Development and Selected Applications of a Low Hydraulic Head Laboratory Permeameter

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SUMMARY. Liquid flow through soil developed under low hydraulic head conditions is discussed. Such conditions arise for example in studies of seepage from shallow ground evaporation tanks, and infiltration phenomena.

A laboratory technique for the determination of soil permeability under these conditions and closely simulating those evident insitu is described. Features of the technique include means for accurately maintaining and measuring the vertically downwards flow from a shallow pool of water ponded on one of the flat ends of a cylindrical specimen.

Special attention has been given to the problem of specimen boundary leakage often encountered in laboratory permeability testing of gravels. A bentonite gel jacket is used to surround the specimen and eliminate leakage. The use of the technique also allows for the direct testing, without re-compaction, of field tube samples and for a study of the effect of drying subsequent to compaction upon permeability.

Certain applications of the use of the technique and associated results are discussed. These applications include a determination of:

(a) The influence of compaction upon the water conductivity characteristics of road shoulder materials after long periods of wetting.

(b) The influence of desiccation, following compaction and prior to wetting, upon the permeability of a clayey-sand.

Comments are then made relating to the practical implications of these permeability measurements.

1 INTRODUCTION

This report discusses a laboratory technique designed to evaluate the water conductivity of soil subjected to a relatively low hydraulic head. The present design of the apparatus limits the maximum head to about a metre. However, many situations of practical importance fall within this range. These include seepage from shallow storage reservoirs such as evaporation tanks. Another application involves a determination of the eventual steady state infiltration into initially unsaturated soil profiles. Such determinations are of importance in studies of catchment run-off (1) and the ingress of water through road shoulders (2).

To produce a reliable estimate of insitu soil permeability from laboratory testing one needs to exercise care in the selection of both apparatus and test procedure. Reports of investigations (e.g. (3), (4) and (5)) into the permeability characteristics of soils describe the considerable influence that factors such as void ratio, degree of saturation, sample preparation procedure, permeant composition, hydraulic gradient and soil swelling, amongst others, have upon permeability. These reports emphasise that the treatment of the test specimen should as closely as possible simulate field conditions in order that the estimate of insitu permeability be of value. Compromises between laboratory and field conditions normally require careful assessment and often entail extensive experimental justification. Under these circumstances it is essential to continue the development of laboratory techniques which improve simulation and restrict experimental errors.

The laboratory technique reported herein possesses features which allow for both flexibility in simulation and a reduction of experimental errors. These features include means for:

(a) Subjecting a cylindrical test specimen to ponded supply conditions on one of its flat ends so that a constant pond depth can be accurately maintained.

(b) Determining axial flow through the specimen by monitoring the input to the pond required to preserve constant depth.

(c) Minimising evaporation losses from the pond surface.

(d) Overcoming experimental errors which arise from seepage along the outer boundary of test specimens (particularly in the case of those formed from gravel). The special procedure developed allows one to test samples following their extrusion from compaction moulds or sampling tubes. This also permits an examination of the influence of soil drying, subsequent to compaction or sampling, upon permeability.

(e) Allowing swell of the material to occur without significant boundary restraint.

(f) Attaining realistic degrees of saturation through test wetting sequences closely aligned with those pertaining to the field circumstances.

In the following section, the low head permeameter is described together with certain details associated with its development. The apparatus in its present form has particular application to the determination of soil permeability when subjected to shallow pond depths (e.g. 10 mm) and a hydraulic gradient of unity. These conditions arise in the study of infiltration behaviour (6).

2 DESCRIPTION OF APPARATUS AND TEST PROCEDURE

Water is maintained at a constant depth of approximately 10 mm above the end surface of a 150 mm high by 100 mm diameter cylindrical specimen. The volume of water transmitted in the axial (in this case vertical) direction of the specimen at various times is measured.

An annotated photograph of the components is shown in Figure 1.

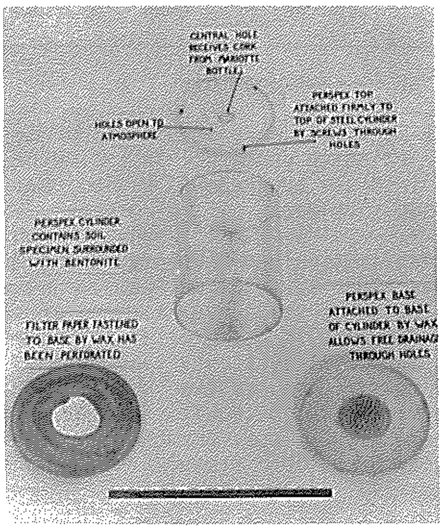

Fig. 1 Components of Permeameter

An outline of the testing procedure is now provided.

A 150 mm diameter filter paper is attached, by applying molten wax around its perimeter, to a perforated perspex base (see Figure (1)). A central disc about 100 mm in diameter is left free of wax.

The cylindrical specimen, prepared in this present study by drop hammer compaction (7), is placed in the centre of the filter paper and waxed to the filter paper and base plate around its bottom circumference. The filter paper prevents particles which are dislodged from the bottom of the specimen from escaping through holes in the perforated perspex plate. The need for the use of the filter paper could be reduced by using smaller holes in the perforated base plate than those existing in the current apparatus. Should clogging of the filter paper cause concern, it may be pierced as shown in Figure (1).

It should be noted that the cylindrical specimen is extruded from its compaction mould and then placed into the permeameter. This allows the specimen to be exposed to a range of pre-testing conditions. For instance, later sections of this report discuss the impact of drying of the material, following compaction at Modified Optimum (7) moisture content upon permeability.

A cylinder (190 mm high, 140 mm diameter and 5 mm wall thickness) is placed around the specimen and waxed to the base plate. The annulus formed between the outside of the specimen and the inside of the cylinder is then filled with bentonite in the form of an aqueous fluid that gels on standing. The bentonite is prepared by high speed mixing.

The height of the cylinder may be increased to accommodate deeper pond depths. The wax used in the current technique to seal the cylinder to the base plate is broken under the influence of pressures arising from approximately 1 metre head of water. This fact thus limits the application of the present apparatus but may be overcome by alternative sealing procedures.

The permeameter unit can then be placed in a shallow dish containing water. The depth of water in the dish is such as to just immerse the bottom of the specimen contained within the permeameter. With compacted granular materials as used in this present study, free drainage from the lower end of the specimen, instead of immersion, had little influence on the flow rate. However, for more permeable materials, it would be necessary to use the shallow dish to form a "downstream" reservoir in order to maintain a comparatively uniform saturation condition throughout the length of the specimen.

During the development of the present test procedure the problem of boundary seepage was carefully examined. From discolouration over the cylindrical boundary surface of specimens following conventional permeability testing (8) using organic dyes it was noted that boundary seepage occurred. This seepage could be expected to contribute to experimental uncertainties, and was particularly evident in tests carried out on gravels. Various techniques were tried in an effort to eliminate the problem. The use of a range of diameters for test cylinders in an attempt to assess the influence of boundary seepage was evaluated. However, inconsistent test results forfeited this approach. For practical reasons, the prospect of employing a relatively impermeable jacket appeared attractive. Several such jackets were examined, including hard setting plaster, silicone rubber set by a catalyst, gelatine and natural clays. As reported above, bentonite gel was adopted.

The effectiveness of the bentonite as a relatively impermeable boundary jacket, under the low head conditions examined, was evaluated using a dummy specimen. No transmission of water was registered. Bentonite slightly penetrates the cylindrical surface of a soil and this action contributes to the effectiveness of the jacket.

It should be noted that the bentonite jacket provides limited restraint should the specimen swell. This is in contrast to the practically infinite restraint offered by steel containers used in conventional permeability testing (8).

Following the placement of the bentonite jacket, the specimen is ready for testing. A pool of water is first established, and then maintained at constant depth(approximately 10 mm in the present study) above the end of the specimen and bentonite annulus. The water supply rate to maintain the constant depth pool is monitored and used to provide permeability values. The principle of the Mariotte Bottle was adopted to provide this pool and monitor the flow. The features and operation of this apparatus are now briefly described.

A perspex tube (2 metres long and approx. 100 mm internal diameter) is mounted vertically. This tube is referred to as the container. The ends of the container are plugged with rubber stoppers. A vacuum valve is fitted to the top stopper. A 6 mm outside diameter open-ended perspex tube also passes through this top stopper and continues almost to the lower end of the container.

The lower stopper is pierced by a supply tube taking water to the pool on top of the test specimen. Figure 2 shows two of these units mounted side by side.

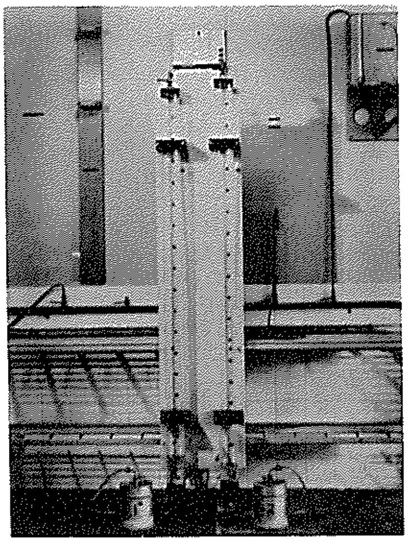

Fig. 2 Mariotte Bottles on Backboard

To commence, the container is filled with water. The valve attached to the top stopper is closed. As water is led off to waste from the supply tube, the water level in the internal tube drops until it reaches the lower end of this tube. Air bubbles then commence to rise through the water in the container. The valve on the supply tube can then be closed. The supply tube is then fitted to the top cap of the permeameter containing the specimen. This cap is held loosely by screws. The supply tube valve is then opened slowly so that erosion of the specimen's upper surface is prevented. Flow will continue until the level of the ponded water above the specimen coincides with the open end of the internal tube within the container. Appropriate adjustment of this level ensures that the desired pond depth is developed. A steady stream of air bubbles from the end of the internal tube indicates that supply is being maintained. The volume of water transmitted can be determined from the change in level of the water surface in the container at various times. This latter determination requires appropriate prior calibration.

In the present study, water supply was maintained for at least 24 hours following the attainment of steady flow, as indicated by a plot of flow versus time.

In the following sections, the use of the permeameter to investigate:

(a) The influence of compaction upon the water conductivity characteristics of road shoulder materials after a long period of wetting.

(b) The influence of drying prior to wetting upon the permeability of clayey-sands is discussed.

3 CONDUCTIVITY OF ROAD SHOULDER MATERIALS

The classification properties of three materials, typical of rural road base materials, are shown in Table 1.

TABLE I

SOIL CLASSIFICATION PROPERTIES

Material	W_L %	W_P %	LS %	Modified Max.Dens. (Kg/m^3)	Modified O.M.C. %	S.G.
Yellow Sand	*NP	17	1	1948	7.8	2.72
Sandy Gravel	NP	20	-	2079	8.5	2.82
Clayey Gravel	29	27	4	2000	9.4	2.66

*NP - not possible

These materials were studied in order to estimate their relative potential in excluding the entry of water into the subgrade of sealed roads through the exposed shoulder.

Permeability values generated using the previously described low head permeameter were determined on the three soils over a range of density values. The results are plotted in Figure (3) in terms of permeability versus void ratio. Also shown on this Figure are the void ratios corresponding to 95% and 100% of Modified Maximum Dry Density (7). These values cover a range representative of the density conditions prevalent in many base course materials in service (2).

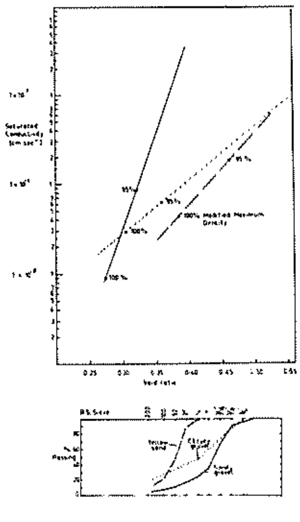

Fig. 3 Laboratory Permeability Values versus Void Ratio for Yellow Sand, Clayey Gravel and Sandy Gravel

The frequently observed (3) linear relationship between void ratio and logarithm of permeability is evident from Figure (3). The apparent reduction of permeability with decrease in void ratio reinforces the value of compaction at shoulder locations.

In comparing the three materials at a void ratio corresponding to 95% of the appropriate

Modified Maximum Dry Density it is noted that the clayey and sandy gravels have similar permeability values and that these are less than the permeability of the clayey-sand.

The relative sensitivity of the permeability of the sandy gravel to void ratio variations suggests that, should the density control of this material be relaxed along the shoulder alignment the permeability of the material will rapidly increase. Additional evidence from Figure (3) indicates that the permeability of the sandy-gravel may well exceed that of the clayey-sand.

The clayey-gravel examined is the least sensitive to permeability change with void ratio. It should be noted that there is in practice a common tendency to favour the use of gravels, with clay contents higher than those generally accepted for inclusion under sealed pavements, at the exposed shoulder location.

Wallace (9) has examined road shoulder water entry behaviour analytically and emphasises the importance of the measurement of permeability at a moisture content established by infiltration from a shallow pond. Attention is also drawn to the experimental difficulties associated with attaining consistent permeability measurements. The techniques described herein serve to reduce these difficulties and act as a means for rationalizing test variability.

It should be emphasised that other factors, such as compressive strength and ease of field compaction also need to be considered when contemplating the use of a material at the shoulder location. Another factor effecting the entry of water into the exposed shoulder is the development of surface crusting. Following a series of intermittent wet and dry periods, this factor may substantially add to the impermeability of the shoulder. However, under traffic action and shoulder maintenance, the crust may be destroyed. The permeability characteristics of the whole layer as examined herein then control water entry to the subgrade.

4 EFFECT OF DRYING UPON PERMEABILITY

As previously mentioned, the present technique enables the low hydraulic head permeability characteristics of soils rewetted after drying from their compacted condition to be examined.

Many instances of post compaction drying followed by inundation can be instanced in semi-arid conditions in Australia. Considerable attention (10),(11),(12) has been given to the flocculated - deflocculated phenomenon which can occur on filling of earth embankment dams. The current work indicates that permeability values following inundation appear to depend upon the character of the desiccation process to which the soil has been subjected. That this could be true is not surprising in view of the well known wetting-drying hysteritic properties shown by soils. The behaviour can be considered as a reflection of the volume and distributions of water amongst the range of pore sizes and in particular the possible generation of a continuous chain of pores capable of water transmission. It is to be noted that the distribution of water amongst the range of pore sizes in a freshly compacted granular material could be considered artificial.

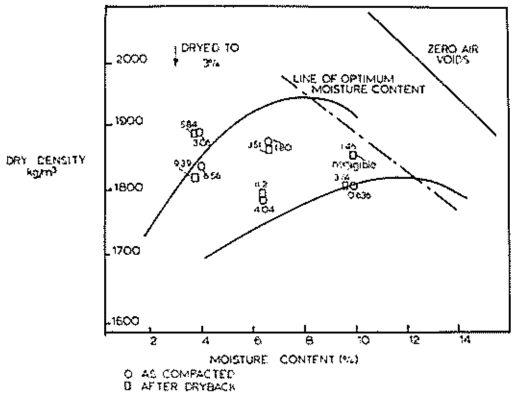

Fig. 4 Influence of Desiccation on Permeability at Prepatation Conditions shown

Figure 4 shows low hydraulic head permeability measurements carried out on a clayey-sand (for properties see Table 1). The permeability measurements in this figure are plotted relative to conventional laboratory compaction curves for the material (i.e. Standard and Modified Compaction (7)). The values associated with circles on Figure 4 represent permeability values determined following compaction at the conditions indicated by these circles (described as the "as compacted" test). The values associated with squares represent permeability values determined following dry back from the as-compacted condition (indicated by the squares) to a moisture content of 3%.

An inspection of these permeability measurements provides the following observations:

(a) Permeability decreases with an increase in specimen preparation dry density. This reflects the influence exerted by a decrease in void ratio.

(b) Dry back of a specimen to a moisture content close to 3% increases the subsequent permeability compared to one tested at its as-compacted condition. This could be a result of the larger number of isolated air voids existing following inundation for the as-compacted test compared with the test after dry back. In the latter case, absorption of water from the drier condition induces the establishment of a more continuous network of water filled voids. A slightly higher degree of saturation may also develop and thus improve permeability.

(c) The influence of entrapped air upon permeability is also apparent from Figure 4 for the series of "as-compacted" tests carried out over a range of moisture contents, but at comparable dry density levels. The permeability decreases to relatively small values as the region of the line of optimum moisture contents is reached. Again as with (b) above, entrapped air is blocking possible flow channels.

The problems of entrapped air mentioned in (b) and (c) have been examined by Christiansen (13). He reports permeability increases of up to 50% over long testing durations (5-6 days) and attributes this to the gradual dissolution of the entrapped air into the water. However, with respect to the present situation where relatively small hydraulic heads apply, it is considered that this dissolution is negligible. Testing also indicates that permeability with passage of time is reasonably constant.

5 CONCLUDING COMMENTS

A laboratory technique for acquiring information relating to the permeability characteristics of soils subjected to relatively low hydraulic heads has been described. The careful simulation of field circumstances which are likely to influence laboratory determined permeability values has been stressed.

Use of the apparatus for assessing and comparing the permeability values of road shoulder materials has been illustrated. In practice, it is necessary to consider both the level of permeability and the sensitivity of this level to changes in density as a result of varying standards of field compaction.

Results are also presented of an investigation conducted using the low head permeameter to examine the influence of desiccation upon permeability. It would appear that desiccation increases the permeability of a clayey-sand, determined under low head conditions, compared with that measured immediately following conventional laboratory compaction procedures.

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