THE HIGHWAYS AGENCY HA 41/90

THE SCOTTISH OFFICE DEVELOPMENT DEPARTMENT

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THE ENVIRONMENT FOR NORTHERN IRELAND

# A Permeameter for Road Drainage Layers

**Summary:** This Advice Note describes the apparatus and test method for determining the horizontal permeability of road drainage layers.

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| VOLUME 4 | GEOTECHNICS AND DRAINAGE |
| SECTION 2 | DRAINAGE |

# HA 41/90

# A PERMEAMETER FOR ROAD DRAINAGE LAYERS

**Contents**

# 1. INTRODUCTION

1.1 A box-type permeameter for testing road drainage layers has been developed by Roads Engineering Division in collaboration with Hydraulics Research Limited (HRL), Wallingford.

1.2 This Advice Note describes the apparatus and sets out a test procedure to be used for determining horizontal permeability.

# 2. SCOPE

2.1 The test described can be used to determine the horizontal permeability of embankment drainage layers, capping materials and sub-bases and may be used to supplement the information required by Clause 640 of the Specification for Highway Works (SHW). Whilst the apparatus and test methods are currently the best available it should be recognised that, as with any test procedure, there are limitations on reproducibility and repeatability. Also it should be noted that the test applied to only laminar flow conditions and not to situations where high hydraulic gradients and turbulent flow could occur in practice.

# 3. BACKGROUND

3.1 Granular layers may be used to effect drainage of pavement layers beneath roads and for the relief of pore pressures within embankments. The granular material must possess the dual role of providing adequate drainage and also load bearing properties. These roles conflict in that a well graded material is required for load bearing but is detrimental to the drainage properties.

3.2 The selection of material for use as a drainage layer is currently achieved by the specification of a grading envelope. Large variations in permeability within such an envelope have been noted (1). In order to ensure adequate drainage properties, it is desirable to be able to specify the permeability of such a material but there is no standard test by which the permeability at working conditions may be ascertained.

3.3 In order to provide a means of testing coarse drainage materials sub-base and capping materials in their compacted states, the Department of Transport devised a large-scale robust permeameter within which the material under test could be compacted to its working state. This permeameter was later modified on the advice of Hydraulics Research Limited (2) (3).

3.4 The University of Nottingham have also contributed to developing the test procedure and method of calculation to ensure that the true Darcy coefficient of permeability is obtained (4 and 5).

# 4. DESCRIPTION OF THE APPARATUS

4.1 An engineering drawing of the apparatus is provided at Appendix B. The permeameter consists of a steel box capable of accepting a sample of size approximately 1.0m x 0.3m x 0.3m (Fig 1). The sample is retained by a grid at either end of the box. The aperture size of the grids will depend on the grading of the material, so that the particles are supported without impeding the flow. Experience has shown that an aperture size of 1-2mm is satisfactory for the materials likely to be tested.

4.2 During testing, a differential head of water is maintained across the sample by an upstream and downstream weir. This may be achieved by varying the pipe heights or by lifting the permeameter at one end. The coefficient of permeability is obtained according to Darcy's Law by measuring the steady-state flow through the sample.

4.3 In order to ensure complete saturation of the sample, a vacuum is applied to the box and maintained whilst slowly filling with water.

# 5. TEST PROCEDURE

The procedure for carrying out the test is described in Appendix A. It is recommended that at least two test runs (each on a different sample) are carried out, each sample being tested at a range of head differences (minimum of 3).

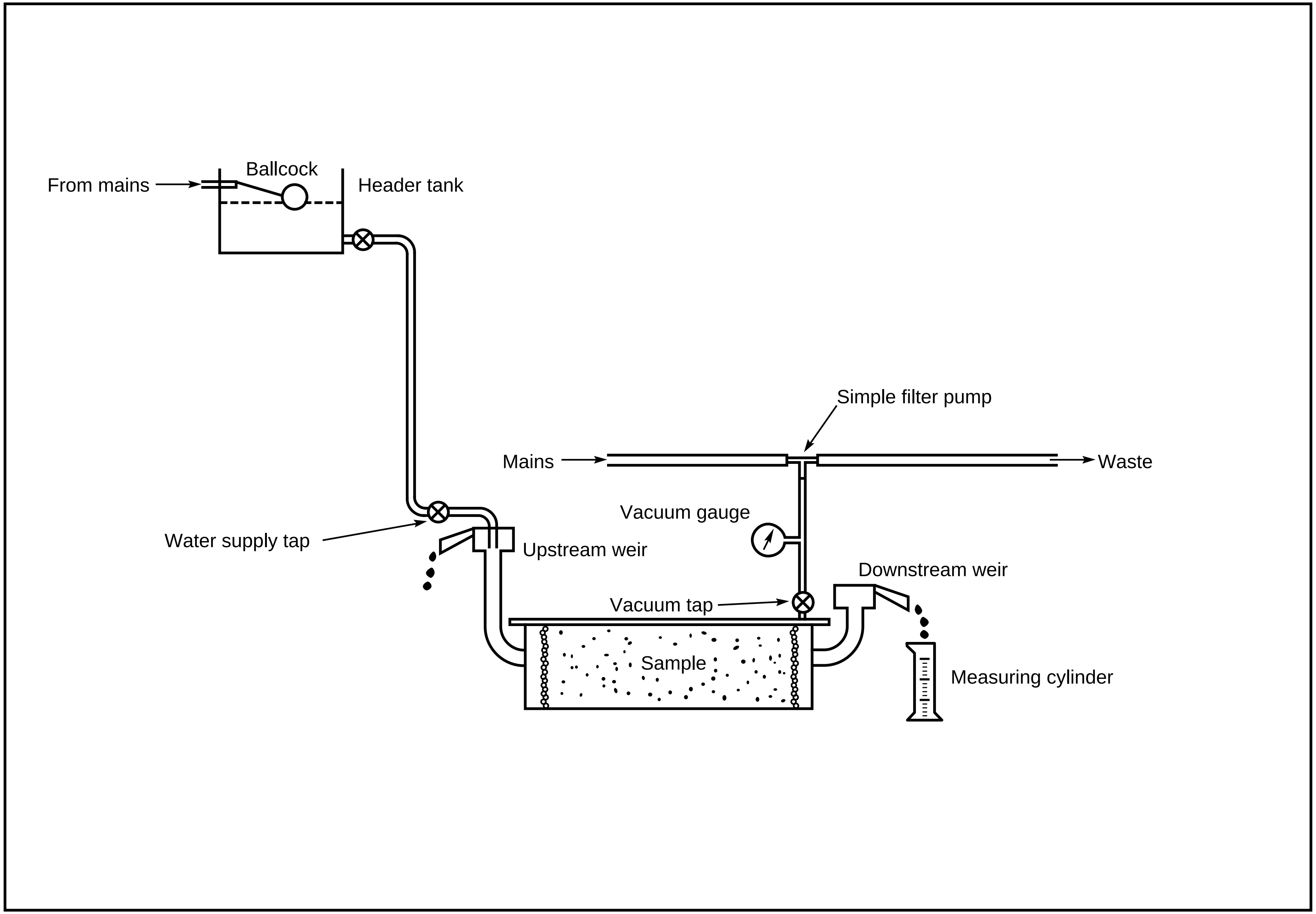


**Fig 1 Schematic diagram of apparatus**

# 6. CALCULATION OF RESULTS

6.1 The coefficient of permeability, k, at any temperature T is given by

$$k = \frac{q}{Ai} \cdot \frac{10^{-6} m/s}{60}$$

where q is the steady state flow rate (ml/min)
A is the cross sectional area of the permeameter ($m^2$)
I is the hydraulic gradient

6.2 For each head difference, ΔH, the hydraulic gradient, i, and the flow rate per unit area, $q_{20}$/A, corrected to the standard laboratory temperature of 20°C are calculated using the equations:

$$i = \triangle H / L$$

$$\frac{q_{20}}{A} = \frac{q.c}{W.D} \, \frac{10^{-6}}{60} \; m/s$$

where ΔH is the vertical head difference across specimen (m)
L, W, D are the length, width and depth of the specimen (m)
C is the temperature correction factor $\mu_T/\mu_{20}$, obtained from a standard chart. (fig 2)
μ is dynamic viscosity of water

6.3 $q_{20}$/A is plotted against i and the best straight line drawn from the origin through those points exhibiting a linear relationship. The gradient of this line gives $k_{20}$, the coefficient of permeability at standard laboratory temperature.

6.4 total porosity, n, can be calculated if required.

$$n = 1 - \frac{M}{L.W.D} \cdot \frac{1}{1000\, G_{sa} \; (1 + \frac{w}{100})}$$

where M is the total mass of aggregate in permeameter (kg)
$G_{sa}$ is the apparent relative particle density
w is the moisture content (%).

6.5 Appendix C shows a suitable test result sheet for the permeability, bulk density, moisture content, relative density, porosity and saturation results. Sample results and calculations are given in Appendix D. For the coarse granular materials falling within the scope of the test, the values of $k_{20}$ will normally be in the range $10^{-4}$ m/sec to $10^{-2}$ m/sec.

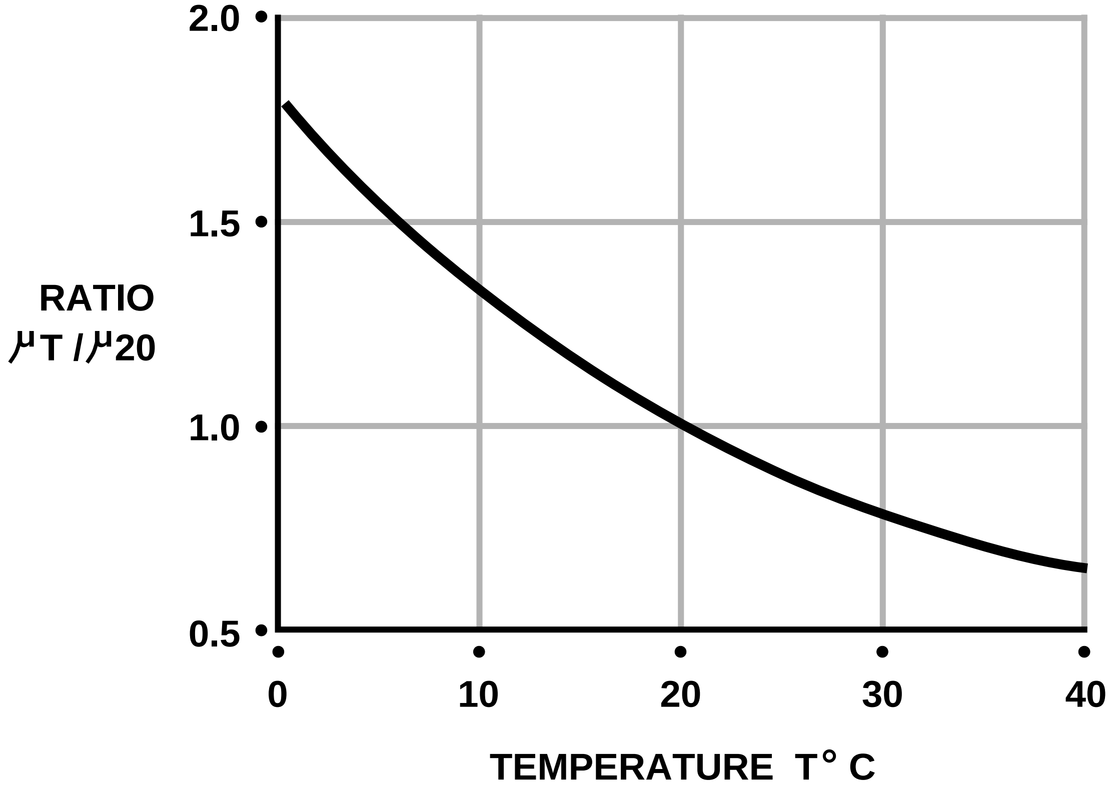


**Fig.2 Relationship between dynamic viscosity of water and temperature (based on data from Kaye and Laby. 1986)**

# 7. NOTES ON TESTING ERRORS

7.1 The following are the major factors which could adversely effect the measurement of k. The influence of each one is assessed below:-

(a) Sampling errors

(b) Aerated water

(c) Non-saturation

(d) Flow around sample - 'piping'

(e) Wall effects

(f) Washing out of fines

(g) Transitional/turbulent (non-Darcy) flow

(h) Temperature effects

7.1.1 Sampling errors: These can be overcome by rigid adherence to BS812: Part 101, (10).

7.1.2 Aerated water: This can be avoided by providing a header tank in which mains water is allowed to settle before being used in the test. The de-airing achieved in this way is by no means complete, but it is felt that usually this is a method appropriate to the volume of water required and the scale of the experiment.

7.1.3 Non-saturation: This is potentially the greatest source of error. The saturation procedures described in Appendix A (A3 Procedure) should minimise the problem and the degree of saturation (Sr) can be calculated if required (Appendix C: Test Result Sheet).

7.1.4 Flow around sample: Care is needed to ensure that flow does not occur over the sample. The sealed cell impermeable foam sheet will provide an effective seal across the top of the specimen because the reinforcing bars on the permeameter lid press firmly into the sheet.

7.1.5 Wall effects: Dudgeon (9) quotes a widely accepted value for the permeameter diameter: median ($d_{50}$) grain size ratio of 10:1. This should be sufficient to ensure that the zones of higher porosity next to the walls of the test box do not allow an unacceptably high flow and thus produce an 'average' flow which is too large. This would allow materials with d50 up to 30mm to be tested.

7.1.6 Washing out of fines: A small amount of fine material may be discharged at the beginning of the test. If this is of concern, sampling the dirty water outflow will give an estimate of the percentage loss of fines. Erosion of the sample and subsequent piping may occur if high flow rates are used. The can be avoided by conducting the test using lower head differences and correspondingly low flow rates.

7.1.7 Transitional/turbulent flow: The method of test described at Appendix A, with small head differences, ensures that non-Darcy flow is unlikely and that laminar flow obtains. The calculation procedure given in para 6(above) rejects data not obeying Darcy's law.

7.1.8 Temperature effects: The dynamic viscosity of water is temperature dependent. Figure 2 gives the ratio of dynamic viscosity of water at temperature T°C to that at 20°C, $\mu_t/\mu_{20}$ i.e. the temperature correction factor, C, used in the calculations.

7.2 Reproducibility: Experience indicates that the results can differ between samples tested by as much as a factor of 10, but it is believed that this reflects sample and compaction variation rather than inaccuracies in the test method. thus the results indicate a characteristic range rather than a single absolute value of horizontal permeability.

# 8. REFERENCES

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# 9. ENQUIRIES

# METHOD OF TEST FOR HORIZONTAL PERMEABILITY OF DRAINAGE LAYERS

A.1 GENERAL

This method is suitable for testing materials having median (d50) particle size up to 30 mm. When compacting in layers the layer thickness needs to be chosen in relation to the maximum particle size (d100).

A.2 APPARATUS The following is required:

(a) A test box as described in this Advice Note and shown in the drawing, at Appendix B.1, with associated extension pipes and weirs. All dimensions are suggested dimensions, hence no manufacturing tolerances are indicated.

(b) A jack and suitable stepped wedges (Appendix B.2) to incline the permeameter and thus achieve small differences in head.

(c) About 250 kg of the material to be tested, which has been sampled in an approved manner according to BS 812: Part 102: (ref 6, above).

(d) An electric vibrating hammer as called for in BS 1377: 1975, Test 14 (ref 8, above), but fitted with a square tamping foot of approx 125mm side. The hammer should first be checked by carrying out the test described in Note 2 to Test 14.

(e) A layer of sealed cell (impermeable) foam, such as a 12mm non-intercellular neoprene foam sheet (NINS)

(f) A simple, laboratory type filter pump, to fit a 12 mm hose from the mains water supply and an (approx) 7 mm, see-through suction hose connected to the vacuum tap in the lid of the box via a vacuum gauge. The vacuum gauge shall be calibrated and readable to 20mm of mercury or the equivalent, or better.

(g) Two rubber bungs to fit the holes in the base of each weir. One should be intact, the other should have a piece of rigid pipe (at least 7mm i.d.) pushed through it such that the bung forms a seal on the outside of the pipe. With the bung plugging the weir, the water supply hose should be sealed on to the exposed end of the pipe.

(h) A supply of settled water (Note 1) consisting of mains water being supplied via a ballcock to a header tank of at least 150 litre capacity. The water should be supplied to the pipe/bung assembly by a hose, with valves at both the tank outlet and the bottom of the hose. The lower valve will be referred to as the water supply tap.

(i) Some pipe jointing compound, and pipe wrenches.

(j) 2 Manometers and scale. The manometers should be mounted on a board behind the apparatus to measure the water levels in the two weirs by means of flexible PVC tubing submerged in each weir away from the circular hole in the base of the weir. (An inclined manometer board is useful for measuring small differences in head).

(k) A spirit level.

(l) A metre rule with sale divisions every 0.5mm.

(m) A stop watch, calibrated to within 1s in 5 min.

(n) A one litre measuring cylinder, graduated every 10 ml, calibrated by weighing the amount of distilled water that it contains at a measured temperature using a calibrated balance and applying the tables in BS 1797.

(o) A thermometer, readable to 0.1 °C, calibrated against a reference standard before using.

(p) Facilities for determination of moisture content and relative density according to BS812: Part 2: 1975 (ref 7, above).

A.3 PROCEDURE

A3.1 Preparation

(a) The box should be placed on a firm, horizontal surface allowing water to be collected or run to waste at either end.

(b) The material should be weighed before it is compacted into the box to find its mass.

(c) Compact the material in 3, 4 or 5 layers (depending on maximum particle size) into the central part of the box between the two end grids. Each layer should be compacted to the density expected on site at the optimum moisture content determined from BS 1377: 1975 Test 14 (ref 8, above) or from BS 5835 Part 1: 1980 (ref 12, above).

(d) Take a sample of the remaining material for moisture content (w) and relative density GSA determinations according to BS812. Part 2: 1975 (ref 7, above).

(e) Measure the dimensions of the sample, ie length (L), width (W) and depth (D) to an acuracy of ± 0.5mm.

(f) Fit appropriate extension pipes and weirs at either end to give a suitable head difference of say 30 to 40mm across the sample. Ensure that all joints are well tightened as they must be capable of holding a vacuum (use pipe jointing compound and PTFE tape where appropriate).

(g) Place a piece of sealed cell foam of appropriate size on top of the sample.

(h) Fit the gasket and then the lid on to the box (the vacuum tap can be at either end of the box) and tighten all nuts and bolts, forcing the bars on the lid down into the foam sheet and ensuring a good seal across the top of the sample and also between the lid and the flange.

(i) Connect the water supply from the storage tank to the bung fitted to the weir furthest from the suction tapping. Fit the plain bung in the other weir. Leave the water supply tap closed.

(j) Open the vacuum tap and lift that end of the box slightly. Apply a vacuum using the filter pump. Tighten the bolts on the lid while the box is under vacuum.

(k) When a vacuum of at least 7m water (20 inches Hg) and preferably around 9.5 m water (27.5 inches Hg) below atmospheric has been achieved, open the water supply tap slightly, allowing water to flow in slowly and saturate the sample.

(l) Water should flow in so as to fill the box in about 15 minutes. When water is seen in the clear hose attached to the vacuum tap, let it flow briefly before shutting the vacuum tap.

(m) Leave the water supply tap open for a few minutes to allow the water pressure to build up. Briefly open the vacuum tap to bleed off any more air which has collected.

(n) Remove the bungs. Fill the box until there is some water in the lower weir. Turn off the water supply tap.

(o) The degree of saturation can be calculated from the total mass of water added (MW1), the mass of water required to fill the box ends and fittings only (MW2) and the density and porosity of the sample. (Appendix C).

A3.2 Testing

(a) Supply the water to the higher (upstream) weir and adjust the flow throughout the test so that this weir just overflows.

(b) Measure the flow rate (q) at the discharge end at 15 minute intervals.

(c) Measure the head difference ($\Delta H$) between the upstream and downstream weirs, by means of the manometers.

(d) Measure the water temperature (T) at both ends of the permeameter throughout the duration of the test and calculate the average.

(e) Continue the test until a steady flow rate is achieved i.e. subsequent measurements within 5% of each other (this may take several hours). Occasionally remove accumulated air by briefly opening the vacuum tap.

(f) Note when the discharge water appears to be clear. If it continues to be very dirty, take some samples, noting the time of sampling.

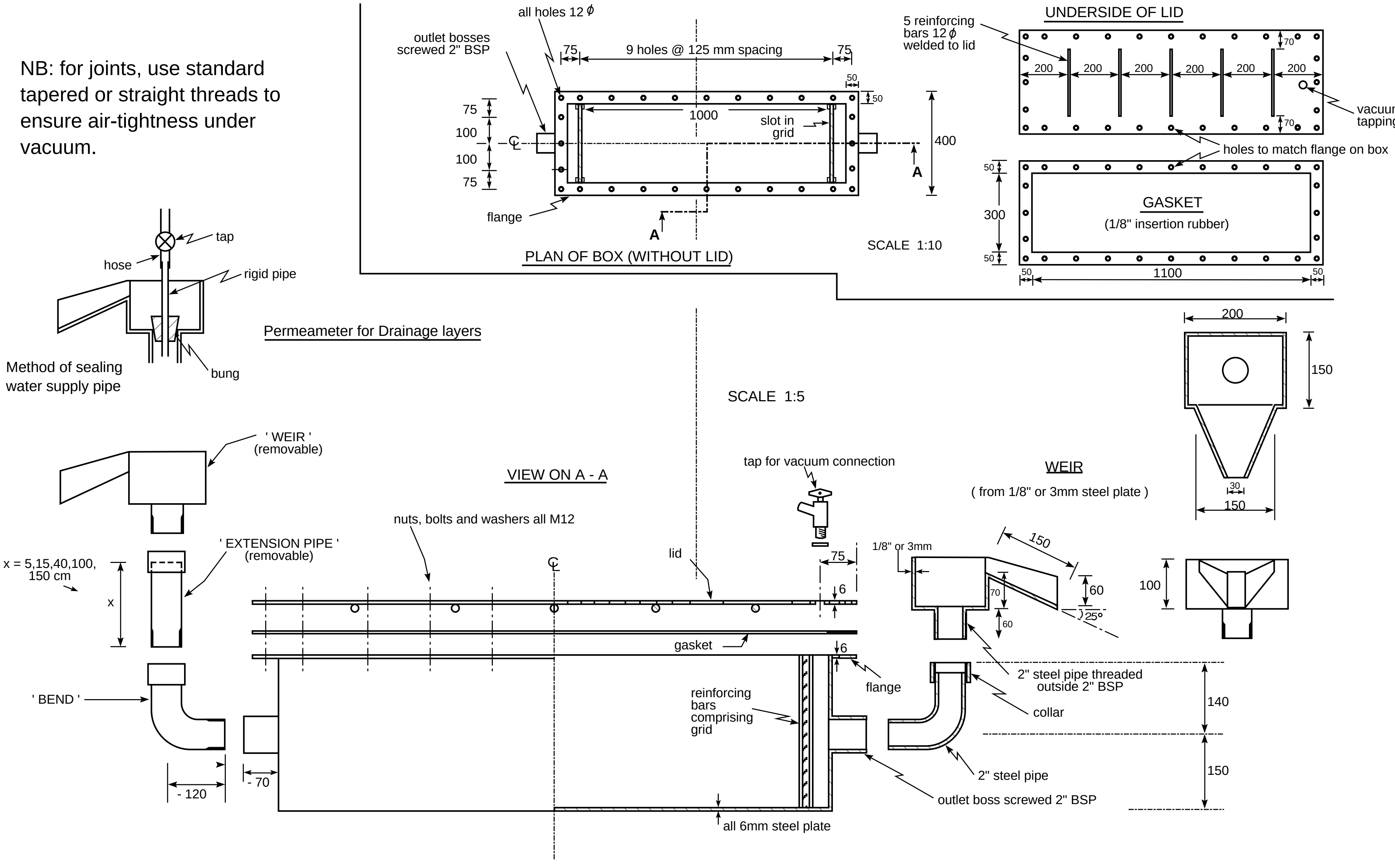
(g) Results should be reported on a record sheet similar to that in Appendix C.

(h) Test the material over a range of head differences. The head difference can be altered either by changing the extension pipes or, for small changes, by lifting the permeameter at one end. During test maintain a plot of flow rate q, against head difference, $\Delta H$. The plot will indicate the linear region for which Darcy's law is applicable.

(i) After testing take a representative sample of material from the permeameter for a particle size distribution analysis (wet sieving test).

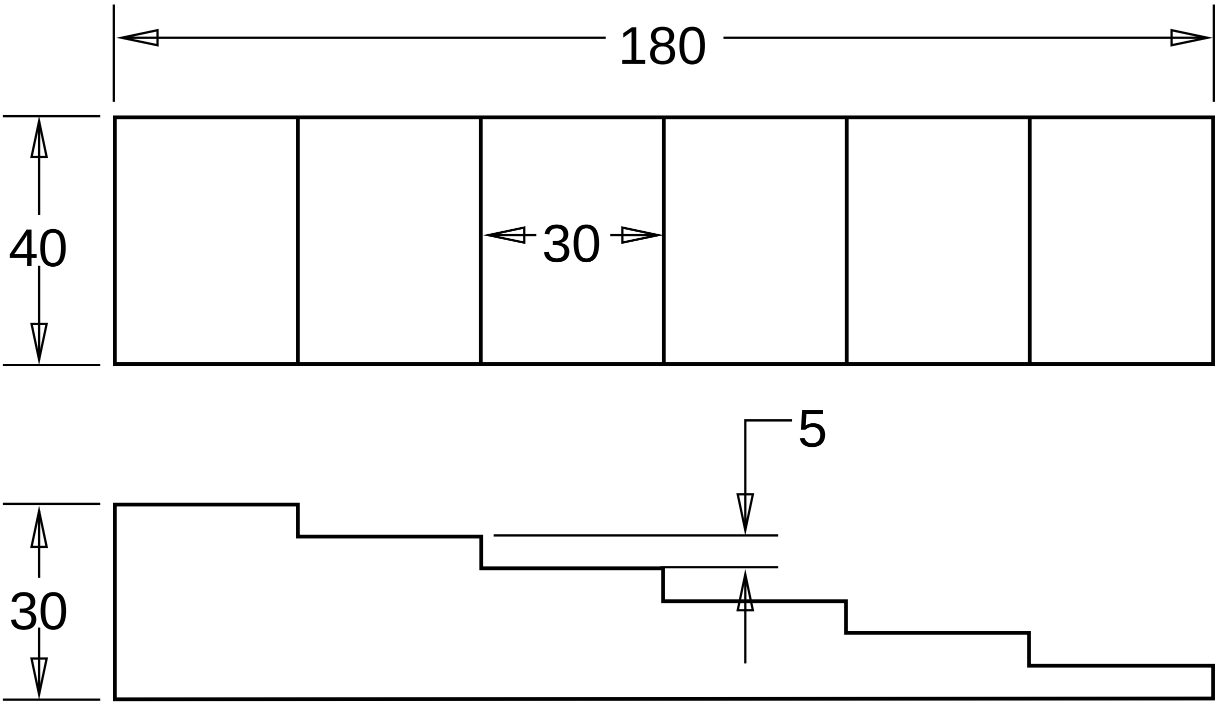
(j) When removing the sample from the box, take note of anything which may adversely have affected the results (eg evidence of piping, flow across top of sample, non-saturation of sample).

Note 1: For tests at low hydraulic gradients, requiring smaller volumes of water, the use of de-aired water, instead of settled water, should be considered.




ALL DIMENSIONS IN MM

## Suggested Dimension mm




## STEPPED WEDGE

# PERMEABILTY TEST RESULTS

Job....................Date....................Operator......................Sheet No..........of......
Sample Ref.............Description.....................................................................
Compaction Method - No. Layers.......Mass per layer................Compactive effort....................

| | | | |
|---|---|---|---|
| Specimen | Length, | L:....................m | Mass of Compacted Material...........Kg Moisture Content, w:.........% |
| | Width, | W;...................m | Bulk Density,...............kg/$m^3$ Dry Density, d................kg/$m^3$ |
| | Depth, | D:....................m | Apparent relative density, Gsa:..........Porosity, n.................. |
| | Area, | A=WD:...........$m^2$ | Saturation - Mass of water added, $M_{w1}$.....................kg |
| | Volume, | V:....................$m^3$ | Mass of water to fill box ends and fittings, $M_{w2}$..........kg |

$$S_r = \frac{(M_{w1} - M_{w2})/V + - d}{1000\ n} = \ldots\ldots\ldots\ldots$$

| | | | |
|---|---|---|---|
| Test Number | | | |
| Head at inlet, $H_1$ (m) | | | |
| Head at oulet, $H_2$ (m) | | | |
| Head Difference $\Delta H = H_1 - H_2$ (m) | | | |
| Hydraulic Gradient $i = \Delta H/L$ | | | |

| Time from start (min) | Flow rate, q (ml/min) | Time from start (min) | Flow rate, q (ml/min) | Time from start (min) | Flow rate, q (ml/min) |
|---|---|---|---|---|---|
| | | | | | |

| | | | |
|---|---|---|---|
| Steady state flow rate, q (ml/min) | | | |
| Temperature (ºC) | | | |
| Temperature correction c = T/20 | | | |
| $q20^{/A} = \frac{qC \times 10\text{-}6}{60A}$ m/s | | | |

Coefficient of permeability (20ºC) obtained from a plot of $q20^{/A}$ versus i:

$$K20 = q^{20/Ai} = \ldots\ldots\ldots\ldots\text{m/s}$$

# SAMPLE RESULTS AND CALCULATION

Sample Description:

Specimen preparation: 190kg compacted in 5 layers at 0% moisture content. Dry Density 2290 g/m$^3$
Dimensions: Length L 0.934m; W 0.300m; Depth, D 0.296m; Area, A = WD 0.089m$^2$
Apparent relative density, $G_{sa}$: 2.82 (meas) Water absorption, $w_A$: 2.9% Total porosity, n 18.9%
Saturation S:...........%
Notes:

| Test Number | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Head Difference, △ H (mm) | 24.5 | 8.3 | 17 | 32 | 10.5 | 3.3 |
| Hydraulic Gradient I = △ H/L | 0.026 | 0.0089 | 0.018 | 0.034 | 0.0112 | 0.0035 |
| Steady state flow rate, q (m/min) | 899 | 429 | 706 | 1091 | 476 | 158 |
| Temperature (ºC) | 12.75 | 13.5 | 13.25 | 13.25 | 13.25 | 13.5 |
| Temperature correction factor, C | 1.21 | 1.18 | 1.18 | 1.19 | 1.19 | 1.18 |
| Flow rate per unit area q20/A = $\frac{q^{C} \times 10^{-6}}{60A}$ m/s | $2.03 \times 10^{-4}$ | $0.95 \times 10^{-4}$ | $1.56 \times 10^{-4}$ | $2.43 \times 10^{-4}$ | $1.06 \times 10^{-4}$ | $0.35 \times 10^{-4}$ |