75m'	k		k		k
1	195	1.086	300	0.947	201	1.015				
2	252	1.403	395	1.247	263	1.328				
3	250	1.392	365	1.152	245	1.237				

TIME →										
SPECIMEN		k		k		k		k		k
1										
2										
3										

TIME →										
SPECIMEN		k		k		k		k		k
1										
2										
3										

NOTE: Suspect all 3 specimens began to leak badly on the 4th around the sides

5

SLOT 1

Type Specimen	14% (2.8%)		Density	117.50 #/Ft³	
Area Specimen	31.68	cm²	% Proctor	92.6 %	
Height Specimen	4.77	cm	Pressure Head	230	cm
Weight Specimen	284.00	gm	Comments		

SLOT 2

Type Specimen	14% (2.8%)		Density	118.31 #/Ft³	
Area Specimen	31.68	cm²	% Proctor	93.2 %	
Height Specimen	4.60	cm	Pressure Head	230	cm
Weight Specimen	276.45	gm	Comments		

SLOT 3

Type Specimen	14% (2.8%)		Density	116.90 #/Ft³	
Area Specimen	31.68	cm²	% Proctor	92.2 %	
Height Specimen	4.77	cm	Pressure Head	230	cm
Weight Specimen	287.72	gm	Comments		

****

TIME →	5-10-76									
SPECIMEN	125m	k	205m	k	70m	k	115m	k	65m	k
1	O.F.	—	532	0.963	249	1.320	380	1.220	213	1.216
← 2	275	0.816	325	0.588	148	0.588	250	0.806	137	0.782
3	O.F.	—	O.F.	—	438	2.335	O.F.	—	385	2.198

TIME →	5-11-76									
SPECIMEN	125m	k	95m	k		k		k		k
1	483	1.434	333	1.300						
← 2	300	0.891	208	0.812						
3	O.F.	—	—	—						

TIME →										
SPECIMEN		k		k		k		k		k
1										
2										
3										

TIME →										
SPECIMEN		k		k		k		k		k
1										
2										
3										

NOTE: Obvious that 1 & 3 are leaking badly around the specimen. Specimen #2 is somewhat questionable

6

SLOT 1

Type Specimen : 14% (2.8 %) | Density : 121.36 #/ft³
Area Specimen : 31.68 cm² | % Proctor : 95.6 %
Height Specimen: 5.09 cm | Pressure Head: 230 cm
Weight Specimen: 313.63 gm | Comments : ONLY 13.3 % &
Specimen prepared incorrectly

SLOT 2

Type Specimen : 14% (2.8%) | Density : 121.08 #/ft³
Area Specimen : 31.68 cm² | % Proctor : 95.4 %
Height Specimen: 5.05 cm | Pressure Head: 230 cm
Weight Specimen: 312.33 gm | Comments : Leaked badly
around the sides

SLOT 3

Type Specimen : 14% (2.8%) | Density : 122.12 #/ft³
Area Specimen : 31.68 cm² | % Proctor : 96.2 %
Height Specimen: 5.08 cm | Pressure Head: 230 cm
Weight Specimen: 315.00 gm | Comments :

****

TIME →	5-15-76		5-17-76									
SPECIMEN	130m	k	62m	k	75m	k	120m	k	145m	k		
← 1	82cc	10.249	90	10.523	165	10.961	267	10.879	307	10.837		
2	100	10.547	150	10.956	290	11.523	465	11.531	525	11.431		
← 3	140	10.425	100	10.637	175	10.922	273	10.899	316	10.861		

TIME →	5-18-76									
SPECIMEN	78m	k	95m	k	100m	k		k		k
← 1	195	10.706	266	11.082	460	11.016				
2	~	~	~	~	~	~				
← 3	185	10.937	250	11.045	436	10.944				

TIME →										
SPECIMEN		k		k		k		k		k
1										
2										
3										

TIME →										
SPECIMEN		k		k		k		k		k
1										
2										
3										

NOTE: #1 & #3 questionable for 5-18-76; suspect leakage

7

SLOT 1

Type Specimen :	22% (4.4%)	Density :	119.39 #/ft³
Area Specimen :	31.68 cm²	% Proctor :	94.1 %
Height Specimen:	5.08 cm	Pressure Head:	Varies ↓
Weight Specimen:	307.95 gm	Comments :	It is 191 cm for days 5-25 to 6-13 ; then it is 230 cm for 6-18 to 6-21-76

SLOT 2

Type Specimen :	22% (4.4%)	Density :	119.52 #/ft³
Area Specimen :	31.68 cm²	% Proctor :	94.2 %
Height Specimen:	5.08 cm	Pressure Head:	[See #1 above]
Weight Specimen:	308.28 gm	Comments :	

SLOT 3

Type Specimen :		Density :	
Area Specimen :		% Proctor :	
Height Specimen:		Pressure Head:	
Weight Specimen:		Comments :	

****

TIME →	5-25-76				5-26-76		5-28-76			
SPECIMEN	395m	k	970m	k	1200m	k	150m	k	320m	k
←1	177	0.206	470	0.222	565	0.214	165	0.505	363	0.520
←2	200	0.232	526	0.246	+650	+.245	170	0.520	353	0.506
↓										

TIME →	6-12-76						6-13-76			
SPECIMEN	200m	k	260m	k	190m	k	720m	k		k
←1	175	0.401	200	0.352	143	0.365	380	0.242		
←2	152	0.348	175	0.308	123	0.314	356	0.223		
↓										

TIME →	6-18-76								6-19-76	
SPECIMEN	95m	k	235m	k	260m	k	120m	k	600m	k
←1	78	0.324	180	0.302	195	0.266	80	0.263	383	0.252
←2	100	0.416	240	0.404	240	0.365	110	0.362	525	0.346
↓										

TIME →	6-21-76									
SPECIMEN	60m	k	160m	k	315m	k		k		k
←1	30	0.197	77	0.190	155	0.194				
←2	40	0.263	95	0.235	205	0.257				
↓										

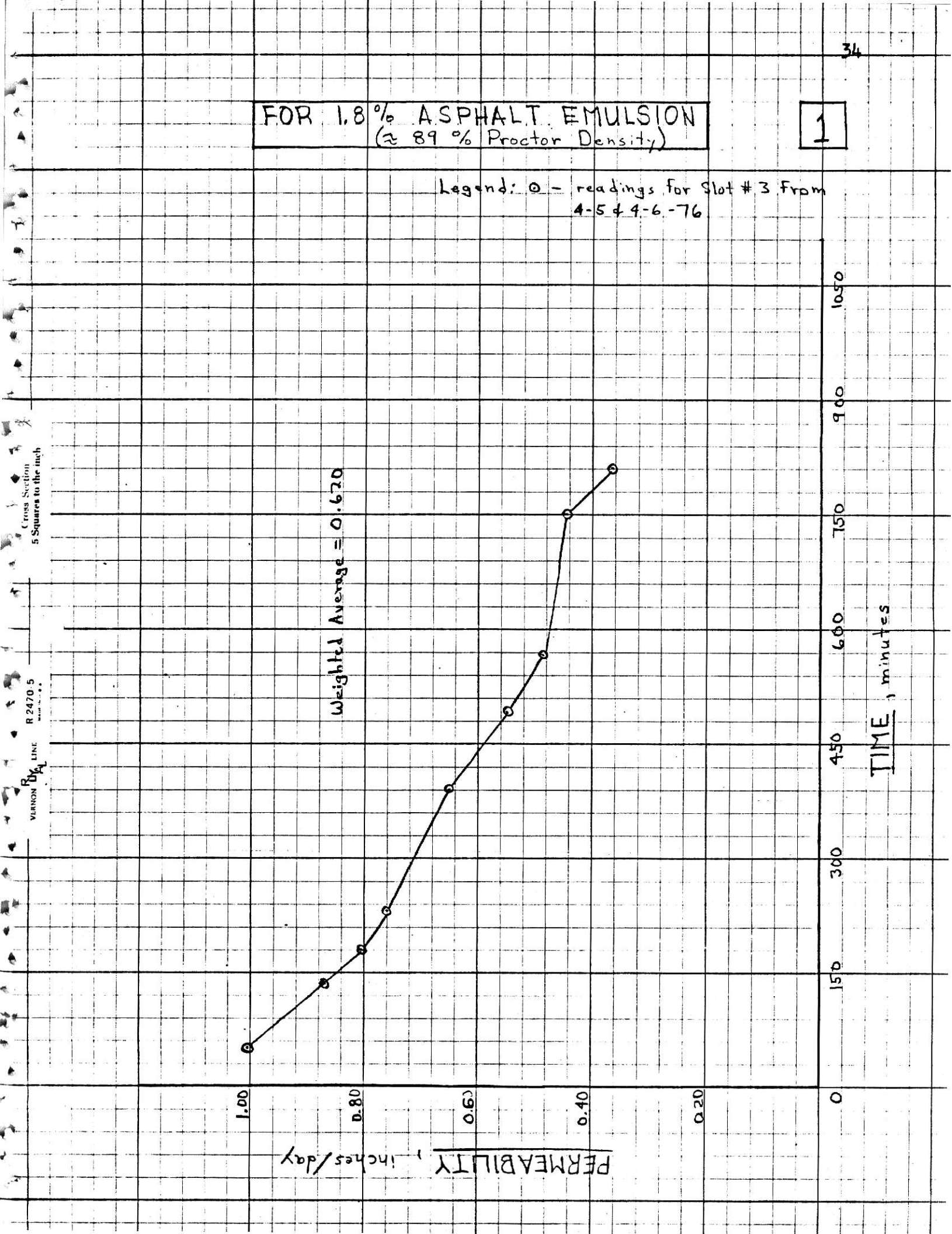
THE FOLLOWING DOCUMENT HAS PRINTING THAT EXTENDS INTO THE BINDING.

THIS IS AS RECEIVED FROM CUSTOMER.

FOR 1.8% ASPHALT EMULSION
(≈ 89 % Proctor Density)

1

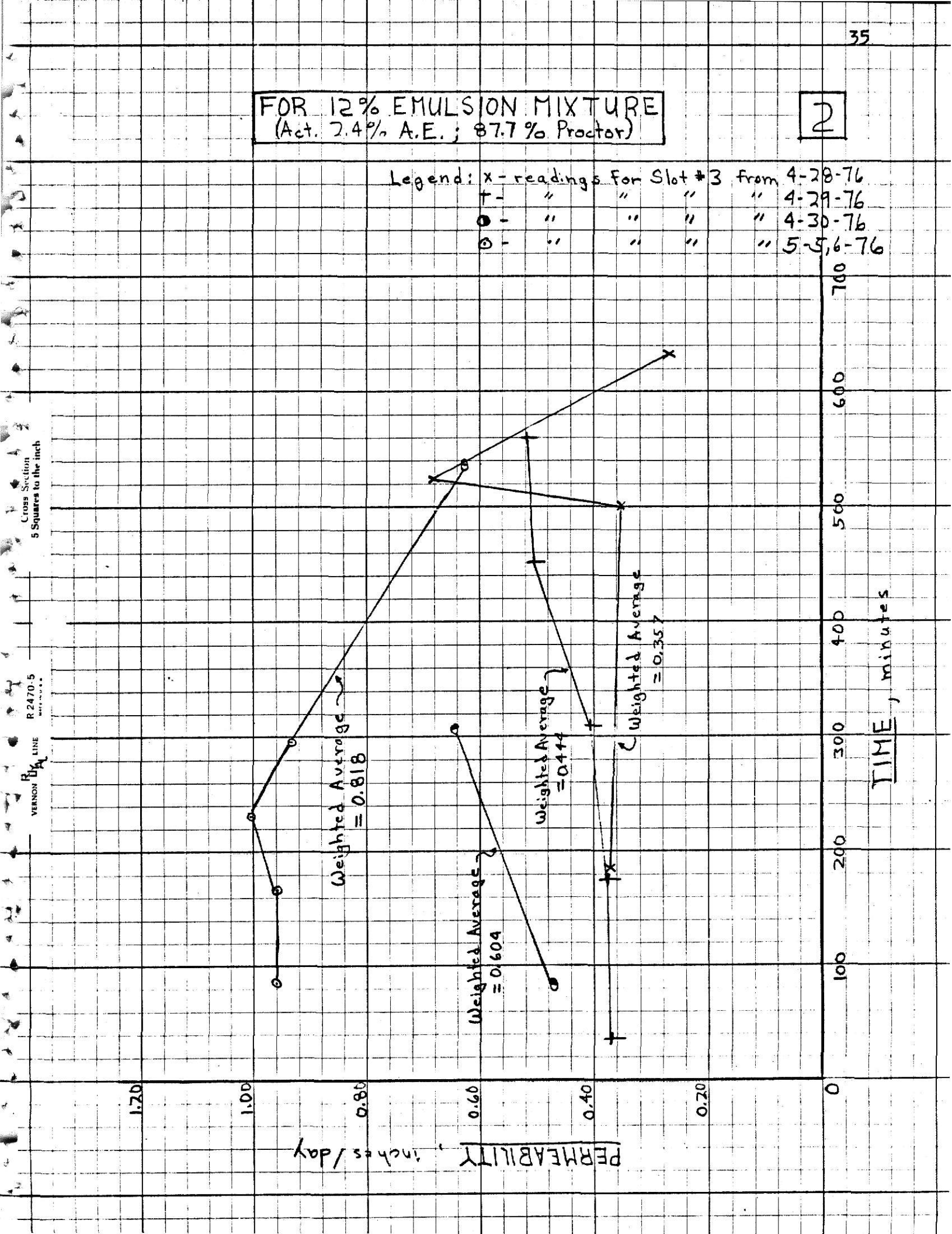
Legend: ⊙ – readings for Slot #3 From 4-5 & 4-6-76

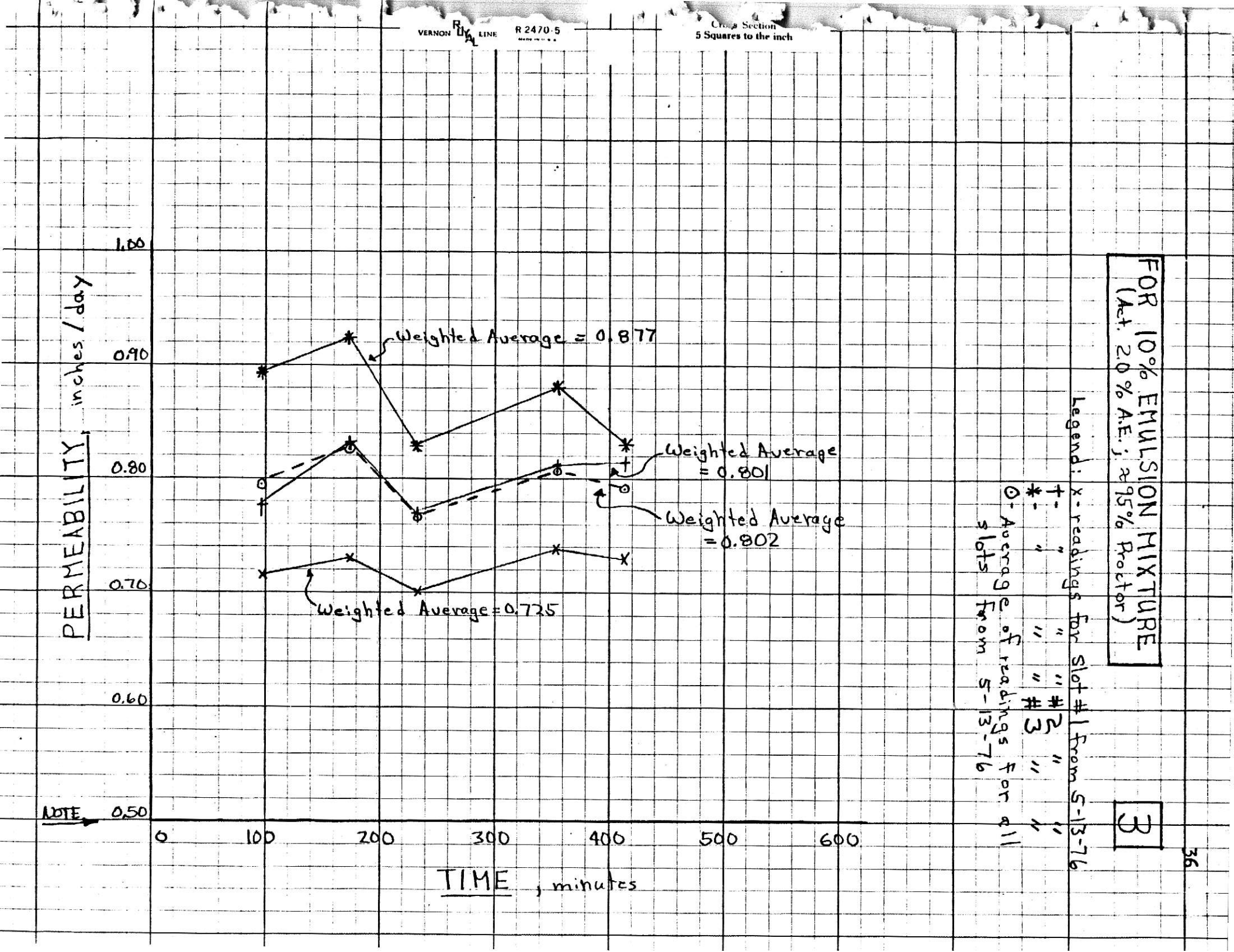


FOR 12% EMULSION MIXTURE
(Act. 2.4% A.E.; 87.7% Proctor)

2

Legend: x - readings for Slot #3 from 4-28-76
+ - " " " " " 4-29-76
● - " " " " " 4-30-76
⊙ - " " " " " 5-5,6-76

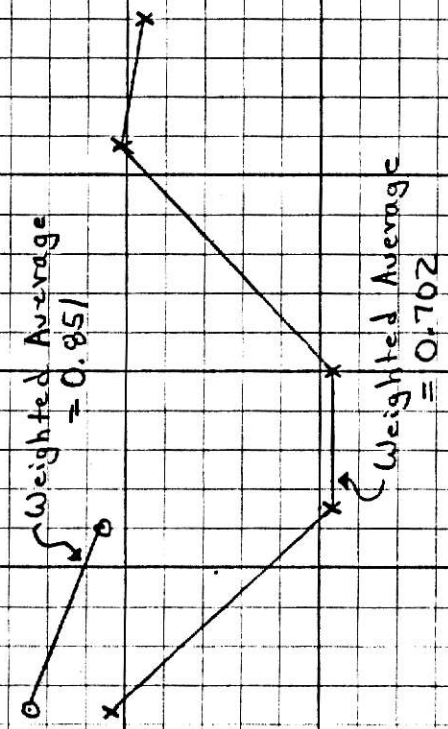




FOR 14% EMULSION MIXTURE
(Act. 2.8% A.E.; 93.2% Proctor)

4

Legend: X - readings for Slot #2 from 5-10-76
⊙ - " " " " " 5-11-76



PERMEABILITY, inches/day

1.00 0.80 0.60 0.40 0.20 0

TIME, minutes

0 100 200 300 400 500 600

Cross Section
5 Squares to the inch

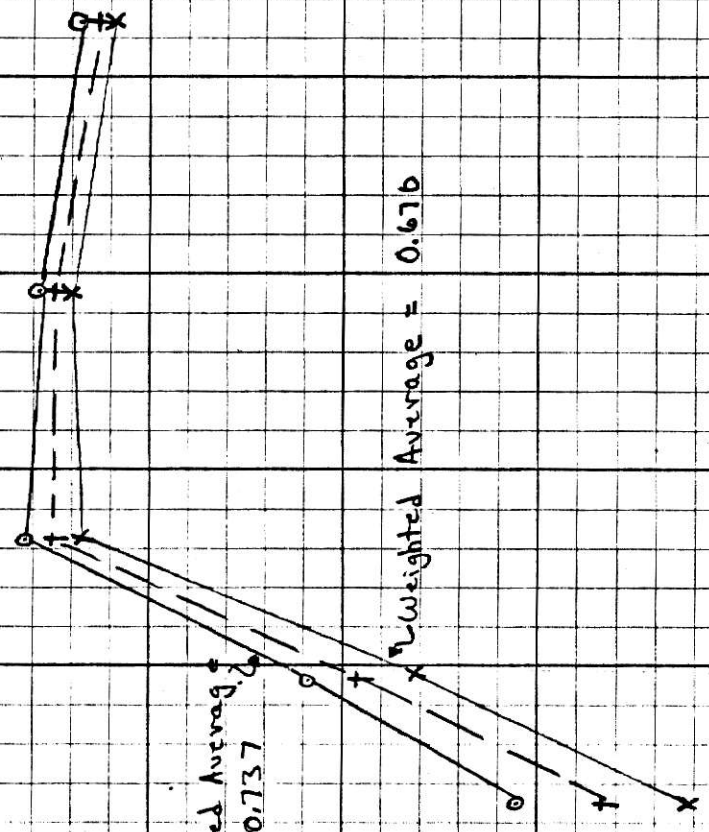
VERNON BKL LINE R 2470-5

FOR 14% EMULSION MIXTURE
(Act. 2.8% A.E.; ≈95% Proctor)

5

Legend: x - readings for Slot #1 from 5-15,17-76
o - " " " #3 " " "
+ - Average of 2 Slots " "

Total Weighted Average
= 0.7035



PERMEABILITY, inches / day

1.00 0.80 0.60 0.40 0.20 0

TIME, minutes

0 100 200 300 400 500 600

THIS BOOK CONTAINS NUMEROUS PAGES THAT ARE CUT OFF

THIS IS AS RECEIVED FROM THE CUSTOMER

FOR 22% EMULSION MIXTURE
(Act. 4.4% A.E.; ≈ 94% Proctor)

6

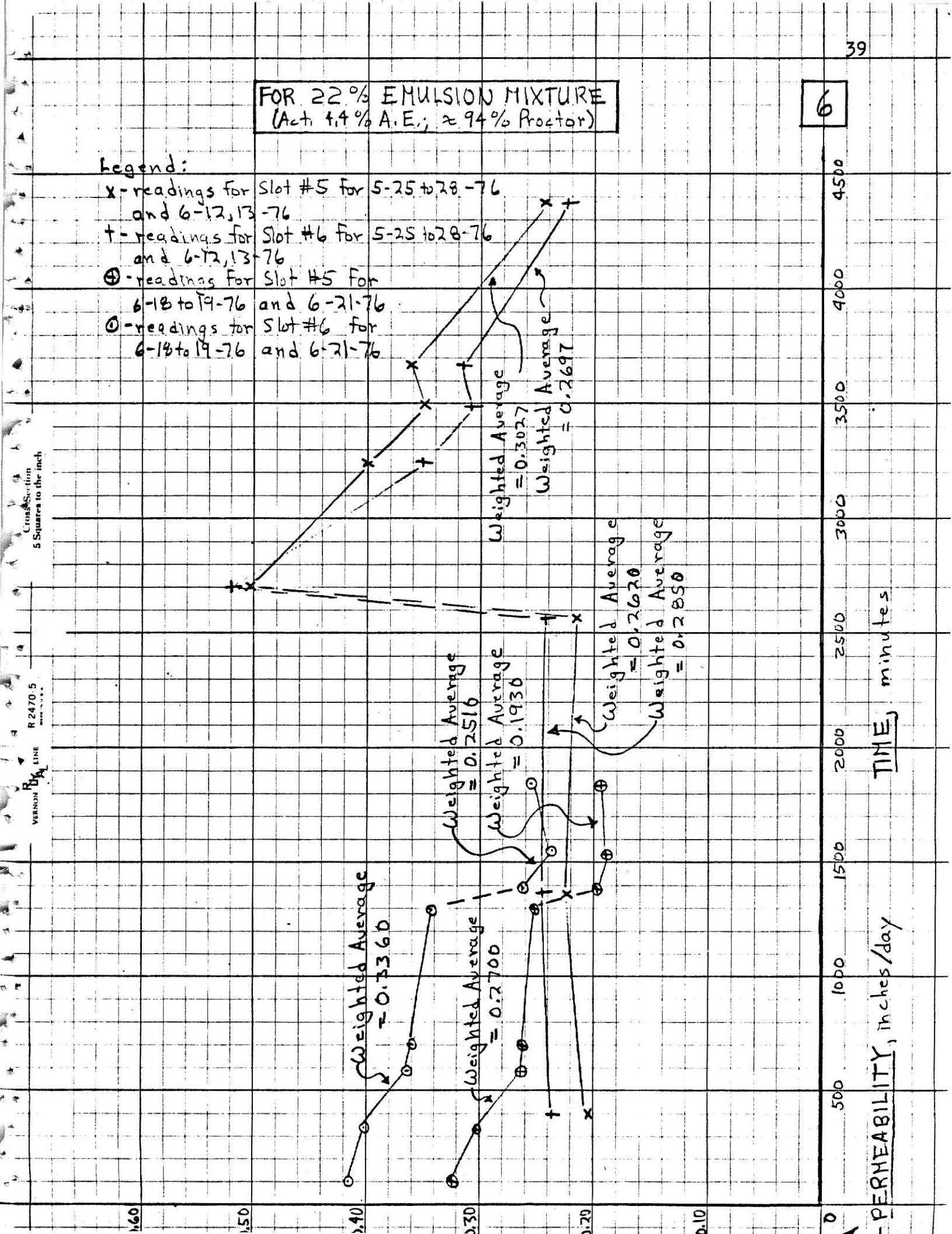
Legend:

x - readings for Slot #5 for 5-25 to 28-76 and 6-12, 13-76

+ - readings for Slot #6 for 5-25 to 28-76 and 6-12, 13-76

⊕ - readings for Slot #5 for 6-18 to 19-76 and 6-21-76

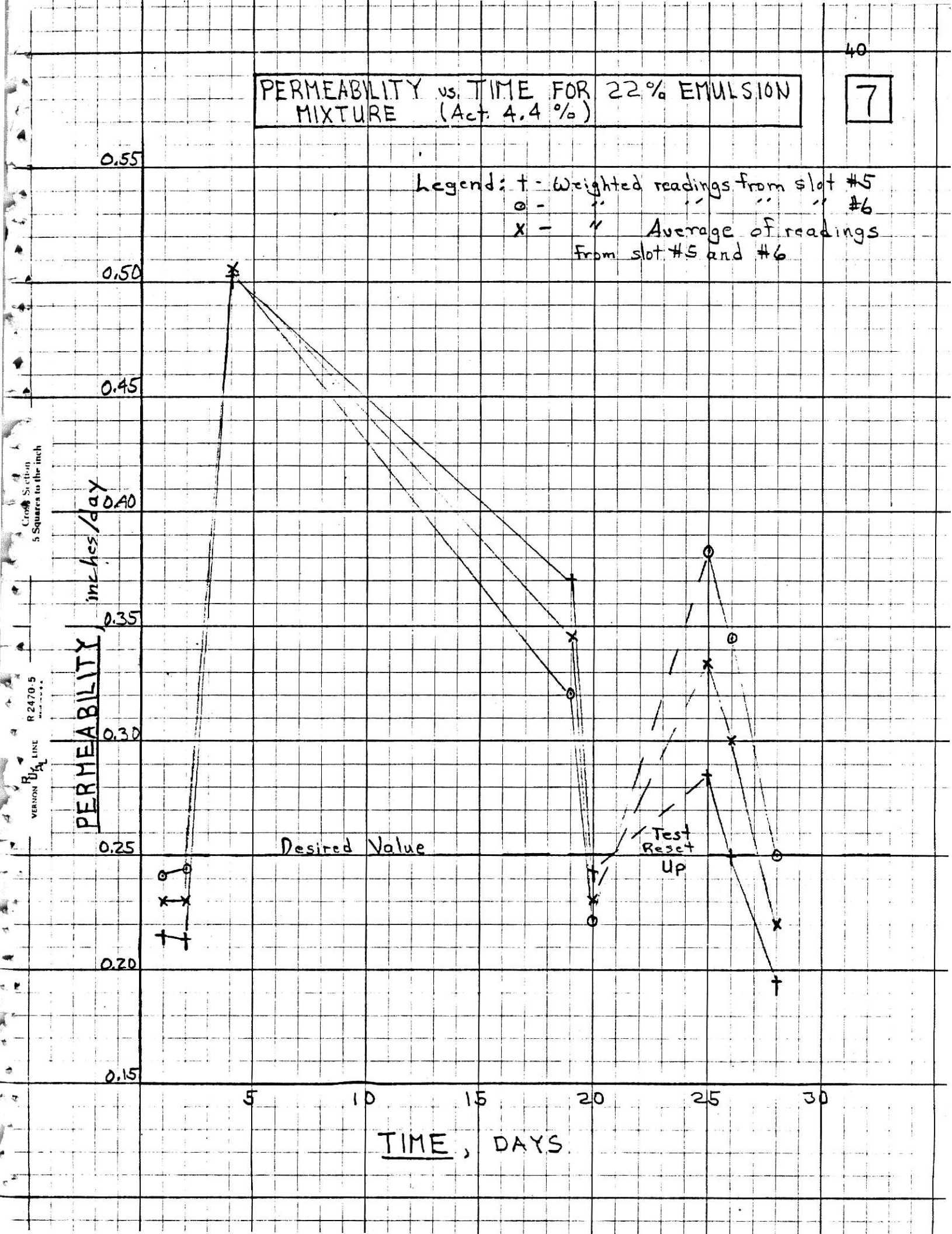
⊙ - readings for Slot #6 for 6-18 to 19-76 and 6-21-76



7

PERMEABILITY vs. TIME FOR 22% EMULSION MIXTURE (Act. 4.4 %)

Legend: † - Weighted readings from slot #5
⊙ - " " " " #6
X - " Average of readings from slot #5 and #6



PER CENT ASPHALT EMULSION → PERMEABILITY

8

1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20

PERMEABILITY, inches/day

⊙8 day
⊗2 day
•1 day
1 day ×
⊗1 day
⊙9 day
⊙3 day
⊙2 day
† 4 day
2 day ×
⊙1 day
† 19 day
† 25 day
† 26 day
† 1 day, 2 day, + 20 day
† 28 day

1.0 2.0 3.0 4.0 5.0

PER CENT ASPHALT EMULSION

D I S C U S S I O N
O F R E S U L T S

The data presented in the previous section will be discussed here in terms of results both practical and theoretical.

The first result to be discussed is the per cent of asphalt emulsion effect on permeability. An increase in per cent of asphalt emulsion mixture in a specimen did seem to lower the permeability. A straight line relationship was not found to be the case as hoped for. The graph of percent asphalt emulsion versus permeability does show an decrease in permeability with increasing asphalt content, but results did not yield a definite curve or function with which to predict permeability.

The effect of time elapsed on permeability was observed, but results are not concrete. In the 1.8% asphalt emulsion specimen (graph 1, table 2) the permeability steadily decreased with time. The 2.4% asphalt emulsion specimen (graph 2, table 3) results do not validate this. There a marked increase in permeability with increasing time was observed. There were points of decreased permeability with increased time and the final readings showed a decreasing permeability, yet the overall effect was an increased permeability with increased time. The 2.8% and 2.0% asphalt emulsion mixture specimens (graph 3 & 4, tables 4 & 5) results indicate only a slight overall decrease in permeability with increasing time. The 2.8% asphalt emulsion specimen (graph 5, table 6) results indicate an overall increase in permeability with

increasing time. However, the 4.4% asphalt emulsion specimen results indicate a definite decrease in permeability with increasing time. The overall decrease is only minimal and was subject to much fluctuation during the time period studied.

The results of relationship of permeability and per cent Proctor density seem inclusive.

In observing the results as a whole it is put forth that due to a misunderstanding by the author of the physical mechanism by which the anionic asphalt emulsion is adhered onto the soil particles that the validity of the results of all specimens prior to the 22% asphalt emulsion mixture (4.4% actual emulsion content) is somewhat questionable. It is also put forth here by the author that the washing away of the asphalt emulsion particles from the soil particles and the ineffective method by which specimens were secured in the permeameters caused the results to be questionable.

As to the results of obtaining the desired permeability rate of 0.25 inches/day, as stated in the purpose of this study, the results indicate that an asphalt emulsion percentage of 4.4 will control the permeability of this soil to 0.25 inches/day $\pm$ 0.05 inches/day. Also the results indicate that after a 28 day period the permeability was within 0.025 inches/day of the desired rate.

C O N C L U S I O N S

The conclusions put forth here are based on the results previously stated and the authors judgment of those results. The conclusions are: (1) that permeability of the soil studied was affected by the addition of anionic SS-1h emulsion diluted with water to the soil; (2) that increasing time does affect the permeability rate of the above mentioned anionic asphalt emulsion soil mixture; (3) that permeability of the soil can be controlled within tolerance of the desired value by the anionic asphalt emulsion.

The permeability of the soil studied was affected by the anionic asphalt emulsion mixed with water to form an 80% water and 20% emulsion mixture and then blended in with the soil. The overall affect of this mixture was to lower the permeability of the soil. The amount that the permeability was lowered was dependent upon the percentage of asphalt emulsion mixture blended in with the soil. It can roughly be concluded that the greater the percentage of asphalt emulsion mixture blended in with the soil the lower the permeability rate will be .

The increasing elapse of time does affect the permeability rate of the asphalt emulsion-soil mixture. If a more than sufficient period of time is allowed for the asphalt particles in the emulsion mixture to "break", or adhere, to the soil particles before saturation takes place then an overall slight decrease in the permeability rate will occur. If insufficient time is allowed

for the particles to "break" before saturation takes place, then an overall increase in permeability rate will result due to the washing away of the asphalt particles.

The permeability of the soil can be controlled within tolerance of the desired value by the anionic asphalt emulsion mixture. The desired value of 0.25 inches/day was achieved within $\pm$ 0.05 inches/day by using 4.4% anionic SS-1h asphalt emulsion diluted with water to an 80% water and 20% emulsion mixture and then blended with the soil. The author concludes that anionic SS-1h asphalt emulsion can be used to control the permeability rate of this soil within reasonable tolerances.

A R E A S F O R F U R T H E R R E S E A R C H

It is the author's hope that similar studies such as this will be conducted. With more extensive laboratory experiments and thereby a greater amount of data from which to base conclusions it would seem that a relationship between per cent asphalt emulsion and permeability could be acheived. It is also recommended that different soils be used and an attempt made to derive a graph of per cent asphalt emulsion versus permeability for each soil. It is recommended that more extensive time studies be made to determine accurately the effect that time has on permeability in soils treated with asphalt emulsions. One other area is recommended and that is that different emulsions be used to determine their effect on soil permeability.

A P P E N D I X A

3-10-76

* Water content determination of natural soil

	#4.1	#3A2	Bowl #2
Wt. of can (or bowl)	13.94	13.89	488.77
Wt. of can + wet soil	63.90	48.56	1150.00
Wt. of can + dry soil	63.17	47.83	1135.32
Wt. of water	0.73	0.73	14.68
Water Content, w%	1.48%	2.15%	2.27%

Value from Bowl #2 judged more accurate and value established as $\text{Water Content}_{\text{natural soil}} = 2.25\%$

* Permeability Determination for natural soil

Formula used:

$$k = \frac{QL}{thA}$$

where, Q = volume in cm^3, t = time in seconds, h = head in cm (constant), L = thickness of specimen in cm, A = area of specimen in cm^2.

To convert from cm/sec to in/day multiply by 3.4015×10^4

First specimen of natural soil

Time	Volume	Thickness	Area	Head	Permeability
600	50	5.08	31.68	208	1.065 inches/day
8700	485	5.08	31.68	208	0.713 inches/day
2400	160	5.08	31.68	208	0.852 inches/day

NOTE: Upon disassembly of the test apparatus it was discovered

that the height of the specimens was not 5.08 cm, but it had been lowered approximately 1.27 centimeters in the middle of the specimen and therefore these values cannot be considered as valid.

3-12-76

Second specimen of natural soil (soaked for 16 hours)

Time	Volume	Thickness	Area	Head	Permeability
9000	425	5.08	31.68	208	1.237 inches/day
4500	200	5.08	31.68	208	1.168 inches/day

Value of 1.214 inches/day derived by giving 2/3 weight to value #1 and 1/3 weight to value #2 and averaging. Natural soil is said to have a permeability of 1.214 inches/day.

* Specific gravity determination for natural soil

Wt. of bottle ..... 184.31 grams
Wt. of Bottle + soil ..... 706.18 grams
Wt. of soil (natural w%) ..... 50.00 grams

Wt. of bowl #6 ..... 485.65 grams
Wt. of bowl #6 + water + soil .....1112.23 grams
Wt. of bowl #6 + dry soil ..... 524.57 grams
Wt. of dry soil ..... 38.92 grams
Wt. of water ..... 587.66 grams

Temperature of bottle + water + boiled soil after cooling = 29°C.

Formula for specific gravity determination

$$G_s = \frac{W_s G_t}{W_s - W_1 + W_2}$$

where, G_t = 0.9960 (pg. 197, Lamb Lab manual)

W_s = 38.92 grams

W_1 = 706.18 grams

$W_2 = W_B + V_B(1 + \Delta T \cdot \epsilon)(\gamma_T - \gamma_a)$

where, W_B = Wt. bottle

V_B = Volume Bottle

$\Delta T = T - T_c$ ($T=29^oC$, $T_c=20^oC$)

ϵ = thermal coefficient of glass = 0.1×10^{-4}

γ_T = value from Lamb Lab manual = 0.9960

γ_a = value for air = 0.0012

so,

$$W_2 = 184.31 + 500(1+9^o(0.1\times10^4))(0.9960-0.0012)$$

$$W_2 = 681.75 \text{ grams}$$

Thus,

$$G_s = \frac{38.92(0.9960)}{38.92 - 706.18 + 681.75} = 2.675$$

*Soil Quantity Determination

With maximum dry density = 112.1 lb/ft^3 = 50893.4 gm/ft^3

= 29.452 gm/in^3

Specimen $2\frac{1}{2}$ inch diameter by 2 inches height = $\pi(1.25 \text{ in})^2 \times 2$

= 9.817 $inch^3$

so amount needed = 9.817 in^3 x 29.452 gm/in^3

= 289.14 grams of dry soil

with natural water content at 2.25% amount of natural soil needed = 1.0225 x 289.14 grams

= 295.6 grams

with optimum moisture content at 13.2% only 10.95% more water needed = 31.6 grams of water

Thus the total weight of specimen at 100% maximum Proctor density and optimum moisture content = 327.2 grams

so at 85 to 90% Proctor density = 278.92 to 294.48 grams

Try for this for first tests.

3-26-76

* 1st attempt at using emulsion.

Using new 3-slot permeameter and old aluminum permeameter.

Plan to use 1%, 3%, 5%, & 8% by weight of emulsion.

Try 1%

Wt. of bowl	500.87 grams
Wt. of bowl + soil	790.00 grams
Wt. of bowl + soil + water	818.25 grams
Wt. of bowl + soil + water + emulsion	821.11 grams

WON'T MIX!!!

Must dilute with water; try 50-50 solution.

For 3%

Wt. of bowl	500.28 grams
Wt. of bowl + soil	753.28 grams
Wt. of bowl + soil + water	781.93 grams
Wt. of bowl + soil + water + emulsion	789.62 grams

WON'T MIX!!!

Try 75-25 water to emulsion mixture

For 5%

Wt. of bowl	500.28 grams
Wt. of bowl + soil	748.28 grams
Wt. of bowl + soil + water	775.43 grams
Wt. of bowl + soil + water + emulsion	789.18 grams
(Wt. soil ..... 248.00 grams)	
(Wt. water ..... 27.15 grams)	
(Wt. emulsion ..... 13.75 grams)	
Wt. of specimen	284.20 grams
Density of Specimen	110.18 lb/ft^3
% Proctor Density	86.8%

NOTE: Conversion factor for changing wt. of specimen to density of specimen is o.3877 for $2\frac{1}{2}$ inch diameter by 2 inch height spec.

IN SLOT # 1

Didn't mix too badly, but try now an 80-20 water emulsion mixture

For 5%

Wt. of bowl	500.80 grams
Wt. of bowl + soil	748.80 grams
Wt. of bowl + soil + water	775.69 grams
Wt. of bowl + soil + water + emulsion	789.44 grams
(Wt. of soil 248.00 grams)	
(Wt. of water 26.89 grams)	
(Wt. of emulsion 13.75 grams)	
Wt of specimen	286.64 grams
Density of Specimen	111.13 lb/ft^3
% Proctor Density	87.5%

IN SLOT #2

Use 80-20 mixture again

For 8%

Wt. of bowl	500.58 grams
Wt. of bowl + soil	741.58 grams
Wt. of bowl + soil + water	767.97 grams
Wt. of bowl + soil + water + emulsion	789.18 grams
(Wt. of soil 241.00 grams)	
(Wt. of water 26.39 grams)	
(Wt. of emulsion 21.21 grams)	
Wt. of specimen	284.87 grams
Density of specimen	110.44 lb/ft^3
% Proctor Density	87.0%

IN SLOT #3

Use 80-20 mixture again

For 10%

Wt. of bowl	500.21 grams
Wt. of bowl + soil	737.21 grams

Wt. of bowl + soil + water ..... 763.16 grams
Wt. of bowl + soil + water + emulsion ..... 789.45 grams
(Wt. of soil ..... 237.00 grams)
(Wt. of water ..... 25.95 grams)
(Wt. of emulsion ..... 26.29 grams)
Wt. of specimen ..... 281.15 grams
Density of specimen ..... 109.00 lb/ft^3
% Proctor Density 85.9%

IN ALUM #1

4-2-76

Slot	Time	Volume	Thickness	Head	Area	Permeability
A1	3600	95	5.08	227	31.68	0.634 inches/day
1	3660	275	5.08	225	31.68	1.821 inches/day
2	3780	182	5.08	225	31.68	1.167 inches/day
3	3900	39	5.08	225	31.68	0.242 inches/day
A1	4260	108	5.08	227	31.68	0.689 inches/day
1	4140	304	5.08	225	31.68	1.780 inches/day
2	3900	198	5.08	225	31.68	1.232 inches/day
3	3660	39	5.08	225	31.68	0.258 inches/day

4-5-76

* Actual water content of #3

Wt. of water = 26.39

+ 0.8(21.21) = 16.97 w% = 17.99 = 18% approximately

43.36

Emulsion/Soil$_{dry}$ = 1.76%

Try 2% emulsion based on dry soil weight; try for optimum moisture.

% water of air dry soil = approximately 2%; with optimum moisture = 13.2%, the we need 11.2% more

Use 256 grams of air dry soil, 28.12 grams of water, and 5.01 grams of emulsion$_{80-20}$

For 1.8% emulsion/ woil$_{dry}$, use 256 grams of air dry soil, 28.62 grams of water, and 4.51 grams of emulsion$_{80-20}$

For 2.5% emulsion/soil$_{dry}$, use 255 grams of air dry soil, 27.84 grams of water, and 6.24 grams of emulsion$_{80-20}$

For 2%

Wt. of bowl ..... 473.30 grams
Wt. of bowl + soil ..... 729.30 grams
Wt. of bowl + soil + water + emulsion ..... 761.87 grams
(Wt. of small bowl ..... 131.37 grams)
(Wt. of small bowl + H_2O .... 159.49 grams)
(Wt. of small bowl + H_2O + E. 164.50 grams)
Wt of specimen ..... 286.93 grams
Density of specimen ..... 111.24 lb/ft^3
% Proctor Density 87.6%

IN SLOT #1

For 2.5%

Wt. of bowl ..... 473.32 grams
Wt. of bowl + soil ..... 729.32 grams
Wt. of bowl + soil + water + emulsion ..... 761.29 grams
(Wt. of small bowl ..... 131.37 grams)
(Wt. of small bowl + H_2O .... 149.37 grams)
(Wt. of small bowl + H_2O + E. 155.61 grams)
ERROR !!! NOT 2.5 %
Wt. of specimen ..... 286.73 grams
Density of specimen ..... 111.16 grams
% Proctor Density 87.6%

IN SLOT #2

For 1.8%

Wt. of bowl ..... 473.33 grams
Wt. of bowl + soil ..... 729.33 grams
Wt. of bowl + soil + water + emulsion ..... 766.58 grams
(Wt. of small bowl ..... 131.42 grams)
(Wt. of small bowl + H_2O ..... 160.04 grams)
(Wt. of small bowl + H_2O + Emul 164.55 grams)
Wt. of specimen ..... 291.63 grams
Density of specimen ..... 113.06 lb/ft^3
% Proctor Density 89.1%

IN SLOT #3

For 1.8%

Wt. of bowl ..... 473.30 grams
Wt. of bowl + soil ..... 728.30 grams
Wt. of bowl + soil + water + emulsion ..... 761.21 grams
(Wt. of small bowl ..... 131.37 grams)
(Wt. of small bowl + H_2O ..... 156.42 grams)
(Wt. of small bowl + H_2O + Emul 161.01 grams)
Wt of specimen ..... 286.56 grams
Density of specimen ..... 111.09 lb/ft^3
% Proctor Density 87.5%

IN ALUM #1

NOTE: thickness, head and area are all constant on these tests at 5.08, 225, & 31.68 respectively

Time →

Specimen	48m	k	83m	k	50m	k	50m	k	160m	k	103m	k
3	175	1.47	305	1.42	175	1.42	175	1.41	-	-	-	-
2	295	2.48	506	2.46	310	2.50	-	-	-	-	-	-
1	125	1.05	179	0.87	100	o.81	94	0.76	260	.656	140	.549
A1	580	4.87	-	-	-	-	-	-	-	-	-	-

Time

Specimen	68m	k	185m	k	65m	k
3	183	1.08	-	-	-	-
2	-	-	-	-	-	-
1	84	.490	207	.452	60	.370
A1	-	-	-	-	-	-

4-12-76

*In reference to laboratory data 3-26-76 & 4-2-76

For 10% of 80-20 emulsion mixture

Wt. of bowl ..... 488.87 grams
Wt. of bowl + soil ..... 725.87 grams
Wt. of bowl + soil + water ..... 751.82 grams
Wt. of bowl + soil + water + emulsion ..... 778.02 grams
(Wt. of soil ..... 237.00 grams)
(Wt. of water ..... 25.95 grams)
(Wt. of emulsion ..... 26.29 grams)
Wt. of specimen ..... 275.38 grams
Density of specimen ..... 113.90 lb/ft^3
% Proctor Density 89.7%

SPECIMEN DESTROYED: ACCIDENT!!!!!

For 10% by wt. of 80-20 emulsion mixture

Wt. of bowl ..... 488.79 grams
Wt. of bowl + soil ..... 725.79 grams
Wt. of bowl + soil + water ..... 751.74 grams
Wt. of bowl + soil + water + emulsion ..... 778.00 grams
(Wt. of soil ..... 237.00 grams)
(Wt. of water ..... 25.95 grams)
(Wt. of emulsion ..... 26.26 grams)
Wt. of specimen ..... 283.90 grams
Density of specimen ..... 117.42 lb/ft^3
% Proctor Density 92.5%
Height of specimen ..... 1 7/8 inches

IN SLOT #1

For 10% by Wt. of 80-20 emulsion mixture

Wt. of bowl ..... 488.82 grams
Wt. of bowl + soil ..... 725.82 grams
Wt. of bowl + soil + water ..... 752.82 grams
Wt. of bowl + soil + water + emulsion ..... 778.90 grams
(Wt. of soil ..... 237.00 grams)
(Wt. of water ..... 27.00 grams)
(Wt. of emulsion ..... 26.08 grams)
Wt. of specimen ..... 285.73 grams
Density of specimen ..... 118.3#/ft^3
% Proctor Density 93.2%
Height of specimen ..... 1 7/8 inches

IN SLOT #2

For 8% by Wt. of 80-20 emulsion mixture

Wt. of bowl ..... 488.74 grams
Wt. of bowl + soil ..... 729.74 grams
Wt. of bowl + soil + water ..... 756.11 grams
Wt. of bowl + soil + water + emulsion ..... 778.93 grams
(Wt. of soil ..... 241.00 grams)
(Wt. of water ..... 26.39 grams)
(Wt. of emulsion ..... 22.82 grams)
Wt. of specimen ..... 286.25 grams
Density of specimen ..... 110.97#/ft^3
% Proctor Density 87.4%
Height of specimen ..... 2 inches

IN SLOT #3

For 8% by Wt. of 80-20 emulsion mixture

Wt. of bowl ..... 488.78 grams
Wt. of bowl + soil ..... 738.78 grams
Wt. of bowl + soil + water ..... 766.15 grams
Wt. of bowl + soil + water + emulsion ..... 788.15 grams

(Wt of soil ..... 250.00 grams)
(Wt of water ..... 27.37 grams)
(Wt of emulsion ..... 22.00 grams)

Wt. of 2nd bowl ..... 477.45 grams
Wt. of 2nd bowl + soil + water + emulsion .... 766.59 grams
Wt. of specimen ..... 287.77 grams
Density of specimen ..... 111.57 #/ft^3
% Proctor Density 87.9%

NOTE: In this specimen preparation a large batch of soil-water-emulsion was prepared and then enough transferred into another bowl to make the specimen.

IN ALUM #1

- - - - - - -

NOTE: Area and height are constant at 31.68 and 225 respectively.

Specimen	Time	Volume	Height	Permeability
A1	200m	542	5.08 cm	1.090 inches/day
1	200m	148	4.77 cm	0.280 inches/day
2	200m	189	4.77 cm	0.358 inches/day
3	200m	181	5.08 cm	0.365 inches/day
A1	195m	+650	5.08 cm	- - - -
1	195m	145	4.77 cm	0.282 inches/day
2	195m	150	4.77 cm	0.291 inches/day
3	195m	195	5.08 cm	0.404 inches/day

4-26-76

It appears from other tests that 10% of 80-20 results in almost exactly 0.25 inches/day. The results are 0.05 inches/day high, so I am going to use 11% of 80-20 for 2 specimens and 12% of 80-20 for 2 specimens.

For 11% by Wt. of 80-20 emulsion mixture

Wt. of bowl ..... 473.28 grams
Wt. of bowl + soil ..... 710.28 grams
Wt. of bowl + soil + water ..... 736.28 grams
Wt. of bowl + soil + water + emulsion ..... 762.28 grams
(Wt. of soil ..... 237.00 grams)
(Wt. of water ..... 26.00 grams)
(Wt. of emulsion ..... 26.00 grams)

Wt. of specimen ..... 287.74 grams
Density of specimen ..... 111.55#/ft^3
% Proctor Density 87.9%

IN SLOT #1

For 11% by Wt. of 80-20 emulsion mixture

Wt. of bowl ..... 473.38 grams
Wt. of bowl + soil ..... 710.38 grams
Wt. of bowl + soil + water ..... 736.28 grams
Wt. of bowl + soil + water + emulsion ..... 762.28 grams
(Wt. of soil .....237.00 grams)
(Wt. of water ..... 26.00 grams)
(Wt. of emulsion ..... 26.00 grams)
Wt. of specimen ..... 286.33 grams
Density of specimen ..... 111.55#/ft^3
% Proctor Density 87.5%

IN SLOT #2

For 12% by Wt. of 80-20 emulsion mixture

Wt. of bowl ..... 473.38 grams
Wt. of bowl + soil ..... 710.38 grams
Wt of bowl + soil + water ..... 736.38 grams
Wt. of bowl + soil + water + emulsion ..... 764.37 grams
(Wt. of soil ..... 237.00 grams)
(Wt. of water ..... 26.00 grams)
(Wt. of emulsion ..... 26.00 grams)
Wt. of specimen ..... 287.11 grams
Density of specimen ..... 111.30 #/ft^3
% Proctor Density 87.7%

IN SLOT #3

NOTE: ALum 1 is deemed not functional. I think that it is leaking through a crack in the polethylene tube.

Time → / Specimen	185m	k	315m	k	24m	k	110m	k
3	186	.373	300	.353	44	.681	80	.269?
2	615	1.230	-	-	-	-	-	-
1	191	.383	325	.382	50	.773	235	.792

Time → 4-29-76

Specimen	35m	k	140m	k	132m	k	146m	k	108m	k
3	35	.371	142	.376	145	.408	200	.508	150	.515
2	-	-	-	-	-	-	-	-	-	-
1	100	1.060	320	.848	-	-	416	1.060	300	1.030

Time → 4-30-76 → 5-3-76

Specimen	84m	k	222m	k	200m	k	240m	k	155m	k
3	108	.477	390	.652	158	.293	175	.271	114	.273
2	-	-	-	-	275	.510	302	.467	183	.438
1	-	-	-	-	175	.324	198	.306	121	.289

Time → 5-4-76 → 5-5-76

Specimen	155m	k	122m	k	62	k	85	k	80	k	65	k
3	105	.251	85	.258	42	.251	220	.960	207	.960	173	1.03
2	150	.359	120	.364	60	.359	305	1.33	274	1.27	225	1.33
1	109	.261	88	.268	45	.269	250	1.09	231	1.07	195	1.11

Time → 5-5-76 5-6-76

Specimen	65m	k	240m	k
3	164	.936	408	.631
2	206	1.17	458	.788
1	181	1.03	475	.734

NOTE: Suspect that readings from 5-3-76 and 5-4-76 are affected by a vapor lock which reduced the head pressure, thus these values are considered invalid. Also the readings from 5-5-76 and 5-6-76 are suspect of being affected by the paraffin leaking around the specimen.

5-7-76

Now try 14% by Wt. of 80-20 emulsion mixture and use 240 grams soil as base, then need 33.6 (i.e. 240 x 0.14) of emulsion solution and 11.54 grams water.

Actual water content = 16%

Actual weight of Asphalt = 6.72 grams

Make up 3 samples at this specification

Wt. of bowl ..... 500.33 grams
Wt. of bowl + soil ..... 740.33 grams
Wt. of bowl + soil + water ..... 755.87 grams
Wt. of bowl + soil + water + emulsion ..... 789.47 grams

Wt. of specimen ..... 284.00 grams
Density of specimen ..... 117.5 #/ft^3
% Proctor Density 92.6%
Height of specimen ..... 1 7/8 inches

NOTE: Specimen compressed to 3055 psi

IN SLOT #1

For 14% by Wt. of soil with 80-20 emulsion mixture

Wt. of bowl ..... 500.41 grams
Wt. of bowl + soil ..... 740.41 grams
Wt. of bowl + soil + water ..... 760.32 grams
Wt. of bowl + soil + water + emulsion ..... 793.92 grams

Wt. of specimen ..... 287.72 grams
Density of specimen ..... 116.96 #/ft^3
% Proctor Density 92.2%
Height of specimen ..... 1 7/8 inches

IN SLOT #3

NOTE: h for tests is 230 cm L for 1&3 is 4.77 cm, & for #2 is 4.60

Time

Specimen	125m	k	205m	k	70m	k	115m	k	65m	k
1	O.F.	-	532	0.963	249	1.320	380	1.220	213	1.216
2	275	0.816	325	0.588	148	0.785	250	0.806	137	0.782
3	O.F.	-	O.F.	-	438	2.320	O.F.	-	385	2.198

Time

Specimen	125m	k	95m	k
1	483	1.434	333	1.300
2	300	0.891	208	0.812
3	O.F.	-	-	-

NOTE: O.F. means overflowed beaker

NOTE: May 11, 6:45 P.M.; obvious to me that #3 & #1 are leaking around the specimen and that #2 is very questionable.

5-12-76

Maximum dry Density = 112.1 #/ft^3
Optimum moisture = 13.2%
Total Density = 126.90 #/ft^3
Take 95% = 120.55 #/ft^3
90% = 114.20 #/ft^3
Now try to hit 95% Proctor Density + 120 #/ft^3
Wt. of 2 inches (5.08cm) specimen = 309.6 grams
Use air dry soil Wt. of 275 grams (allows a little loss in mixing)
NOTE: Air dry soil with equivalent of 1.0% now.

Now try 10% by Wt. of air dry soil of 80-20 emulsion mixture.
NOTE: Use enough water to allow adequate mixing but try to obtain optimum moisture. (i.e. - 10% of 80% water - 20% emulsion mixture increases water content of soil by 8%; so if W.A.D.S. = 1% then with 8% from emulsion 80-20 = 9%; so need equivalent of 4.2% more water).

Wt. of mixing bowl ..... 488.83 grams
Wt. of mixing bowl + soil ..... 763.83 grams
Wt. of mixing bowl + soil + water ..... 771.33 grams
Wt. of mixing bowl + soil + water + emulsion ..... 798.83 grams
Wt. of soil ..... 275 grams
Wt. of water ..... 7.5 grams
Wt. of emulsion ..... 27.5 grams
SPECIMEN DESTROYED ACCIDENTLY!!!

New Procedure, put water in with emulsion
NOTE: Use water to rinse out bowl where emulsion mixture was into mixing bowl with soil while watching the scale so as not to add to much water.

Wt. of bowl ..... 488.83 grams
Wt. of bowl + soil ..... 763.83 grams
Wt. of bowl + soil + water + emulsion ..... 802.77 grams
Wt. of specimen ..... 312.14 grams
Height of specimen ..... 2 inches
Density of specimen ..... 120.98 #/ft^3
% Proctor Density 95.3%

IN SLOT #1

* Two more specimens prepared with same amounts as above

Wt. of specimen #2 ..... 312.99 grams
Height of specimen #2 ..... 2 inches
Density of specimen #2 ..... 121.31 lb/ft^3
% Proctor Density #2 ..... 95.6%

IN SLOT #2

Wt. of specimen #3 ..... 311.95 grams
Height of specimen #3 ..... 2 inches
Density of specimen #3 ..... 120.90 lb/ft^3
% Proctor Density #3 ..... 95.3%

IN SLOT #3

Time →

Specimen	96m	k	77m	k	60m	k	123m	k	65m	k
1	182	.718	148	.728	111	.700	240	.739	125	.728
2	197	.777	169	.831	122	.770	264	.813	140	.816
3	227	.896	188	.925	131	.827	286	.881	143	.833

Time →

Specimen	68m	k	120m	k	75m	k
1	195	1.086	300	.947	201	1.015
2	252	1.403	395	1.247	263	1.328
3	250	1.392	365	1.152	245	1.237

NOTE: Suspect all 3 specimens began to leak badly around the sides

5-14-76

For 14% by wt. of 80-20 emulsion mixture

Use $wt_{air\ dry\ soil}$ = 270 grams

Wt. of bowl ..... 500.35 grams
Wt. of bowl + soil ..... 770.35 grams
Wt. of bowl + soil + water + emulsion ..... 815.42 grams
(NOTE: only 13.3%; emulsin weight = 36 grams)
Wt. of specimen ..... 313.03 grams
Height of specimen ..... 2 inches

Density of specimen ..... 121.36 lb/ft^3
% Proctor Density 95.6%

IN SLOT #1

Same as above

Wt. of bowl ..... 500.33 grams
Wt. of bowl + soil ..... 770.33 grams
Wt. of bowl + soil + water + emulsion ..... 815.33 grams
Wt of specimen ..... 312.33 grams
Height of specimen ..... 2 inches
Density of specimen ..... 121.08 lb/ft^3
% Proctor Density 95.4%

IN SLOT #2

Same as above

Wt. of bowl ..... 500.31 grams
Wt. of bowl + soil ..... 770.31 grams
Wt. of bowl + soil + water + emulsion ..... 820.14 grams
Wt of specimen ..... 315.00 grams
Height of specimen ..... 2 inches
Density of specimen ..... 122.12 lb/ft^3
% Proctor Density 96.2%

IN SLOT #3

NOTE: head constant at 230 cm 5-15 to 18-76

Time →	May 15		May 17							
Specimen	130m	k	62m	k	75m	k	120m	k	145m	k
1	82	.249	90	.523	165	.869	267	.879	307	.837
2	180	.547	150	.956	290	1.53	465	1.53	525	1.43
3	140	.425	100	.637	175	.922	273	.899	316	.861

Time →	May 18					
Specimen	78m	k	95m	k	180m	k
1	195	.988	260	1.082	460	1.010
2	-	-	-	-	-	-
3	185	.937	250	1.040	430	.944

5-19-76

* Taking prepared samples home to test. Make two of each (3 if possible)

For 18% by wt. of 80-20 emulsion mixture

Use 265 grams of air dry soil

Wt. of bowl	500.26 grams
Wt. of bowl + soil	765.26 grams
Wt. of bowl + soil + water + emulsion	809.87 grams
Wt. of specimen	308.92 grams
Height of specimen	2 inches
Density of specimen	119.76 lb/ft^3
% Proctor Density	94.3%

REPEAT !!!

Wt. of specimen #2	311.93 grams
Height of specimen	2 inches
Density of specimen	120.93 lb/ft^3
% Proctor Density	95.3%

NOTE: These two specimens encased in wax and marked #1 and #2 respectively

For 20% by wt. of 80-20 emulsion mixture

Use 265 grams of air dry soil

Wt. of bowl	500.33 grams
Wt. of bowl + soil	765.33 grams
Wt. of bowl + soil + water + emulsion	811.45 grams
Wt. of specimen	310.74 grams
Height of specimen	2 inches
Density of specimen	120.47 lb/ft^3
% Proctor Density	94.9%

REPEAT !!!

Wt. of specimen #4 ..... 312.32 grams
Height of specimen #4 ..... 2 inches
Density of specimen #4 ..... 121.08 lb/ft^3
% Proctor Density #4 ..... 95.4%

NOTE: These two specimens encased in wax and marked #3 and #4 respectively

For 22% by wt. of 80-20 emulsion mixture
Use 260 grams of air dry soil

Wt. of bowl ..... 500.37 grams
Wt. of bowl + soil ..... 760.37 grams
Wt. of bowl + soil + water + emulsion ..... 808.37 grams

Wt. of specimen #5 ..... 307.95 grams
Height of specimen #5 ..... 2 inches
Density of specimen #5 ..... 119.39 lb/ft^3
% Proctor Density #5 ..... 94.1%

REPEAT !!!

Wt. of specimen #6 ..... 308.28 grams
Height of specimen #6 ..... 2 inches
Density of specimen #6 ..... 119.52 lb/ft^3
% Proctor Density #6 ..... 94.2%

NOTE: These two specimens encased in wax and marked #5 and #6 respectively

ALL specimens and equipment taken home and set up 5 days later in my home basement. Pressure head = 198 centimeters

The 22% specimens (#5 & #6) were placed in the permeameter and tried first.

Time →	May 25,76 -------->				May 26,76		May 28 ---------->			
Specimen	395m	k	470m	k	1200m	k	150m	k	320m	k
5	177	.206	470	.222	565	.214	165	.505	363	.520
6	200	.232	520	.246	+640	+.245	170	.520	353	.506

Time → / Specimen	June 12,76 200m	k	260m	k	180m	k	June 13,76 720m	k
5	175	.401	200	.352	143	.365	380	.242
6	152	.348	175	.308	123	.314	350	.223

June 17th, 76

The 22% relocated at university; saturated for one day

(head constant at 230 centimeters)

Time / Specimen	June 18,76 95m	k	235m	k	260m	k	120m	k	June 19,76 600m	k
5	78	.324	180	.302	175	.266	80	.263	383	.252
6	100	.416	240	.404	240	.365	110	.362	525	.346

Time / Specimen	June 21,76 60m	k	160m	k	315m	k
5	30	.197	77	.190	155	.194
6	40	.263	95	.235	205	.257

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A STUDY OF PERMEABILITY CONTROL WITH ASPHALT EMULSIONS

by

DON A. DRUMM

B.S., Kansas State University, 1975

AN ABSTACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Civil Engineering

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1976

The study was undertaken to determine the effect of asphalt emulsions on the permeability of soil. A slow curing anionic asphalt emulsion was used on a Kansas river valley silt. A specific value was sought based on criteria set by the Environmental Protection Agency and the Kansas Public Health Administration.

The emulsion was mixed with soil in a diluted form arrived at by trial and adjustment. Each specimen was tested over a varying period of time and the permeability rate was recorded and observed. Testing was conducted at the Kansas State University Civil Engineering Soils Laboratory.

The study showed that slow curing anionic asphalt emulsion can be used to affect the permeability rate of the soil tested. The overall affect observed was one of a reduced permeability rate with the addition of the emulsion. The specific permeability rate sought for was attained within tolerable limits. The study also showed that the time effect on permeability was one of only moderate decreased permeability rate with increasing time. The study also showed that a decrease in permeability rate was observed with increasing amounts of emulsion added to the soil.