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DRAINAGE TEST APPARATUS FOR POROUS (OR DRAINAGE) ROAD MIXES

FIELD OF INVENTION

This invention relates to a simple falling head device for measuring the drainage performance of porous road mixes, which are also called drainage road mixes. Porous road mixes are relatively new road materials in the road industry, being first used in Europe in 1984, and was recently introduced for Singapore roads in 1994 by the Public Works Department.

BACKGROUND OF THE INVENTION

Porous (or drainage) road mixes are a new technology in road materials and there is as yet no systematic way of measuring their drainage performance. The impetus for use of these types of mixes in the tropics with its high and frequent rainfall is their ability to rapidly drain off rain water so as to provide a dry riding surface even in heavy downpours. This will greatly enhance road safety as a dry riding surface would eliminate the problem of wet skidding, aquaplaning, and reduced visibility caused by splashing of surface water by vehicle tires.

Existing equipment for measuring permeability of porous materials are mainly confined to apparatus for measuring flow through soils. Broadly, there are only two main principles of permeability measurements (Bowles, 1992). The first type is called the constant head test, where a constant head difference is maintained between the inlet and the outlet face of a porous cylindrical specimen, and a steady state is established at which the discharge rate is measured to calculate the material permeability using Darcy's law, which states that the specific discharge is the product of the soil permeability and the applied hydraulic gradient across the soil specimen. The second type is called the falling head test, where a variable head difference is maintained between the inlet and outlet face of the cylindrical specimen, and the discharge rate is measured by the falling head through an inlet tube of constant cross section. From the falling head measurement the permeability of the specimen material can be deduced.

The constant head test for soils had been standardized by standards bodies in the USA and UK. The tests designations are ASTM D 2434-1968 (1984), AASHTO T 215-1970 (1984) for the US standards, and BS 1377:5:1990 for the British standards. These procedures are suitable for soils having permeability in the range of 10^{-5} to 10^{-2} m/s, which are typical of silty to sandy

soils, whose particle size range from 0.06 mm to 2 mm nominal diameter. The permeability of these soils are often used in the design of earth structures such as dams, retaining walls, and reclaimed land. Therefore standard test procedures are introduced for the permeability measurements of these soils.

The falling head test, however has not been standardized by any standards organizations as of 1991 (Bowles, 1992). Thus this test remain very much in the realm of research type testing. However, due to the simplicity of test method and apparatus, many institutions use this test procedure as one of the viable method for soil permeability measurements. Due to the wide variability in soils permeability, even within the same soil type, accurate permeability measurements are seldom required in engineering practice. As such the apparatus for permeability testing in practice see very little improvement compared to the early design of the equipment. Despite the advancement in measurement technology, permeability testing still rely on simple hand and eye measurements with the use of a stop clock and a graduated measuring cylinder to determine the discharge flow rate from the specimen. This crude and simple method is adequate so long as we are dealing with silts and sands, which are slow draining enough to allow fairly accurate determination of flow rate within a reasonable length of testing time.

For the drainage of very porous materials such as crushed stones and gravels, whose particle size range from 10 to 25 mm, no standards exist for the measurement of the drainage properties of these materials as evident in existing research papers and text like Bowles, 1992. Due to the large voids in these materials, rapid drainage is easily achieved, and therefore no attempt were made to measure their drainage properties in roads applications, where they are used mainly as basecourse materials. However, when porous road mixes were introduced as surface wear carpet in road engineering, issues concerning their drainage performance under traffic loading and clogging potential from silts and sands washed into their voids become important.

When testing for drainage in porous road mixes, which consists of crushed stones and gravels, together with bituminous binder and mineral fillers, permeability measurement for drainage characterization becomes more complex. With such large voids in the mixes (about 20% air voids), the flow through the material is no longer laminar, which means that the linear Darcy's law is no longer valid. Also the flow rate is very rapid, making it very difficult to measure flow rate accurately with a simple unaided hand and eye measuring method, such as the use of a graduated cylinder with a stop clock to measure flow rate through porous mix specimens.

To date there are no standard procedures for measuring the drainage performance of these

mixes. A very recent patent for a device to measure the permeability of porous road mixes is a French patent by Di Benedetto H., Esgleas F., and Heurtebise F., filed in 1994. This is a constant head device with a differential pressure transducer to measure the head difference kept constant between the inlet and outlet face of the porous specimen, and temperature control elements in the invention. It is apparent that such a device will be quite expensive to produce requiring sophisticated components in its design, and also it is not easily made portable for it to be used in the field. Thus, the impetus for our invention to allow for the automated data capturing of the flow rate through the porous mixes by a falling head method.

OBJECT OF THE INVENTION

The object of the invention is to provide a simple and inexpensive device which will enable the accurate measurement of the drainage property of porous road mixes using very simple technology in its components. The device must be able to measure the permeability of the porous road mixes using established fluid mechanics principles, where the permeability is a measure of the ease with which the mixes allow the flow of water through its pores.

As stated in the previous section, the permeability constant (k) for laminar flow through a saturated porous medium can be determined from Darcy's law, which is :

$$v = \frac{Q}{A} = k\frac{\delta h}{l} = ki \qquad (1)$$

where v = specific discharge (m/s)

Q = fluid discharge at steady state (m^3/s)

A = Specimen cross section area (m^2)

k = permeability coefficient (m/s)

δh= hydraulic head difference held constant between inlet and outlet end of specimen (m)

l = specimen thickness (m)

i = hydraulic gradient across specimen (m/m),

In general, the fluid flow through porous road mixes is neither laminar nor turbulent; the actual flow is a transition between the two regimes. Thus the flow law governing drainage through road porous mixes is better described by :

$$v = ki^n \quad (2)$$

where n is an experimentally determined exponent that describes the type of flow behaviour, n=1 for laminar flow, n=0.5 for turbulent flow, and n between 1 and 0.5 for transition from laminar to turbulent flows. The proposed falling head apparatus can be used to determine both k and n experimentally to characterise fully the flow through a porous road mix.

BRIEF DESCRIPTION OF DRAWINGS

The drawings Figs. 1 to 3 show one embodiment of the present invention. The drawing in Fig.4 show another embodiment of the same invention.

Fig.1 A schematic overview of the falling head apparatus, showing the inlet cylinder (1) containing the upstream falling head from level (2) to level (3) during the test, while the downstream head is held constant at level (4) by overflow (5) from the base basin (6).

Fig.2 A trap door device (15,16) to control initial upstream head at level (2) of water which can be set at any desired level by use of the trap door.

Fig.3 A specimen holder jig (10) as a positioning device, consisting of a flexible rubber membrane (11) held in place by o-rings (17), and cylindrical half clamps (18,19).

Fig.4 An alternative means of the trap door design (15), and rigid mould (11) to hold specimen (10) in place during falling head test.

DESCRIPTION OF THE INVENTION

Figure 1 shows the overview of the proposed falling head device for measuring the permeability of porous mixes. The device comprises of an inlet clear plastic cylinder (1) of the same internal diameter as the test specimen (10), which are supported in a cylindrical basin (6) to keep the specimen saturated and immersed in water throughout the test, and to provide a constant water head at level (4) for the bottom outlet end (12) of the specimen. For a constant temperature test, water in basin (6) and inlet cylinder (1) can be kept at a constant temperature by means of a water bath system installed in basin (6), if desired. An overflow tank (9), serves to capture the excess water overflow (5) from level (4) to level (13), which can be extracted from outlet (14) to

be recycled by a submersible water pump if desired.

The first essential feature of the invention is the trap door mechanism shown in detail in Fig.2. This mechanism consists of a rubber stopper (16) with a skeletal pair of vertical rods connected to a horizontal ring handle (15), which enable the trap door to be shut against the bottom end of the specimen holder (12), and to be opened instantly to start the falling head test. To prepare a test, the trap door is initially shut as in Fig.2a, and the upper cylinder (1) can now be filled with water to provide an initial upstream head of any level (2) to create an initial hydraulic gradient of head difference between levels (2) and (4) as desired. To start the falling head test, quick release of the trap door handle (15) as in Fig.2b is applied, the trap door opens instantly, allowing the water in (1) to flow through the specimen uniformly from level (2) to any desired level (3) above the overflow level (4) of container basin (6).

The second essential feature of the invention is a sensitive submersible pressure transducer (7) which must detect accurately pressure changes of as little as 1 mm of water. This transducer is activated at the start of test, and with a simple data logger, it can be set to measure the falling head in cylinder (1) at 1 seconds interval. With this falling head data, the permeability of the porous specimen can be calculated by using the flow law of Eqn(2) which accurately characterise the flow behaviour of porous mixes, being neither fully laminar nor fully turbulent in nature.

The third essential feature of the invention is the specimen holder jig as shown in Fig.3. The specimen is a cylindrical cake of a porous mix formed either by compaction into a fixed mould or cored from the road by means of a cylindrical core cutter. The specimen may come in several different dimensions from 100 mm to 150 mm diameters, and heights from 50 mm to 150 mm. Thus it is essential to have a specimen holder that can adapt to this different dimensions with minimum adjustment to the apparatus. The best system for doing this is to use a flexible rubber membrane of slightly smaller diameter than the specimen to provide an impermeable wall boundary around the specimen. The specimen holder in Fig.3 consists of two thin wall rings of inner diameter same as the specimen, and fitted to the top and bottom end of the specimen. The top ring is for connection to cylinder (1), and the bottom ring is for receiving the trap door stopper before the start of the test. The specimen and rings are encapsulated by the stretched flexible rubber membrane (11), and the ends sealed by o-rings (17). To provide rigidity to the holder, the top and bottom rings are clamped together by cylindrical half clamps (18,19). This system provide a very simple and easy means of holding the specimen in vertical alignment with the inlet flow cylinder (1) for the falling head test.

An alternative to the trap door mechanism and the specimen holder is shown in Fig.4. This trap door consists of a pair of vertical rods connected to a horizontal handle (15). The trap door is held shut against the bottom of the specimen by a spacer block (15) between the rod handle and the mouth of the inlet cylinder (1). For the specimen holder, an alternative to the flexible wall cylinder provided by the rubber membrane is to use the rigid wall compaction mould itself as the specimen holder. This would require the use of rubber gasket and seal joints for the top and bottom of the specimen mould (19) held together by vertical rods with nuts and bolts clamps. The flexible wall system is preferred for its ease of use compared to the rigid wall system.

As the falling head test is a non-destructive test, several tests can be repeated for the same specimen to ensure high quality results and to check on the consistency of test data. Repeated tests on the same specimen conducted in the prototype apparatus indicate variations of less than 1% in the values of (k and n) the permeability and flow exponent for about 30 repeated falling head tests for a single specimen. Therefore the test method is highly reliable and is an excellent means of measuring the flow characteristics of porous road mixes.

This device can be applied in several situations of porous road mixes design and construction. It can be used to make objective comparisons of the drainage performance of alternative porous road mixes which are competing for the same job application. It can also be used to check on the drainage performance of newly laid roads as a means of quality control using a drainage performance criteria during road construction. It can also be applied for evaluating the deterioration of drainage performance of porous road mixes subjected to siltation by fines silts and sands, weathering and traffic densification.

* C L M S *

CLAIMS

(1) A device for the determination of the flow characteristics of a porous road mix in terms of its permeability coefficient *(k)* and its flow exponent *(n)* by a falling head test method, which is characterised by :

(i) an inlet cylinder (1) same internal diameter as specimen cross section, from which fluid is passed through the specimen (10) at a falling head during the test,

(ii) an outlet basin (6) which allows for the lower head at the bottom of the specimen to be kept constant at level (4),

(iii) the means to hold specimen in place either by a flexible wall (rubber membrane) specimen holder as in Fig.3, or a fixed wall (rigid mould) specimen holder as in Fig.4,

(iv) trap door assembly as in Fig.2,

(v) submersible pressure transducer (7) at the base of inlet cylinder (1).

(2) Device in accordance with Claim 1, characterised by a trap door assembly consisting of a rubber stopper (16) with a skeletal pair of vertical rods connected to a horizontal ring handle (15), which enable the trap door to be shut against the bottom end of the specimen holder (12), which permits the setting up of falling head test for a very porous road material at any desired initial head of the upper water level at the top end of the test specimen.

(3) Device in accordance with Claims 1 and 2 characterised by a trap door release mechanism which allows for the sudden release of fluid from the inlet cylinder through the porous specimen to start the falling head test instantaneously.

(4) Device in Claim 1 characterised by either a flexible wall specimen holder (Fig.3), which allows for a quick and easy means of fitting the specimen from the field cores samples into the test device, or a rigid wall specimen holder (Fig.4), which allows for test specimen compacted in steel mould to be attached directly to the inlet and outlet cylinders by rubber seals fastened with bolts joints.

(5) Device in Claim 1 is characterised by a submersible pressure transducer (7) at the base of the inlet cylinder (1) which can record falling head data to a precision of 1 mm at intervals as small as 1 second depending on the type of data logger and pressure transducer used.

ABSTRACT

A device for performing the falling head permeability test on porous road mixes consists of an inlet cylinder (1), specimen holder (Fig.3), an outlet cylinder (12), made impermeable by a flexible rubber membrane (11). A trap door assembly (Fig.2a) in the closed position will permit the setting up of the falling head test at any desired initial upper head water level at the top end of the test specimen. The activation of the test can be initiated by the sudden release of the trap door as in Fig.2b. This will cause the upper head to fall while the lower head remains constant. The rate of fall of the upper head can be measured accurately by a submersible pressure transducer (7) at the base of the inlet cylinder. From the falling head data, the permeability of the porous road specimen can be calculated from established theory.

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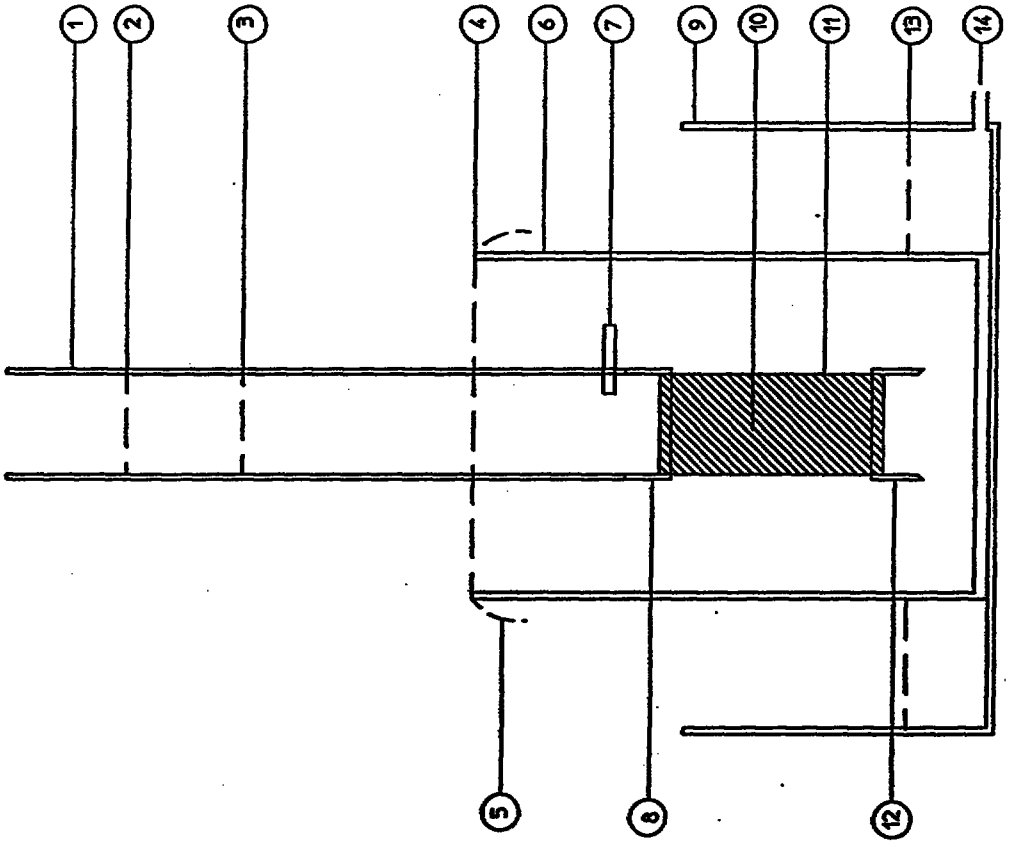


Fig. 1 Overview of Falling Head Test Apparatus

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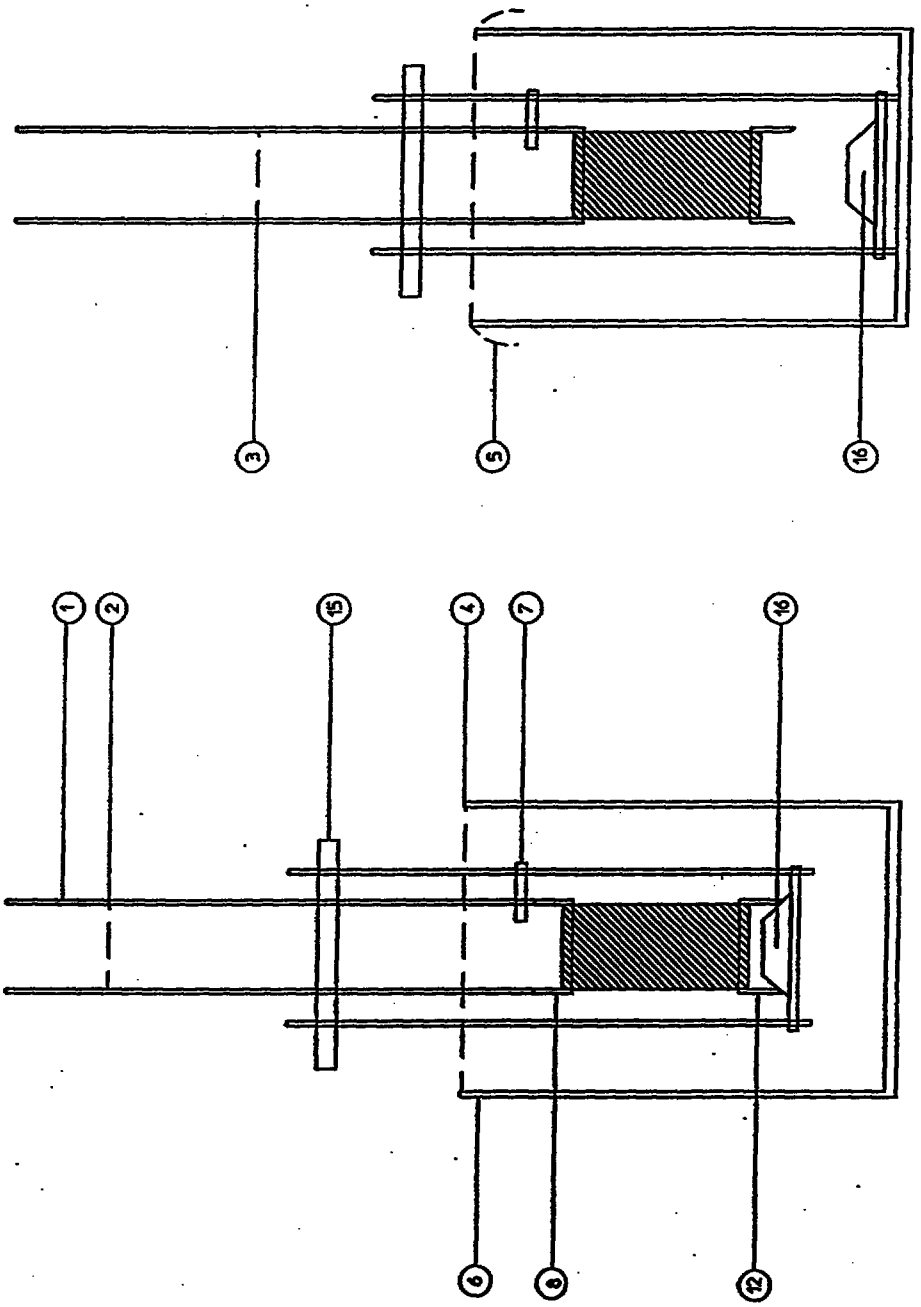


Fig. 2b Trap Door open with desired Head of Water

Fig. 2a Trap Door Shut with desired Head of Water

Fig. 2 Control of Initial Head of Water in Cylinder

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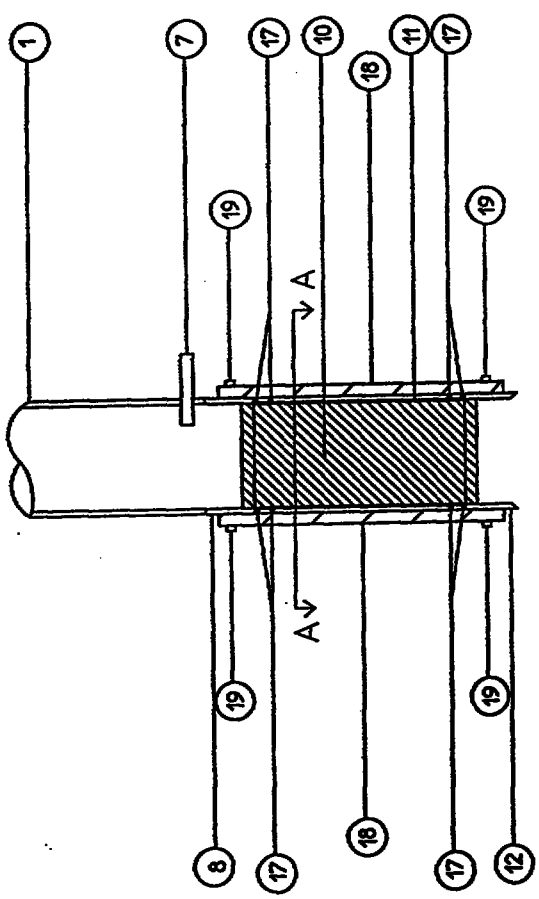
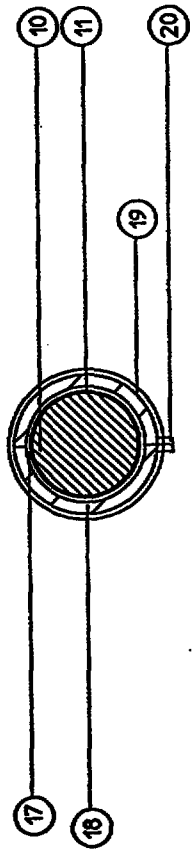
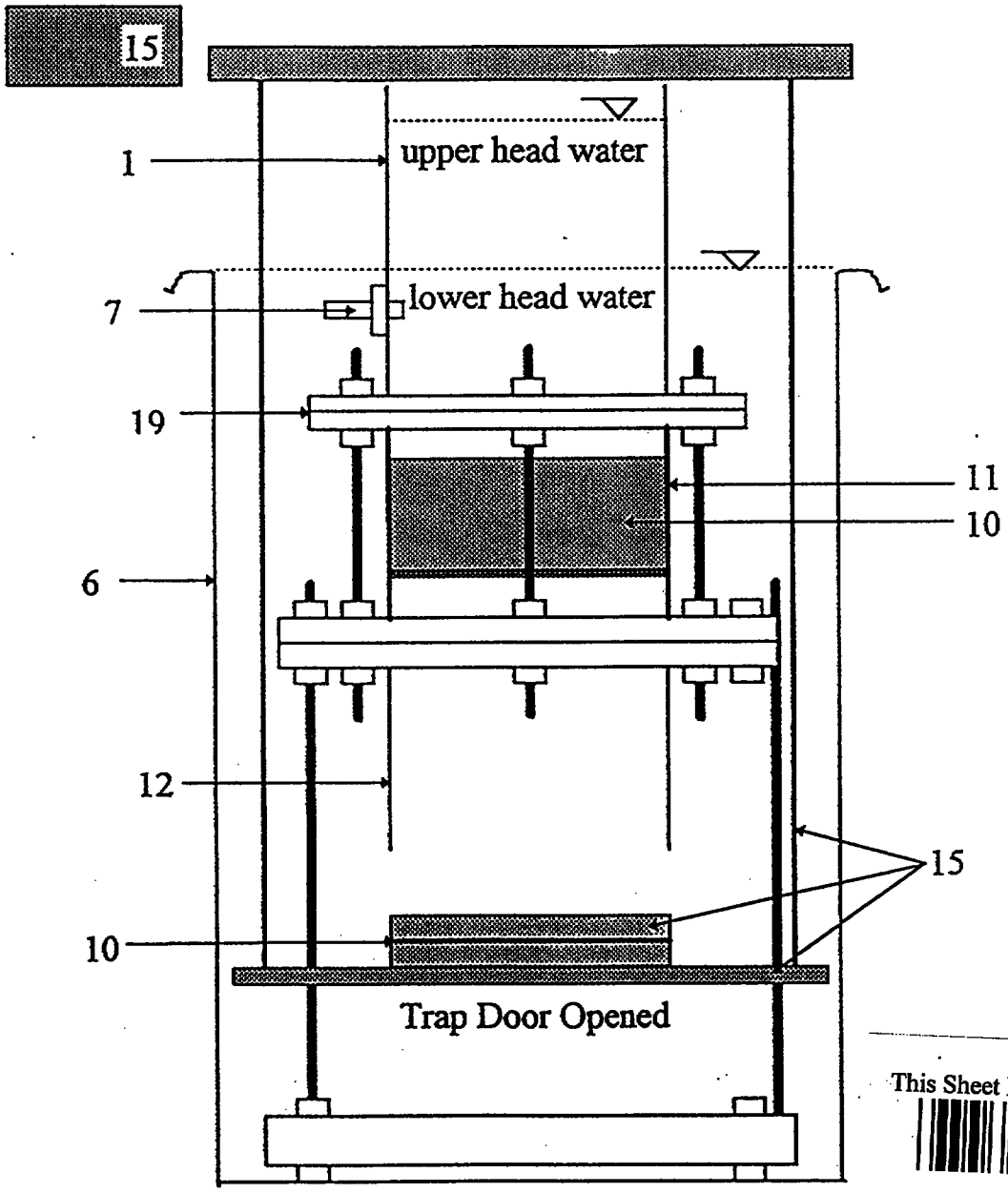


Fig. 3 Specimen Rig



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FIGURE 4. Test device with rigid mold–trap door opened

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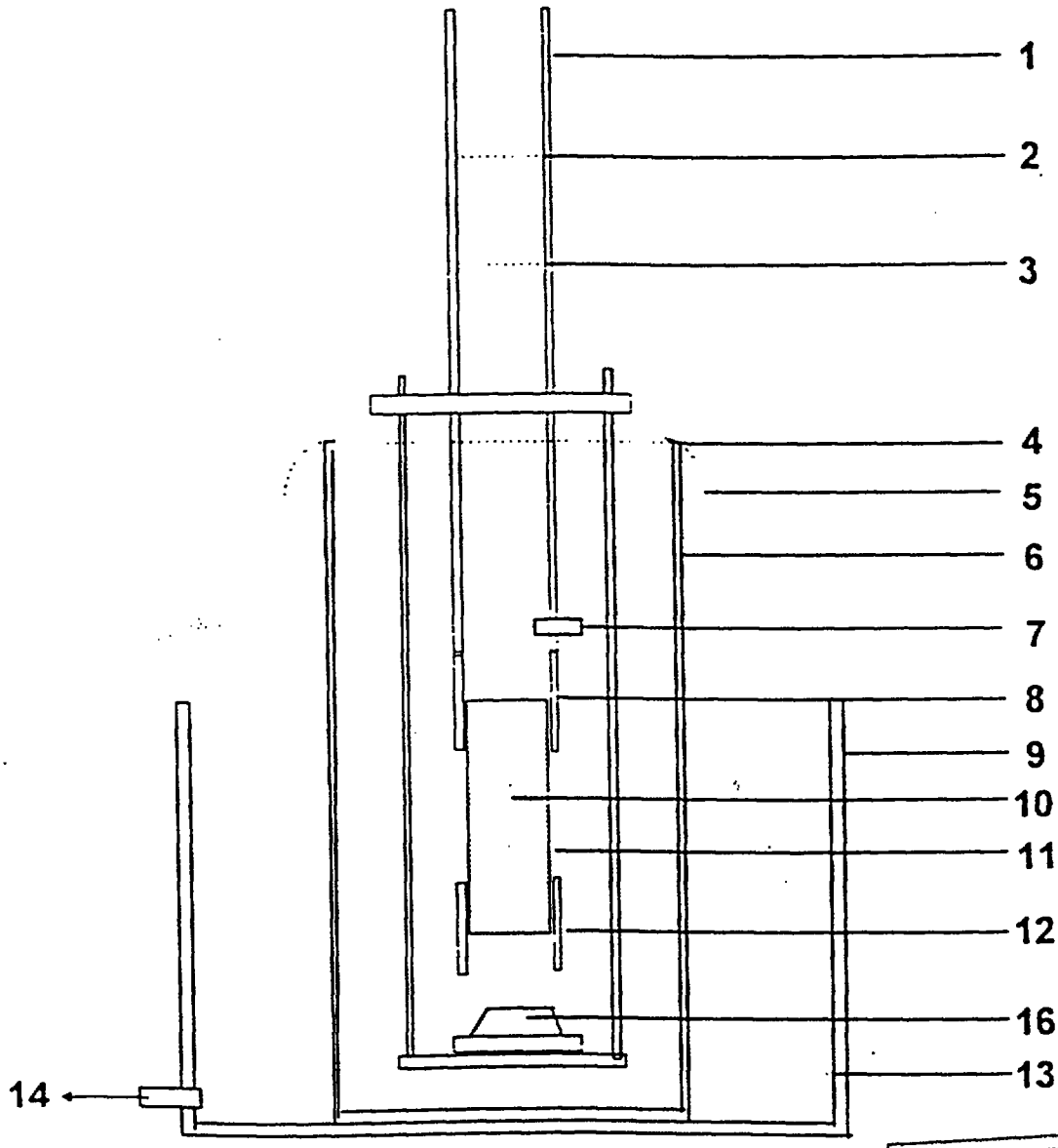
ABSTRACT

DRAINAGE TEST APPARATUS FOR POROUS (OR DRAINAGE) ROAD MIXES

A device for performing the falling head permeability test on porous road mixes consists of an inlet cylinder (1), specimen holder (Fig.3), an outlet cylinder (12), made impermeable by a flexible rubber membrane (11). A trap door assembly (Fig.2a) in the closed position will permit the setting up of the falling head test at any desired initial upper head water level at the top end of the test specimen. The activation of the test can be initiated by the sudden release of the trap door as in Fig.2b. This will cause the upper head to fall while the lower head remains constant. The rate of fall of the upper head can be measured accurately by a submersible pressure transducer (7) at the base of the inlet cylinder. From the falling head data, the permeability of the porous road specimen can be calculated from established theory.

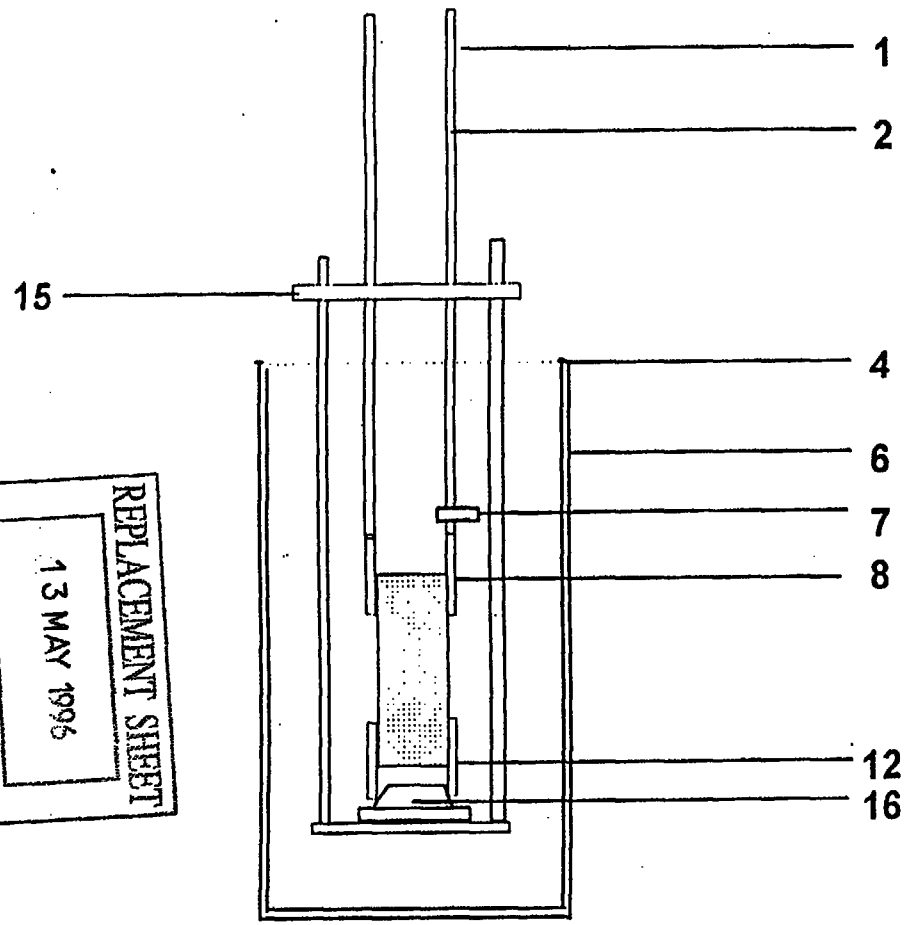
(Fig.2a; Fig.2b and Fig.3 are to be published)

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Fig. 1 Overview of the Dual Mode Permeability Apparatus



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Fig. 2a Trap Door Shut with desired Head of Water

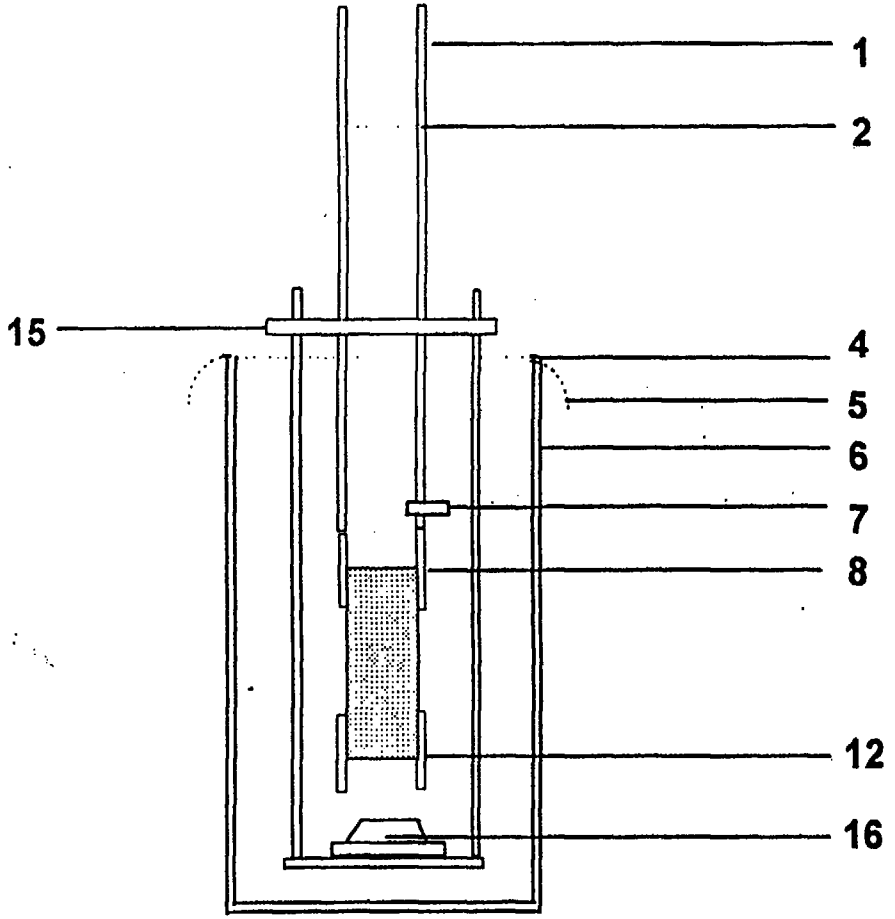


Fig. 2a Trap Door Open

Fig. 2 Control of Initial Head of Water in Cylinder

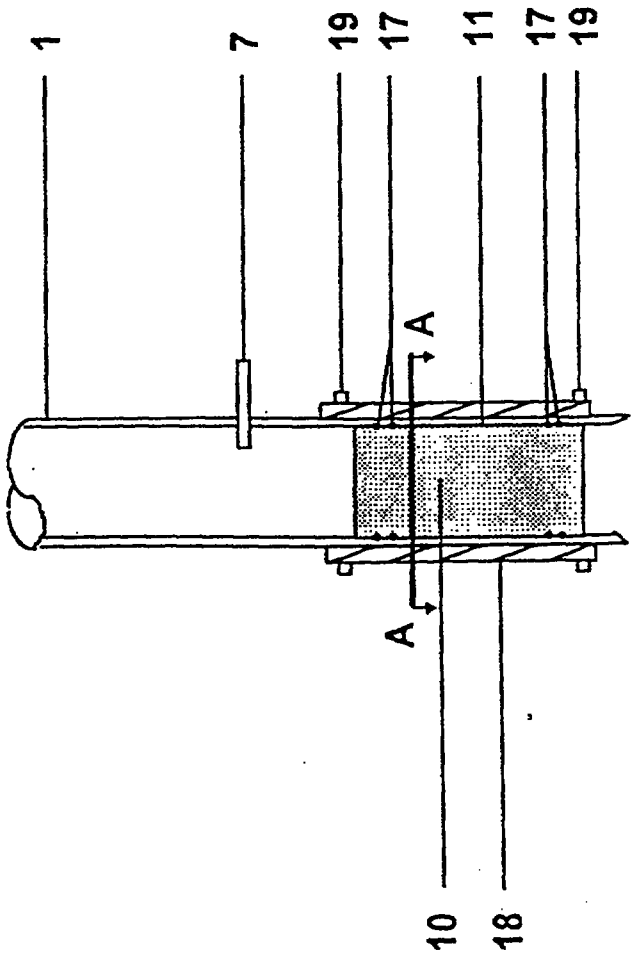
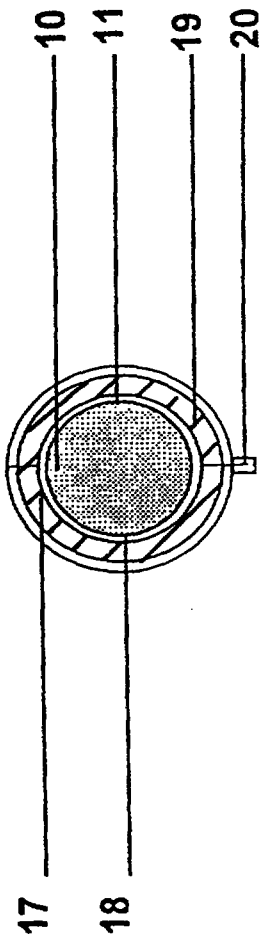
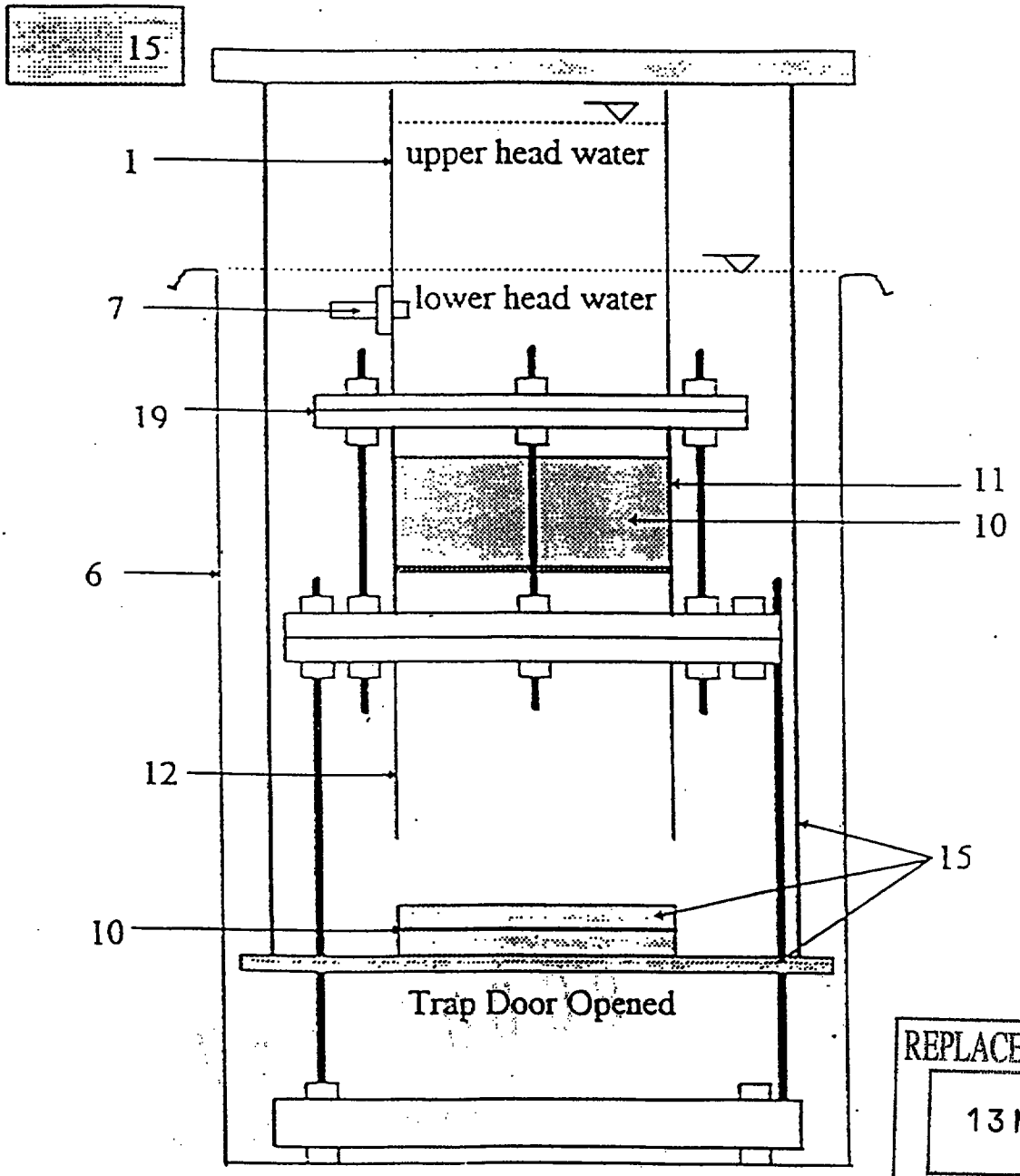


Fig. 3 Specimen Rig



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Figure 4 Test device with rigid mold-trap door