HIGHWAYS DEPARTMENT

SUBSOIL DRAINAGE FOR ROAD PAVEMENTS

Research & Development Division

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CONTENTS

TABLES

Sub-soil Drainage for Road Pavements

1. Introduction

This Guidance Notes replaces the 2001 version of Road Note 8 as the standard for the design of sub-soil drainage for road pavements. This Guidance Notes is to be read in conjunction with HyD Guidance Notes RD/GN/042, Guidance Notes on Pavement Design for Carriageway Construction.

2. Background

2.1 Water has a damaging effect on most of the materials used in road construction. In the summer months heavy rainfall can cause water infiltration into the cracks and joints of road pavement, with resulting weakening of the pavement structure, which can develop into deformation, cracking and potholes. Likewise, saturation of the pavement sub-layers due to a high water table will reduce the moduli of elasticity of the sub-layers giving rise to early rutting and cracking and requiring early maintenance.

2.2 It is therefore important that efficient permanent sub-soil drainage is provided to prevent the level of the water table rising to formation level and to drain water which may have penetrated through the edge or cracks and joints in the road pavement into the road structure. As a general requirement, sub-soil drainage systems should be provided to prevent the water table from rising to within 600 mm of the formation level. The installation of adequate sub-soil drains allows the designer to use higher soil strength in assessing the pavement thickness.

2.3 This Guidance Notes provides:

(a) information and criteria for lowering the ground water table underneath the pavement;

(b) criteria for the design of sub-soil drains and surrounding filter materials and typical drawings for their installation;

(c) guidance on the assessment of the rainfall infiltration through cracks and joints in the road pavements;

(d) guidance on calculating the permeability required of the sub-base to drain the rain water that has infiltrated the pavement;

(e) guidance on calculating the permeability required of the filter backfill in the sub-soil drain trench to intercept seepage beneath the road formation; and

(f) the range of permeabilities that can be obtained with the common pavement construction materials.

3. Design considerations

3.1 Minimum soil suction to maintain designed CBR of the subgrade

3.1.1 The California Bearing Ratio (CBR) is a measure of the strength of the subgrade and is used to design the thickness of road pavements built over the soil. However, the strength of the subgrade and hence its CBR value are affected by the soil moisture content and can decrease significantly if the subgrade soil remains saturated for an appreciable length of time.

3.1.2 The CBR value of a soil is normally determined by laboratory test. It is sufficient to carry out CBR test on test samples at the dry density and moisture content likely to be achieved in the field without soaking. However many designers prefer to carry out CBR test on soaked samples to simulate the worst condition, i.e. high water table and poor subsoil drainage (saturated in service). This is really a design judgement that the designer has to exercise. Because CBR determinations are coupled with dry density and moisture content determinations, the tests are of necessity slow, giving results with a delay of 24 hours. It is usual, therefore, to adopt supplementary CBR measurements in situ which can be carried out more quickly. However the Engineer is required to carry out checks to establish the relationship between laboratory tests and tests in situ for the soils in question. This is because the degree of confinement of the soil in laboratory tests and in those conducted in situ is clearly different. This influences the stress distribution under the plunger, and the load-penetration curves. Because of the mould restraint factor, laboratory CBR values tend to be greater than measurements in situ at the same density and moisture content. For heavy clays and for other cohesive soils having an air content of 5% or more, the difference between the results of laboratory tests and those of tests in situ is small. For other less cohesive soils with low air voids content and most granular materials the difference is much larger and tests in situ should not be carried out.

3.1.3 The CBR value can also be estimated from the suction and plasticity characteristics of the soil together with its true angle of friction(1). Based on this, Russam(2) developed the relations between CBR value and suction for partially saturated soils in the undisturbed state with plasticity indices ranging from 10 to 80 and these relations are reproduced on **Figure 1**.

The construction of an impervious pavement prevents moisture changes in the subgrade due to rainfall and evaporation and this resulted in a fairly stable moisture distribution particularly away from the pavement edge. It has been shown that with such a sealed surface, an equilibrium moisture distribution in the subgrade is reached with respect to the position of the water table when the water table is close to the surface. Partially saturated conditions will often be found above the water table. This is the result of capillary action, which occurs through the attractive forces between each water molecule and: (a) other water molecules (surface tension), and (b) moist surfaces (wetting). The amount by which moisture can rise above the water table by this effect differs in different soil types. The pressure at a free water surface of the water table is atmospheric and drops away in the capillary as the height above the water table increases. There is thus a tension called matrix suction in the water which is resisted by the molecular attractions and a counter-balancing compression in the soil. The presence of dissolved salts will cause additional solute tensions (or suction) due to osmosis. Within clays there are also internal osmotic and surface adsorption tensions at work. The combined effects of all these tensions on the water are to produce a soil suction, or negative pore pressure. The total suction is zero at the surface of a water table; and increases with distance above the water table.

When the water table is close to a sealed surface, it will exert a controlling influence on the subgrade moisture content as outlined above and under this condition, the suction of the soil is related to the position of the water table by the following equation ('close to the surface' means within 6 m of the surface in clay soils, or 3 m in sandy clays or silts, or 1 m in sands):

$$S = \alpha P - U$$

Where	S	is the soil suction (m of water)
	U	is the pore water pressure at any point in the soil above the water table. (m of water)
	P	is the vertical pressure due to the pavement on the in-situ soil and α is the fraction of this pressure transmitted to the soil water and
	α =	0 for plasticity index (P.I.) < 5;
	α =	1 for plasticity index (P.I.) > 40;
	α =	0.027 P.I. - 0.12 for 5 $\leqq$ P.I. $\leqq$ 40.

Therefore under equilibrium condition, the suction at any depth in the soil under a road pavement can be easily calculated from a knowledge of the plasticity characteristic of the soil, the density of the soil and pavement, the thickness of the pavement, and the position of the water table.

3.1.4 The following example illustrates the application of the above equation to estimate the depth to which the water table should be lowered below the top of the subgrade to maintain the designed CBR value:-

Assume a flexible pavement thickness of 610mm (which includes thickness of the sub-base) is adequate if the subgrade has a CBR value of 6%.

Average pavement bulk density	=	2250 kg/m³
P.I. of subgrade soil	=	10

The suction S at which a subgrade soil of P.I. 10 has a CBR value of 6% is, from Fig. 1, equivalent to 1.35 m of water.

α for the soil = $0.027 \times 10 - 0.12$

$$= \quad 0.15$$

The overburden pressure P is due to the pavement only

	P	=	2250×0.61 kg/m²
		=	1372.5 kg/m²
		=	1372.5/1000 or 1.37 m of water
			(Density of water = 1000 kg/m³)
Since	S	=	$\alpha P - U$
	1.35	=	$0.15 \times 1.37 - U$
	U	=	-1.14 m

Thus the water table should be lowered to a depth of 1.14m below the top of the subgrade or formation in order to maintain a subgrade CBR value of 6%.

3.1.5 The relations between CBR values and suction for partially saturated soils shown in Figure 1 do not apply to granular soils. However laboratory determined suction curves shown in **Figure 2**, which is reproduced from Reference 3, shows suction curves for a range of soils including cohesive and granular soils. By applying the equation $S = \alpha P - U$ to the appropriate suction curve, the equilibrium moisture content for a granular soil with respect to a water table depth under a sealed surface can be determined. This moisture content, together with the dry density likely to be encountered in the field, will determine the CBR value of the granular subgrade.

Figures 3 and 4, which are also reproduced from Reference 3, shows typical laboratory determined CBR versus moisture content and dry density curves for a silty sand and a well-graded sand.

In order to determine the water table to be lowered to achieve a required CBR value for the granular subgrade in the territory, it will be necessary to carry out laboratory determination of the suction and CBR/moisture curves for the typical granular soils encountered in the territory. In the interim, it is regrettable that such information is not available.

3.2 <u>Estimation of the required size of the sub-soil drains and the quantity of discharge required to lower the water table by a given depth</u>

3.2.1 Several methods are available for the estimation of drawdown and considerable research has been carried out into methods of field drainage for agricultural purposes. The results of road drainage studies by McClelland[4] provide a particularly useful guide to road engineers and the experimentally determined relations can be summarised in the dimensionless ratios as shown in **Figure 5**, which is reproduced from Reference 5.

3.2.2 The following calculation estimates the discharge required and the size of sub-soil drains required to lower the water table by a given depth:

Consider the cross section shown in Figure 5

Let the permeability of the subgrade be 10^{-4} m/sec (such as might occur in saturated fine sand). Also let the dimensions shown in the figure have the following values:

D = 1.0 m   W = 12 m

The flow rate into the drains will be greatest if drainage has just started. Using McClelland's results, with d/D = 0.06, the flow into each pipe is given by:

q/KD = 0.8 where q = flow into each pipe (m^3/sec/metre of pipe)

or $q = 8 \times 10^{-5}$ m^3/sec/metre length of pipe

Now the flow intercepted per metre of pipe can be approximated by

$Q = N.A.Cd\,(2.g.h)^{1/2}$ (from Bernoulli's equation)

Where Q = flow through perforations (m^3/sec)
N = number of perforations in a metre of pipe
A = area of each perforation (m^2)
Cd = coefficient of discharge of each perforation
g = acceleration due to gravity (9.81 m/sec^2)
h = hydraulic head to the perforations

Now, suppose the head to the perforations is 5 mm, and take Cd = 0.8

Then $Q = N.\ A.\ (0.8)\ (2 \times 9.81 \times .005)^{1/2}$
$Q = 0.25\ N.\ A.$ m^3/sec/metre of pipe

But in the example considered, the flow into the pipe is q.
Therefore equating Q and q, we have

$Q = q = 8 \times 10^{-5} = 0.25.\ N.\ A$

Hence the total area of perforations required in each metre of pipe is

$N.\ A = 32 \times 10^{-5}$ m^2/metre of pipe

Or   N. A = 320 mm^2/metre of pipe

Suppose the perforations are circular holes of 5 mm diameter

Then $A = \pi(2.5)^2$ mm^2

So $N = 320/[\ \pi(2.5)^2\ ] = 16.3$

Hence, seventeen 5 mm diameter holes per metre of pipe would be sufficient. However as the minimum area of perforations in a perforated pipe is 1000 mm^2 per metre length of pipe (see section 6.5), fifty one 5 mm diameter holes per metre of pipe should be provided.

The value of permeability used is higher than what would normally be encountered, and so seventeen 5 mm holes (subject to a minimum of 1000 mm^2) are the most ever likely to be required in the pipe except where abnormal sub-surface flows are entering the pipe (such as might occur in sloping ground) or where rainfall is infiltrating through the cracks and joints in the road pavement. It should however be noted that the calculation is based on idealized flow conditions, and that many simplifying assumptions have been made.

Based on the value of q, the size of the sub-soil drain can be calculated using the Manning's Formula or the Colebrook White Equation (this has not taken into account abnormal sub-surface flow and infiltration through the cracks and joints in the road pavements). However the length and diameter of pipe must be chosen so that the pipe does not run full near its outlet and flood the surrounding filter material. This can be evaluated based on the flow entering the drain, and the gradient and roughness of the pipe. Also the pipe must be able to intercept all the water entering the drain without causing high heads in the filter material. Backing up of water in the filter material of a drain is undesirable as this reduces the depth to which the water table can be lowered, and its rate of lowering.

3.3 Infiltration of rainfall through the cracks and joints in the road pavement

3.3.1 Findings reported by Cedergren(6) show that substantial quantities of water can enter even very narrow cracks in a pavement under field test conditions. [Cracks 0.125 in (3 mm) wide admit more than 95 percent of water falling at an intensity of 2 in/h (50 mm/h), even with steep pavement transverse slopes. Cracks as narrow as 0.035 in (0.89 mm) can absorb 70 percent or more of runoff at the same intensity.] In practice these rates may be reduced somewhat, due to debris at the bottom of the crack or to buildup of water in the crack. Nevertheless, infiltration rates become quite high at low levels of cracking or open joints in the pavement surface.

3.3.2 According to Reference 7, to estimate the amount of infiltration to the pavement structure through the cracks and joints in the pavement, the practice in the USA is to apply an infiltration factor to the amount of rainfall to the section of pavement in question from a 1-hour duration, 1-year frequency storm. The infiltration factor to be applied is 0.50 to 0.67 for concrete pavements and 0.33 to 0.50 for bituminous pavements. According to Reference 8, the practice in Australia is to apply an infiltration factor to the amount of rainfall in question from a 1-hour duration, 2-year frequency storm, the infiltration factor to be applied being 0.3 to 0.4 for concrete pavements and 0.2 to 0.4 for bituminous pavements. Since in Hong Kong, the intensity versus duration curve for rainstorms is available for a 2-year frequency storm but not available for a 1-year frequency storm, unless data from field instrumentation is available, the method used in Australia for calculating the amount of rainfall infiltration will be adopted in the territory.

3.3.3 Markow(9) bases the classification of the sub-drainage quality of a pavement to drain the rainfall infiltration on the coefficient of permeability of the sub-base beneath the pavement:

Poor: 0.1 ft/day (0.03 m/day)
Fair: 100 ft/day (30.5 m/day)
Good: 10,000 ft/day (3050 m/day)

Using the EAROMAR system (the EAROMAR system is a Federal Highway Administration's simulation model of freeway performance that enables one to conduct economic analyses of different strategies for roadway and pavement reconstruction, rehabilitation and maintenance), Markow simulates pavement performance under various moisture conditions due to rainfall infiltration. The results of the simulation indicate that pavement performance under good and fair sub-drainage conditions is virtually identical, however the rate of pavement damage increases with poor sub-drainage conditions, resulting in worse pavement conditions over time and increased pavement related costs to both the highway agency and road users. This means that a minimally acceptable value of sub-base permeability should lie between the poor and fair values [0.1-100 ft/day (0.03-30.5 m/day)] if rainfall infiltration is not to cause substantial damage to the road pavement, and this should be aimed at in the selection of the sub-base material.

3.3.4 An example is given below to illustrate how to calculate the permeability of the sub-base required for disposal of a calculated quantity of infiltration water:

Assume the quantity of infiltration water has been calculated to be 2.4×10^{-3} m^3/h per metre length of carriageway.

It is proposed to utilise a sub-base 200 mm thick to carry this water to the subsoil drain on the low side of the pavement. The pavement crossfall is 3% and the longitudinal gradient is 4%. The combined effect of crossfall and grade results in a downslope of 5% at an angle of about 37º to the centreline. A longitudinal 1 m run of pavement is therefore 0.6 m wide along the line of maximum slope.

Using the Darcy equation for saturated laminar flow conditions:

$q = kiA$

Where q = volume rate of flow
k = coefficient of permeability
i = hydraulic gradient
A = cross sectional area

Rearranging gives:

$$k = 2.4 \times 10^{-3}/(0.05 \times 0.2 \times 0.6)$$
$$= 0.4 \text{ m/h}$$
$$= 1.1 \times 10^{-2} \text{ cm/s}$$

Thus the required permeability of the sub-base is 1.1×10^{-2} cm/s. Please note this is not a strictly correct use of Darcy's Law since, in practice, the sub-base, being sufficiently permeable, would not be saturated completely, but only up to a curved saturation line. The true solution to the problem is to use a flow net for a two dimensional laminar flow condition. However the answers obtained are similar.

3.3.5 **Figure 6** shows the typical gradations and permeabilities of granular filters and drainage materials encountered in Hong Kong. The figure illustrates the levels of permeability that are possible for a range of material gradations and is reproduced from Reference 10. **Table 1** shows the permeability ranges of the commonly encountered pavement materials. This table is reproduced from Reference 8.

3.4 <u>Unusual seepage beneath the road formation</u>

3.4.1 An example is included below to illustrate how to calculate the permeability required of the filter backfill in the trench of the sub-soil drain to intercept seepage beneath the road formation:

Figure 7 shows a permeable layer of material which has been intersected by the cutting for a road formation. The permeable layer has a saturated thickness of 2 m and is on a 20% slope. The layer consists of silty sand having a maximum permeability of 1.5×10^{-3} cm/s.

From Darcy's Law, the maximum flow to be intercepted by the sub-soil drain is:

$$
\begin{aligned}
q &= kiA \\
&= 1.5 \times 10^{-5} \times 0.2 \times 2 \\
&= 6 \times 10^{-6}\ \text{m}^3\text{/s per metre length of pipe}
\end{aligned}
$$

By adopting a conservative approximation to the real situation, the required permeability of the filter material in the trench of the sub-soil drain can be calculated. Such a situation is shown in **Figure 8**, with the actual shape of the phreatic line being shown dotted.

Suppose the width of the trench of the sub-soil drain is 450 mm, and is to collect the seepage from the aquifer shown in Figure 7.

Seepage theory relates the slopes of phreatic lines to the permeability of materials at interfaces as follows:

	$\tan\beta / \tan\alpha$	$= k_a / k_f$
now	$\tan\beta$	$= W/T$
	$\tan\alpha$	$= 1/\sigma$
thus	k_f	$= k_a T / W\sigma$
where	W	$= 0.45$ m
	σ	$= 0.2$ m/m
	T	$= 2$ m
and	k_a	$= 1.5 \times 10^{-5}$ m/s
thus	k_f	$= 1.5 \times 10^{-5} \times 2 / (0.45 \times 0.2)$
		$= 3.3 \times 10^{-4}$ m/s
		$= 3.3 \times 10^{-2}$ cm/s

Thus the minimum permeability of the filter material should be 3.3×10^{-2} cm/s. A coarse washed sand or 3 to 5 mm aggregate would be suitable.

3.4.2 Where unusual seepage beneath the road formation is encountered, the designer should seek geotechnical advice from a geotechnical engineer on the possible source and quantity of seepage flow required to be intercepted by the sub-soil drain and on the possible adverse effect of the seepage, if any, on slope stability.

4. Filter requirements for the filter material surrounding the sub-soil drain

The filter requirements are summarised in **Table 2**, which is reproduced from Reference 11. These requirements are explained as follows:

4.1 Stability

The pores in the filter must be small enough to prevent excessive migration of the base soil being drained and the common rule of limiting $D_{15}F/D_{85}S$ to 5 is appropriate. As an additional measure against failure, the filter should not be gap graded to prevent the loss of fine particles from the filter itself.

4.2 Permeability

The filter must be sufficiently more permeable than the material being drained. This requirement would be satisfied by limiting the $D_{15}F/D_{15}S$ ratio to at least 5. The presence of fine particles in significant quantities could also influence the permeability of the filter. Hence the amount of particles finer than 63μm should not exceed 5%, the particle size of 63μm has been chosen to correspond to the BS sieve size nearest to 75μm. The filter should also be cohesionless to prevent the formation of shrinkage cracks in the filter as a result of drying.

4.3 Segregation

The filter should not become segregated or contaminated prior to, during, and after installation. To minimize the problem of segregation, the filter should not have a broad grading and the maximum size of the particles should be limited. It is recommended that the coefficient of uniformity should be restricted to between 4 and 20 with the maximum size of the particles limited to 50 mm.

4.4 Filter requirements for filters for sub-soil drains located in silt and clay soils. Concrete sand to BS 882, Zone 2 or similar material is recommended for all silt and clay soils. The concrete sand is fine enough to act as a filter for silts, and it will protect the sub-soil drain from any fine non-cohesive particles in clays.

4.5 Other design considerations

For the design of granular filters, the base soil particle distribution should be determined by wet sieving without the use of dispersants. The chemicals in the dispersants break down the clay aggregation and result in a large increase in percentage of fine particles in the particle size distribution. Dry sieving is not recommended as clay particles may adhere to the larger sized particles, and the particle size distribution so obtained will not be representative of the material.

Regarding Note (2) of Table 2, it is known that the coarse particles of widely graded base soils, which are commonly found in Hong Kong, have little effect on the filtration process. Therefore, for those base soils containing a significant amount of both gravel and fines, the coarse part should be ignored, and a revised base soil grading curve consisting of the particles smaller than 5 mm only should be considered.

Under Rule 3 of Table 2, the relative permeability of the base soil and filter has been assumed to be largely dependent on the $D_{15}F/D_{15}S$ ratio. However, for base soils whose mass permeability is predominantly governed by that of relict discontinuities, it would be necessary to check that the permeability of the filter designed in accordance with Table 2 is at least 25 times that of the soil mass.

5. Recommended hole size of sub-soil drain

5.1 The General Specification for Civil Engineering Works 2006 (GS) Clause 7.200(3) specifies that the D_{15} particle size of the filter material shall be at least 15% larger than twice the maximum dimension of the perforations of the perforated pipes. However the Guidance Notes on GS Clause 7.197(3) also state that the criteria for the grading of filter in relation to pipe perforations can also be referred to Geotechnical Manual for Slopes (2nd Edition), which requirements are identical to those outlined in Section 5.2 below. The designer can exercise his discretion in deciding which criteria to adopt.

5.2 Based on the examination of various experimental results, and drainage practices in the United States, Spalding[(5)] recommends the following hole size criteria for sub-soil drains should be adopted:

maximum diameter of circular holes	= D85F
maximum width of slots	= 0.83 × D85F

For any given filter material, circular holes of the sub-soil drains are allowed to be wider than slots. The reason for the different limits is that particles can form interlocking arches in any direction over a circular hole, but in only one direction over a slot. Slots must therefore be somewhat smaller than holes to ensure that the necessary arches will form.

5.3 Spalding recommends that hole diameters in sub-soil drains, or the width of slots, be 3 – 5 mm, in order to decrease the possibility of the filter entering the sub-soil drain. There is a danger however, that very small holes (say 2 mm diameter) could become blocked by slime inside the sub-soil drain. Also in some circumstances (e.g. where abnormal sub-surface flow is encountered), sections of the sub-soil drain having larger perforations would have to be provided.

6. Construction details and maintenance requirements

6.1 HyD Standard Drawings Nos. H3102 and H3103 show typical sub-soil drainage for pavement on embankment and pavement on cutting respectively.

6.2 For soils of high permeability, sufficient drainage will normally take place fairly quickly after installation of the sub-soil drains and the final water table will tend towards the bottom of the sub-soil drains. For less permeable soils, the time taken for lowering the water table may be in the order of a few days to several weeks. On heavily saturated soils with very low permeability the drainage may take many months. Thus in the summer months, if water penetrates the road subgrade at a faster rate than the permeability of the soil, then this water will accumulate under the road structure and the subgrade will be saturated even though subsoil drains may be present. For prolonged heavy rainfall, the water table may ultimately reach the surface of the subgrade. In such circumstances, the design engineer should be careful in selecting the design CBR. A low CBR with shallow sub-soil drains may be more appropriate than a high CBR with sub-soil drains installed at a greater depth.

6.3 For pavement constructed on embankment, the sub-base should be carried through to the edge of the embankment with fall towards the edge of the embankment. In such case, installation of sub-soil drains will not be necessary. A drainage layer should be considered at the interface of the new fill and the in-situ soil, particularly if the permeability of the in-situ soil is low. The filter criteria discussed in Section 4 also apply to this drainage layer. With this drainage layer, the new filling material can be protected against the damaging effect of rising water table from underneath or loss of fine soil particles in open jointed rock mass areas.

6.4 For pavements constructed in cuttings, a drainage layer should be considered at the bottom of sub-base particularly if the permeability of the subgrade soil is low or the original ground water table is high. The filter criteria discussed in Section 4 also apply to this drainage layer.

6.5 In general, sub-soil drains can either be perforated concrete pipes to BS 5911 or proprietary pipes of plastic type materials. The pipes should have an impermeable invert over approximately one third of the circumference. The required size of the perforations in a perforated pipe has already been dealt with in Section 5, however the total area of perforations shall be not less than 1000 mm^2 per metre length of pipe as a precaution against localised clogging of the backfill (based on the requirement of BS 5911-110 : 1992). Porous concrete pipes should not be used as local experience indicates that these pipes do not comply with the relevant BS standards and the service life is limited.

6.6 The sub-soil drainage system should be capable of being inspected and cleaned regularly and its layout should be shown in the overall as-constructed drainage layout plans. The sub-soil drainage system and the surface run-off drainage system should be carried in separate systems to ensure that surface run-off discharge does not back up into the sub-soil drainage system thereby damaging the road pavement structure. If it is not practicable to carry the two systems in separate systems, the sub-soil drainage system can be connected to the manholes and catchpits of the surface runoff system, provided that the design engineer has ensured that the surface run-off discharge does not back up into the sub-soil drainage system thereby damaging the road pavement structure.

Since most of the surface runoff drainage system is free surface water flow and not surcharged flow, a rule of thumb to ensure that surface discharge does not back up into the sub-soil drain is to make sure that the invert of the sub-soil drain is above the crown of the outfall pipes of the manholes and catchpits. The drainage outlet should be carefully located to avoid discharge which could adversely affect the stability of slopes, especially downhill slopes.

6.7 A typical detail of the manholes and rodding eyes for the sub-soil drainage system is shown in **Figure 9**. Usually a rodding eye is provided at the upstream end of the sub-soil drain and manholes, which serve as intermediate inspection pits and rodding eyes, are provided at about 100 to 140 m intervals. If the subsoil drain is connected to the manholes or catchpits of the surface runoff system, the latter manholes or catchpits will serve as the inspection pits and rodding eyes. The subsoil drainage system should be inspected at least once a year and preferably shortly after a prolonged heavy rainstorm. The quantity and quality of the outflow should be observed and recorded. If muddy or significant discharge is observed, further investigation on the possible source of the discharge and its effect on the concerned pavement should be conducted. Subsoil drains can be cleared and maintained by rodding. If a blockage cannot be cleared by rodding, the subsoil drain should be replaced.

7. References

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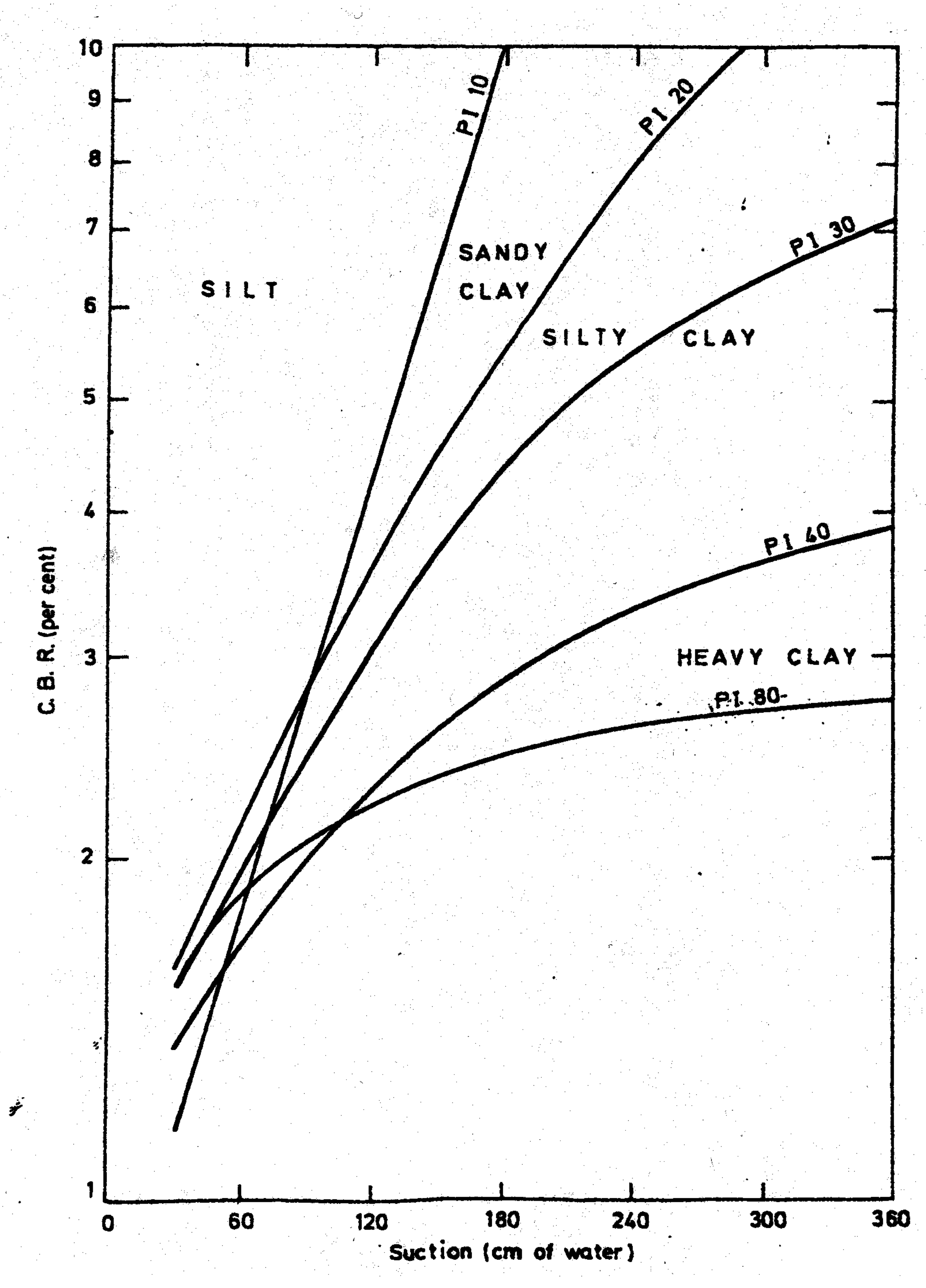


Figure 1
Relation between C. B. R. value and suction for soils
of various plasticities

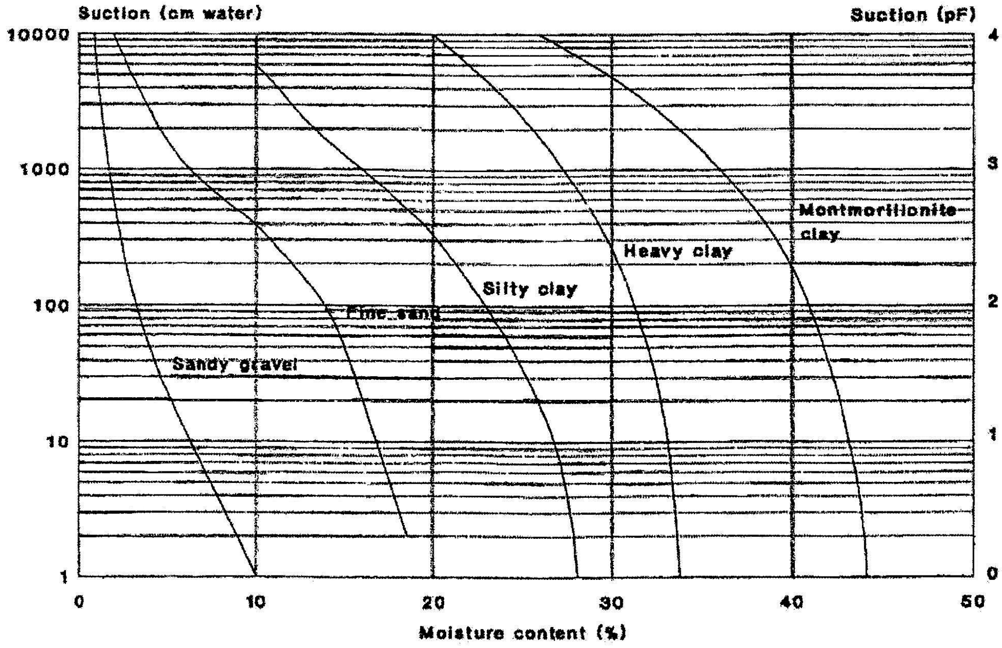


Figure 2

Relation between suction and moisture content for cohesive and non-cohesive soils (drying condition)

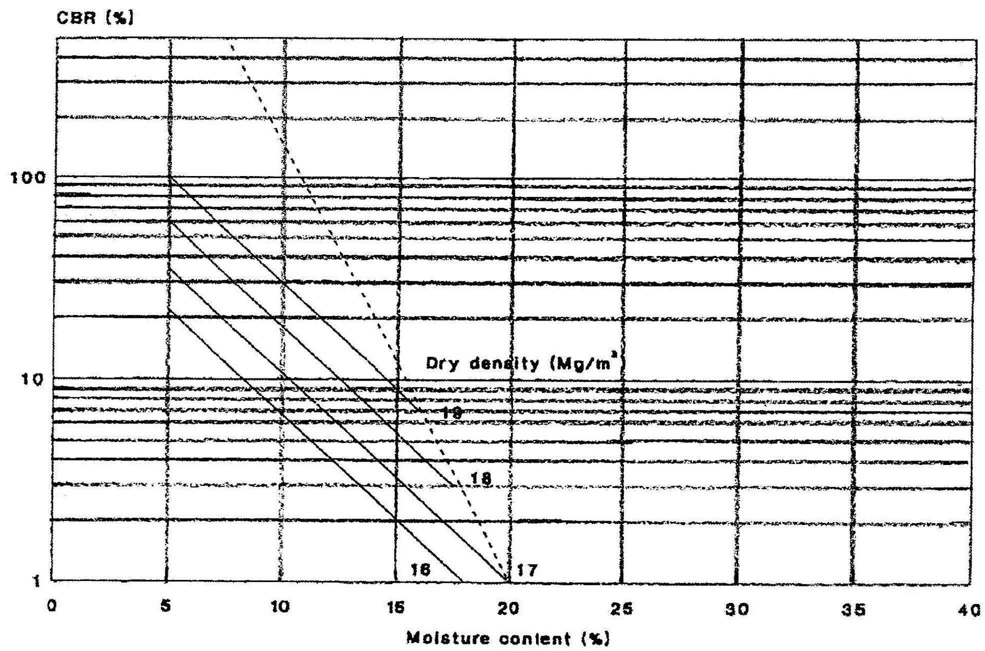


Figure 3

Laboratory measurements relating CBR, moisture content, and dry density for a silty sand

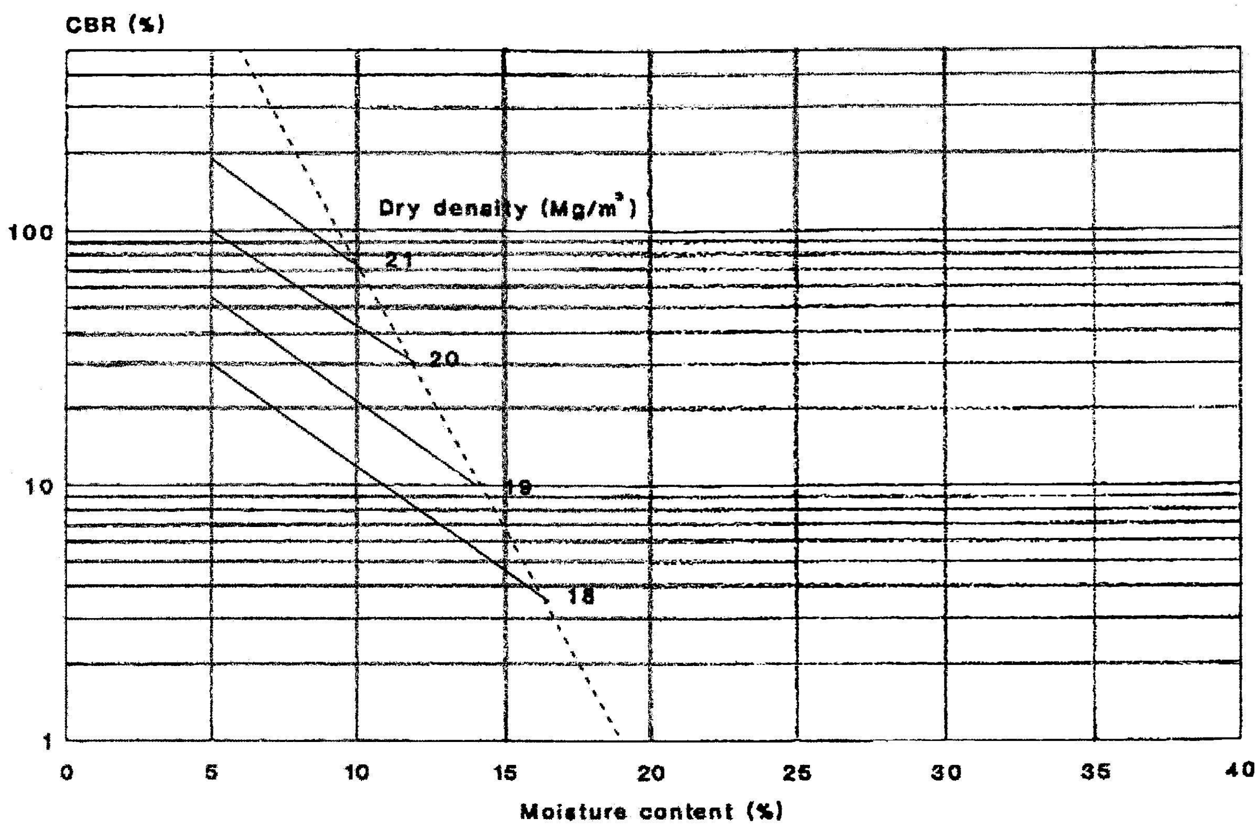
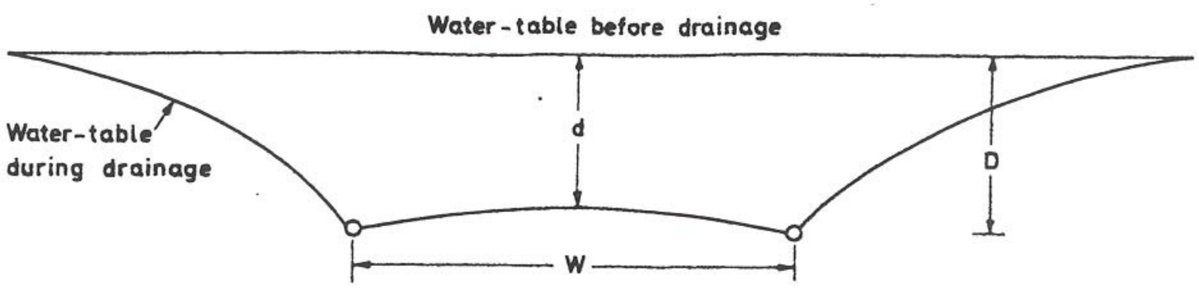


Figure 4
Laboratory measurements relating CBR, moisture content, and dry density
for a well graded sand



q = discharge per unit length per unit time

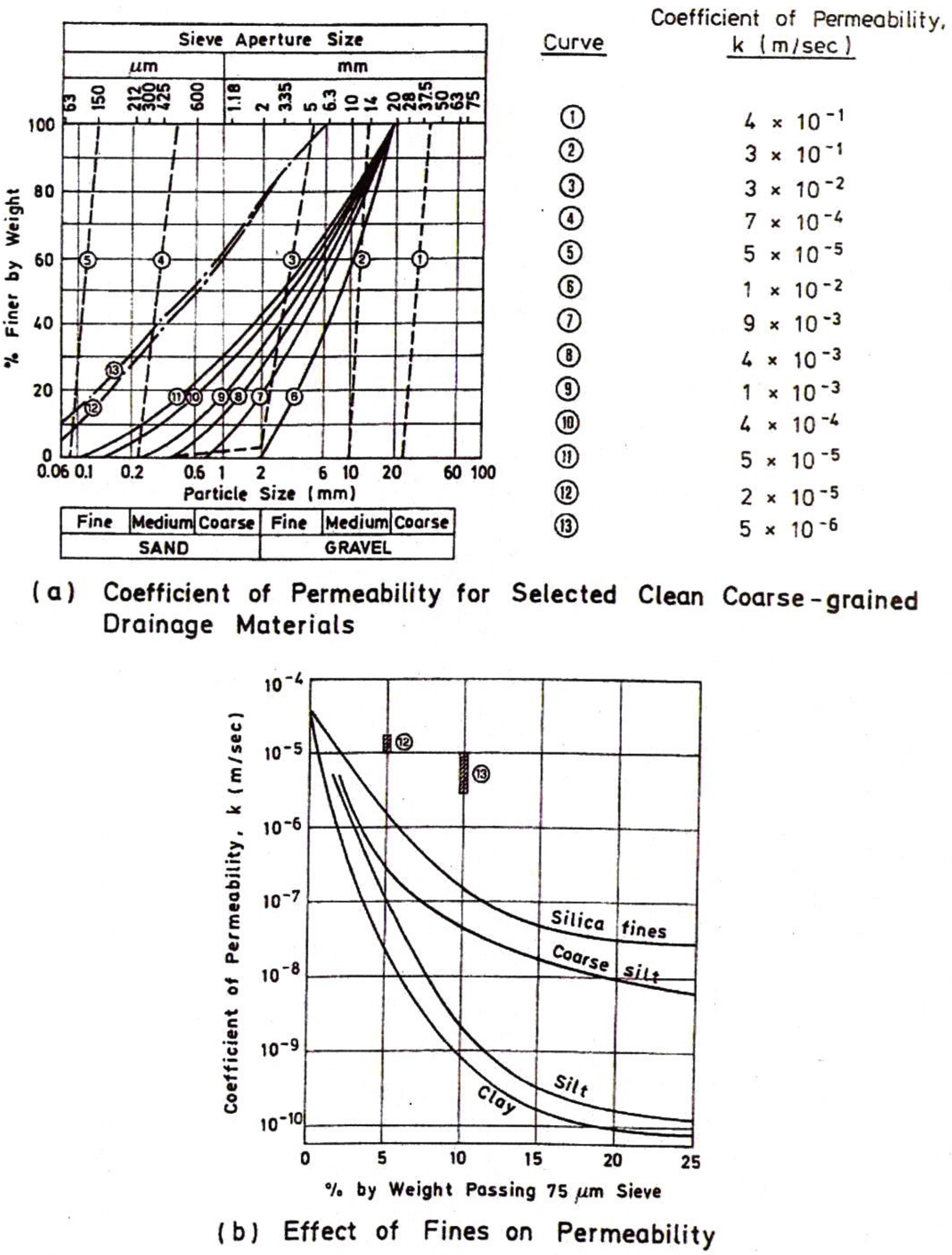
t = time since beginning of drainage

k = coefficient of permeability

y = volume of drainable water per unit volume of soil

Dimensionless ratios		
$\frac{tkD}{yW^2}$	$\frac{d}{D}$	$\frac{q}{kD}$
0·001	0·06	0·80
0·01	0·37	0·47
0·1	0·79	0·25

Figure 5
Dimensionless ratios for drainage by two parallel sub-soil drainage pipes (after McLelland)



(a) Coefficient of Permeability for Selected Clean Coarse-grained Drainage Materials

(b) Effect of Fines on Permeability

Notes :
(1) Figure based on NAVFAC (1982a) and Hong Kong data.
(2) Curves ⑫ and ⑬ in (a) and the corresponding data in (b) are for filter materials composed of granitic quarry fines compacted to 95% of their maximum dry density.

Figure 6

Typical gradations and permeabilities of granular filters and drainage materials encountered in Hong Kong

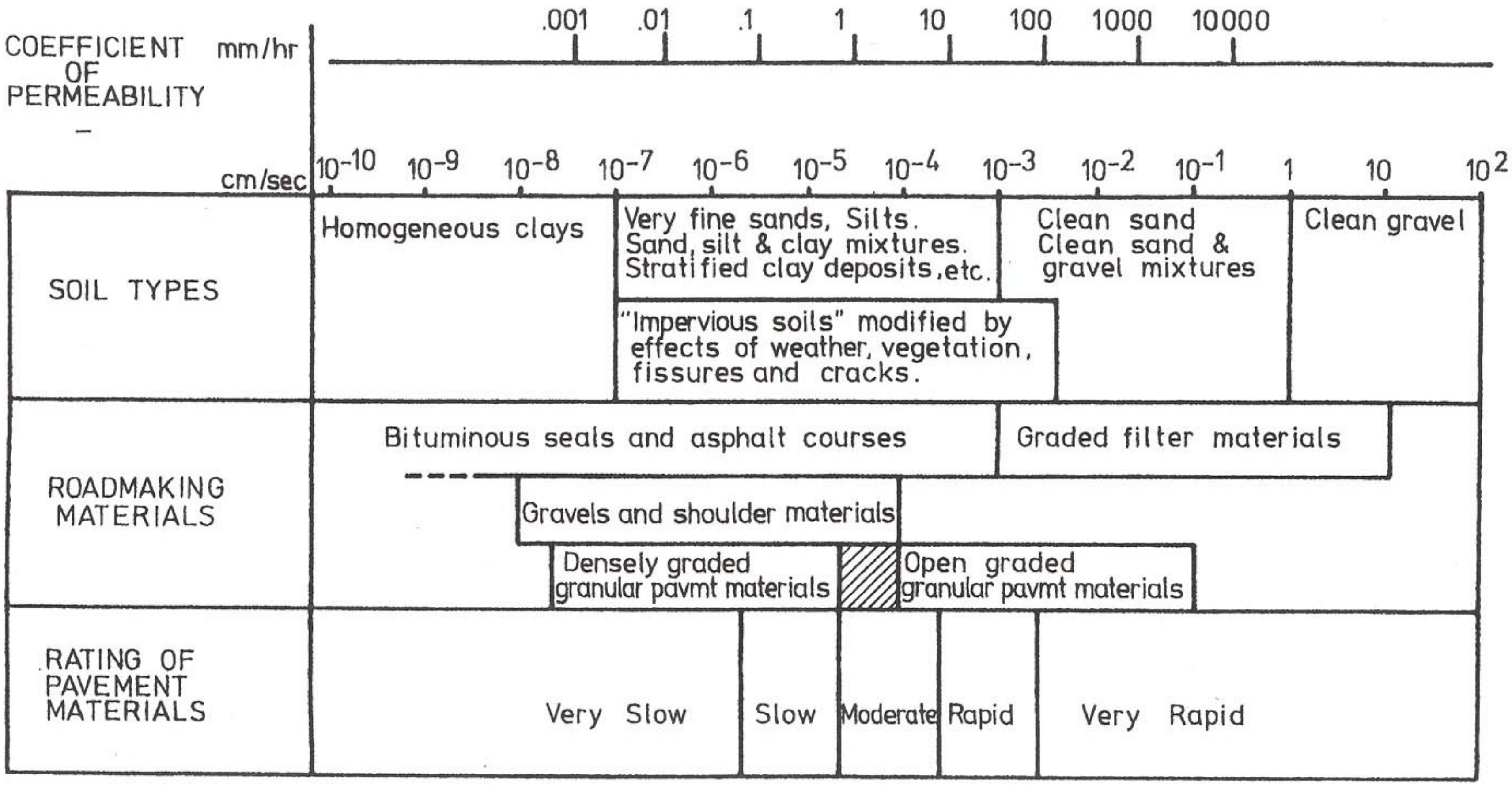


Table 1

Permeability ranges of common pavement materials

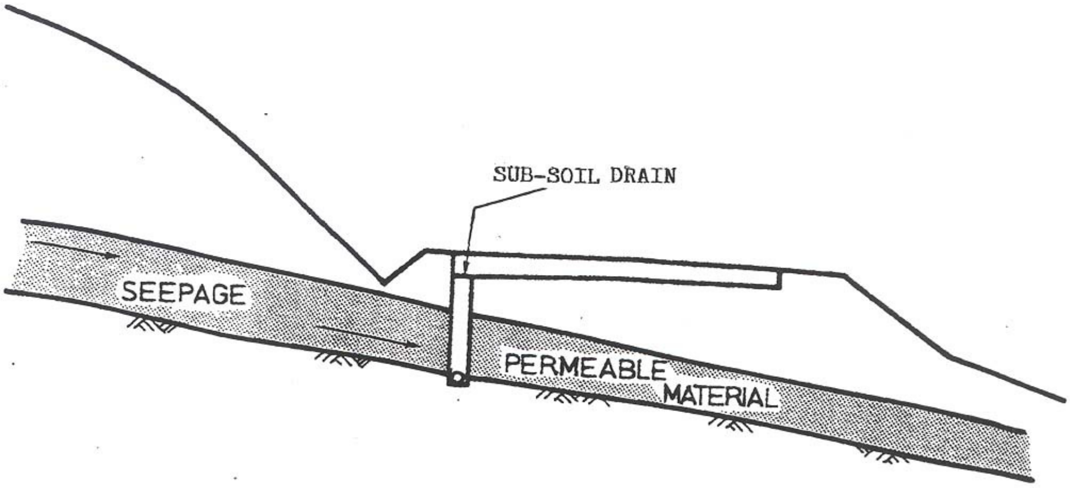


Figure 7
Intercepting flow in an inclined aquifer

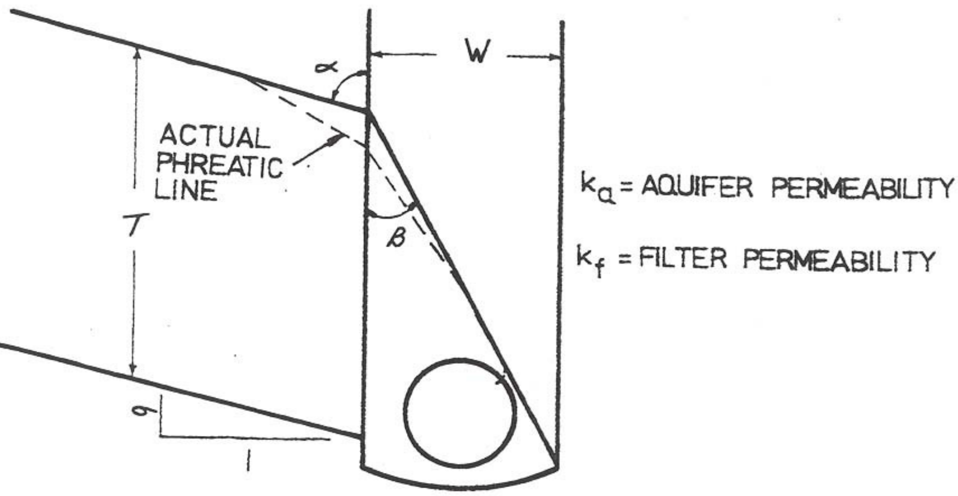


Figure 8
Trench width of sub-soil drain to intercept seepage

Rule Number	Filter Design Rule[1]	Requirement
1	$D_{15}F_c < 5 \times D_{85}S_f$	Stability (i.e. the pores in the filter must be small enough to prevent infiltration of the material being drained)
2	Should not be gap-graded (i.e. having two or more distinct sections of the grading curve separated by sub-horizontal portions)	
3	$D_{15}F_f > 5 \times D_{15}S_c$	Permeability (i.e. the filter must be much more permeable than the material being drained)
4	Not more than 5% to pass 63μm sieve and that fraction to be cohesionless	
5	Uniformity Coefficient $4 < \dfrac{D_{60}F}{D_{10}F} < 20$	Segregation (i.e. the filter must not become segregated or contaminated prior to, during, and after installation)
6	Maximum size of particles should not be greater than 50 mm	

Notes :

(1) In this Table, $D_{15}F$ is the size of sieve (in mm) that allows 15% by weight of the filter material to pass through. Similarly, $D_{85}S$ is the size of sieve (in mm) that allows 85% by weight of the base soil to pass through. The subscript c denotes the coarse side of the envelope, and subscript f denotes the fine side.

(2) For a widely graded base soil, with original $D_{90}S > 2$ mm and $D_{10}S < 0.06$ mm, the above criteria should be applied to the 'revised' base soil grading curve consisting of the particles smaller than 5 mm only.

(3) The thickness of a filter should not be less than 300 mm for a hand-placed layer, or 450 mm for a machine-placed layer.

(4) Rule 5 should be used to check individual filter grading curves rather than to design the limits of the grading envelope.

(5) The determination of the particle size distributions of the base soil and the filter should be carried out without using dispersants.

Table 2

Design criteria for granular filters

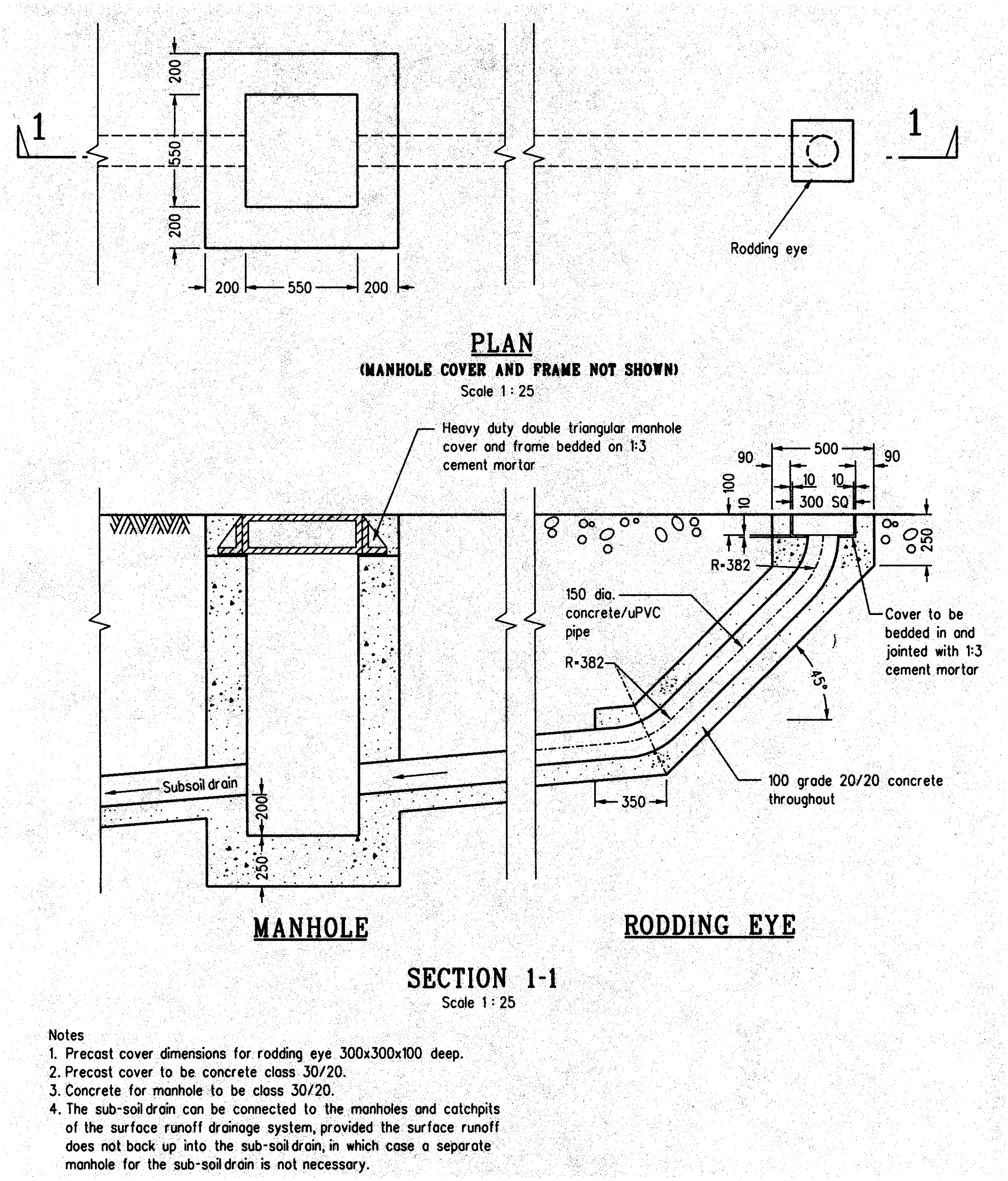


Figure 9
Details of manholes and rodding eyes for sub-soil drain