Design Manual for Roads and Bridges

Pavement
Design

CD 225
Design for new pavement foundations

(formerly IAN 73/06 revision 1 (2009), HD 25/94)

Revision 1

Summary
This document sets out the design procedure for pavement foundations in terms of the ability of the foundation to resist loads applied both during construction and the service life of the pavement.

Application by Overseeing Organisations
Any specific requirements for Overseeing Organisations alternative or supplementary to those given in this document are given in National Application Annexes to this document.

Feedback and Enquiries
Users of this document are encouraged to raise any enquiries and/or provide feedback on the content and usage of this document to the dedicated Highways England team. The email address for all enquiries and feedback is: Standards_Enquiries@highwaysengland.co.uk

This is a controlled document.

Contents

Release notes 3

Foreword 4
Publishing information . . . 4
Contractual and legal considerations . . . 4

Introduction 5
Background . . . 5
Assumptions made in the preparation of this document . . . 5
Mutual Recognition . . . 5

Abbreviations and symbols 6

Terms and definitions 7

1. Scope 9
Aspects covered . . . 9
Implementation . . . 9
Use of GG 101 . . . 9

2. Subgrade assessment and requirements 10

3. Foundation designs 12
Applicability for restricted, performance and widening foundations . . . 12
General requirements . . . 12
Restricted foundation designs . . . 13
General requirements . . . 13
Options and restrictions . . . 13
Thickness charts . . . 13
Performance foundation designs . . . 19
General requirements . . . 19
Layer stiffness requirements . . . 20
Thickness design requirements . . . 20
Widening of pavement foundations . . . 20

4. Procedure for performance foundation designs 23

5. Normative references 25

6. Informative references 26

Appendix A. Example performance foundation design charts 27

Appendix B. Worked examples 33
B1 Example 1 – Restricted foundation design procedure . . . 33
B2 Example 2 – Performance foundation design procedure . . . 33
B3 Example 3 – Restricted foundation design procedure for widening . . . 33
B4 Example 4 – Performance foundation design procedure . . . 35

Appendix C. A permeameter for road drainage layers 36
C1 Overview . . . 36
C1.1 Introduction . . . 36
C1.2 Scope . . . 36
C1.3 Background . . . 36
C2 Apparatus . . . 36
C2.1 Introduction . . . 36
C2.2 Apparatus required . . . 39

C3 Method of test for horizontal permeability of drainage layers . . . 40
C3.1 General . . . 40
C3.2 Procedure . . . 40
C3.3 Notes on testing errors . . . 41
C4 Results calculation . . . 42
C4.1 Coefficient of permeability . . . 42
C4.2 Total porosity . . . 44
C4.3 Recording of results and sample calculations . . . 45
C4.4 Sample results and calculation . . . 45

Notification **47**

Release notes

Version	Date	Details of amendments
1	Apr 2020	Revision 1 (April 2020): Clarification of typo in Equation 2.4; function tables relaid for all equations (2.4, and C.1 to C.5). Revision 0 (March 2020) CD 225 replaces IAN 73/06 Revision 1 (2009) and HD 25/94. This full document has been rewritten to make it compliant with the new Highways England drafting rules and extensively restructured, with corresponding updates to the MCHW Volume 1 Series 800 and MCHW Volume 2, Series 700 and Series 800.

Foreword

Publishing information

This document is published by Highways England.

This document supersedes IAN 73/06 Revision 1 (2009) and HD 25/94 which are withdrawn.

Contractual and legal considerations

This document forms part of the works specification. It does not purport to include all the necessary provisions of a contract. Users are responsible for applying all appropriate documents applicable to their contract.

Introduction

Background

The main function of a pavement foundation is to distribute the applied vehicle loads to the underlying subgrade, without causing distress in the foundation layers or in the overlying layers. This is required both during construction and during the service life of the pavement.

Pavement foundations are designed on the basis of practical minimum layer thicknesses for construction, protection of the subgrade during construction and long term provision of support to the overlying pavement layer. Other considerations include drainage and durability.

In the short-term during pavement construction, the stresses in the foundation are relatively high. It is expected that loads are going to be applied to the foundation by delivery vehicles, pavers and other construction plant. At any level where such loading is applied, the stiffness and material thickness of the layer has to be sufficient to withstand the load without damage occurring that might adversely influence, to any significant extent, the long-term performance.

In the longer-term during the in-service life of a pavement, the stresses in the foundation are expected to be lower than during construction; although the foundation is going to experience repeated loads from traffic. It is essential that the assumed support of the foundation to the pavement is maintained, otherwise, deterioration of the upper pavement layers is going to occur more rapidly than anticipated.

This document sets out the permitted approaches that can be taken when designing a new pavement foundation. A variety of materials can be utilised in the foundation in the capping and subbase layers. The designer can take advantage of improved foundation materials by using them to construct stronger and stiffer foundations that require a reduced thickness of overlying pavement construction (refer to CD 226 [Ref 1.N]).

Three foundation design approaches are presented:

1) A restricted design approach that offers assurance of performance of the foundation through use of a limited palette of well understood materials.
2) A performance design approach that gives flexibility to the designer in terms of the materials that can be used in the foundation conjunction with top of foundation testing to confirm performance requirements have been met.
3) A widening design approach that utilises a restricted or performance design approach to assure the performance of the foundation whilst considering the additional requirements to provide sub-surface drainage continuity between the existing pavement and the widening.

Assumptions made in the preparation of this document

The assumptions made in GG 101 [Ref 3.N] apply to this document.

Mutual Recognition

Where there is a requirement in this document for compliance with any part of a "British Standard" or other technical specification, that requirement may be met by compliance with the Mutual Recognition clause in GG 101 [Ref 3.N].

Abbreviations and symbols

Abbreviations

Abbreviation	Definition
CBR	California bearing ratio
msa	Million standard axles
NINS	Non-intercellular neoprene foam sheet

Symbols

Symbol	Definition
A	Cross sectional area of the permeameter
c	Temperature correction factor μ_T/μ_{20}, obtained from a standard chart
d_{50}	Median grain (particle) size
d_{100}	Maximum particle size
E	Estimated subgrade surface modulus
G_{sa}	Apparent relative particle density
ΔH	Head difference across specimen
Hg	Mercury (as used in pressure measurement)
i	Hydraulic gradient
k	Coefficient of permeability
k_{20}	Coefficient of permeability at standard laboratory temperature of 20°C
L, W, D	Length, width and depth of the specimen
M	Total mass of aggregate in permeameter
MPa	MegaPascal
M_w	Mass of water
n	Porosity
q	Steady state flow rate
q_{20}/A	Flow rate per unit area standardised to 20°C
R_c	Compressive strength
Sr	Degree of saturation
T	Temperature
V	Volume of sample
μ	Dynamic viscosity of water
μ_T	Dynamic viscosity of water at ambient temperature
μ_{20}	Dynamic viscosity of water at standard laboratory temperature of 20°C
ρ_s	Dry density of sample
ω	Water content

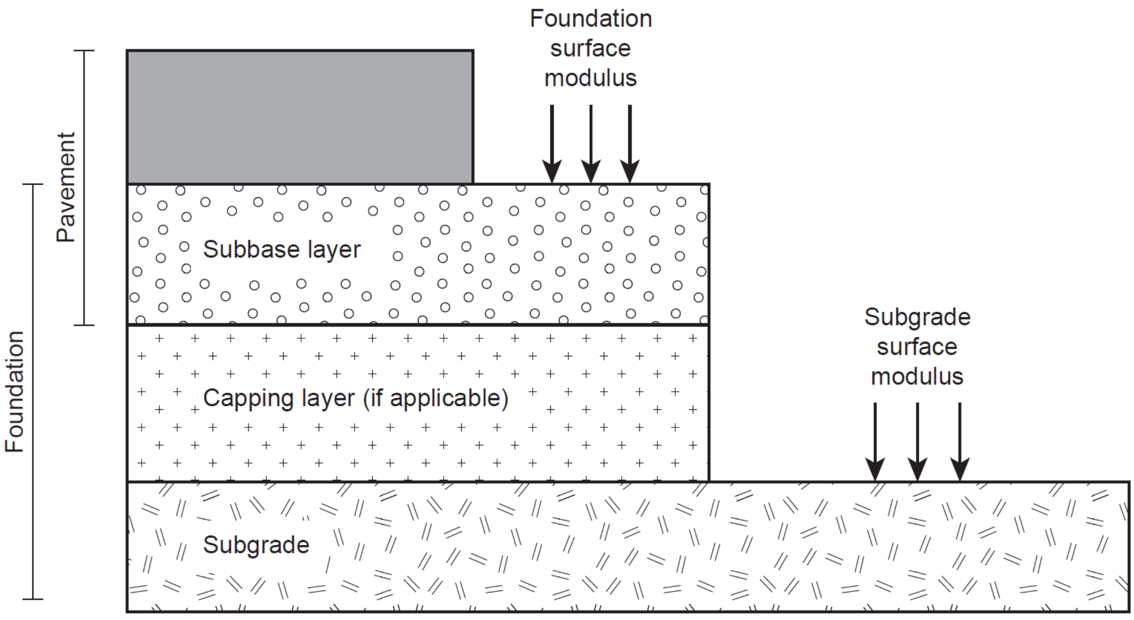
Terms and definitions

Term	Definition
Apparent relative particle density	Ratio obtained by dividing the oven-dried mass of an aggregate sample by the volume it occupies in water including the volume of any internal sealed voids but excluding the volume of water in any water accessible voids (apparent relative density synonymous with apparent specific gravity G_{sa}).
Capping	An improvement layer on top of the subgrade, protecting the subgrade from damage and/or increasing the stiffness at formation level.
Coefficient of permeability	The mean discharge velocity of flow of water in a soil under the action of a unit hydraulic gradient.
Construction subgrade surface modulus	A value of stiffness modulus of the subgrade measured during construction.
Design subgrade surface modulus	An estimated value of stiffness modulus for the subgrade used for foundation design. It is the lower of the short-term and long-term subgrade surface modulus.
Formation	Level upon which subbase is placed.
Foundation	All materials up to and including subbase.
Foundation surface modulus	A stiffness modulus based on the application of a known load at the top of the foundation; it is a composite value representing all of the foundation layers under the completed pavement. A design value for the confined foundation under a pavement.
Foundation surface modulus class	The design class of the foundation, based upon the long-term foundation surface modulus.
Horizontal permeability	The ability of a material to allow the passage of a fluid in the horizontal plane.
Hydraulically bound mixture	A mixture which sets and hardens by hydraulic reaction.
Hydraulic gradient	The ratio of the difference in total head of water on either side of a layer of material or soil, to the thickness of the layer measured in the direction of flow.
Layer stiffness	The stiffness modulus assigned to a given layer that accounts for in-service conditions and degradation.
Long-term subgrade surface modulus	An estimated value of stiffness modulus for the subgrade when a state of equilibrium is reached under the pavement.
Loose bulk density	The quotient obtained when the mass of dry aggregate filling a specified container without compaction is divided by the capacity of that container.
Pavement	All layers above formation.
Short-term subgrade surface modulus	An estimated value of stiffness modulus for the subgrade during construction.

(continued)

Term	Definition
Standard axle	An axle exerting or applying a force of 80 kN. The structural wear associated with each vehicle increases significantly with increasing axle load. Although alternative methods are available, structural wear for pavement design in the UK is taken as being proportional to the 4th power of the axle load. The number of standard axles is the estimated structural wear factor for the vehicle class.
Steady-state flow	In which flow into a system is equal to flow out of the system.
Stiffness modulus	The ratio of applied stress to induced strain.
Subbase	A platform layer upon which the main structure of a pavement is constructed. The subbase is both part of the foundation and pavement.
Sub-formation	Level upon which capping is placed.
Subgrade	Soil or fill underlying a pavement.
Surface modulus	A stiffness modulus based on the application of a known load at the top of a layer.

The following figure provides a diagrammatic representation to illustrate some of the key definitions above.



1. Scope

Aspects covered

1.1 This document provides details of the requirements that shall be used to design pavement foundations.

Implementation

1.2 This document shall be implemented forthwith on all schemes involving the construction, improvement and maintenance of pavements on the Overseeing Organisations' motorway and all-purpose trunk roads according to the implementation requirements of GG 101 [Ref 3.N].

Use of GG 101

1.3 The requirements contained in GG 101 [Ref 3.N] shall be followed in respect of activities covered by this document.

2. Subgrade assessment and requirements

2.1 The design subgrade surface modulus shall be used in the pavement foundation design (Section 3).

2.2 The pavement foundation shall be divided into characteristic sections of subgrade, each having a single design subgrade surface modulus value.

2.2.1 The characteristic sections should be based on the type of subgrade material and its condition.

2.3 The short-term subgrade surface modulus and long-term subgrade surface modulus shall be determined for each characteristic section of subgrade.

2.3.1 The process outlined in LR1132 [Ref 13.I] may be used to review soil properties and construction assumptions when estimating the short-term subgrade surface modulus and/or long-term subgrade surface modulus.

NOTE The presence of a high or perched water table (300 mm or less below formation level) can reduce subgrade stiffness, culminating in low subgrade surface modulus values at the time of construction. Guidance on determining subgrade surface modulus values in the presence of a high or perched water table is given in LR1132 [Ref 13.I].

2.3.2 For widening schemes, where the subgrade is consistent across the width of the existing carriageway and the proposed widening, use of the in situ long-term subgrade surface modulus of the subgrade below the existing carriageway may be used for design purposes.

2.4 Equation 2.4 shall be used where California bearing ratio (CBR) is used in the estimation of short-term and/or long-term subgrade surface modulus:

Equation 2.4 CBR to subgrade surface modulus conversion

$$E = 17.6(CBR)^{0.64}$$

where:

E	is the estimated subgrade surface modulus (MPa)
CBR	is the California bearing ratio (CBR) of the subgrade

NOTE Equation 2.4 is valid for CBR values in the range 2 to 12 per cent.

2.5 The design subgrade surface modulus shall be determined as being equal to the lower of the short-term subgrade surface modulus and the long-term subgrade surface modulus values.

2.5.1 For widening schemes, the depth at which the design subgrade surface modulus is determined may be dependent on any requirements to maintain drainage continuity between the existing carriageway and the proposed widening.

2.6 For each characteristic section of subgrade, the following shall be detailed:

1) start and end chainage;
2) short-term subgrade surface modulus (MPa);
3) long-term subgrade surface modulus (MPa); and,
4) design subgrade surface modulus (MPa).

2.7 Where the design subgrade surface modulus is lower than 30 MPa, improvement of the subgrade shall be undertaken.

NOTE 1 Subgrades with a design subgrade surface modulus value lower than 30 MPa are unsuitable to support the construction of a pavement foundation.

NOTE 2 Options for improvement of the subgrade include excavation and replacing between 500 to 1000 mm of the soft subgrade with granular fill, mechanical stabilisation (geogrids and/or geotextiles) and soil stabilisation.

2.8 The upper limit on design surface modulus for areas of improvement of the subgrade shall be 50 MPa.

2.9 A testing regime, specified in accordance with the MCHW [Ref 4.N], shall be detailed to establish the construction subgrade surface modulus.

2.10 Where the construction subgrade surface modulus is found to be lower than the design subgrade surface modulus, then action shall be taken by either effecting improvement of the subgrade (see clause 2.8) or by reviewing the design subgrade surface modulus with a view to redesign using the lower value (see clause 2.5).

3. Foundation designs

Applicability for restricted, performance and widening foundations

3.1 Subgrade characteristic sections shall be divided into one or more foundation areas.

3.2 Each foundation area shall have a single design approach.

3.3 The design approach for each foundation area shall be one of the following:

1) restricted;
2) performance; or,
3) widening (restricted or performance).

NOTE Restricted and performance design approaches can be implemented on the same scheme where different design approaches are appropriate depending on the requirements of specific areas within the scheme e.g. slip roads versus mainline.

3.4 The design approach shall be determined based on the scheme type, the availability of materials and economics.

NOTE 1 The restricted foundation design options are based on a limited selection of materials linked to an assumed performance which does not require verification via performance testing of the foundation.

NOTE 2 Performance foundation designs can offer economic benefits through innovation and/or the use of materials not permitted within restricted foundation designs. Assurance of material performance is provided by the performance related specification outlined within the MCHW [Ref 4.N].

NOTE 3 Foundation designs for carriageway widening can follow either a restricted or performance foundation design approach with additional measures to ensure drainage paths are not impeded by the widening of the carriageway.

General requirements

3.5 For each foundation area, the design approach shall be detailed, i.e. restricted or performance, and whether it is widening.

3.6 Details of foundation designs shall be recorded as required in CD 226 [Ref 1.N] Section 6.

NOTE See Clauses 2.6, 3.5, 3.11, 3.24 that define the foundation design details to be recorded.

3.7 The design for all foundation areas shall be based on achieving a foundation class selected from Table 3.7.

Table 3.7 Foundation classes

Foundation class	Assumed long-term confined foundation surface modulus (MPa)
1	≥ 50
2	≥ 100
3	≥ 200
4	≥ 400

NOTE Foundation class 4 is not available for the restricted foundation design approach due to a lack of performance data sets generated since the inclusion of this foundation class in 2006. Therefore, foundation class 4 is only permitted as a performance foundation.

3.8 The foundation class shall be used in the pavement design within CD 226 [Ref 1.N].

3.9 The design subgrade surface modulus (see Section 2) for each characteristic section shall be used in the foundation design.

3.10 Design layer thicknesses in this section assume the foundation carries up to 1000 standard axles during construction. Where higher levels of construction traffic are anticipated (e.g. for a haul road), the design layer thickness shall be assessed for suitability versus the limiting requirement on vertical strain the subgrade (see Section 4).

3.10.1 LR1132 [Ref 13.I] may be used to establish the subbase thickness required for different levels of cumulative construction traffic.

3.10.2 Additional subbase thickness may be required for other reasons such as at interfaces, regulation or for drainage continuity.

Restricted foundation designs

General requirements

3.11 For each foundation area and for each layer to be constructed, the following shall be detailed:

1) start and end chainage;
2) foundation class;
3) materials to be used; and,
4) nominal layer thicknesses to be constructed.

Options and restrictions

3.12 Where the short-term subgrade surface modulus is 50 MPa or lower, the foundation design shall consist of subbase and capping.

NOTE 1 Foundations built on a construction subgrade surface modulus of 50 MPa or less have a relatively high risk of structural rutting during construction. This can be prevented through subgrade improvement and/or the use of a capping layer.

NOTE 2 Following subgrade improvement, a capping layer is not necessarily required, dependent on the estimated short-term subgrade surface modulus value.

3.13 The materials used in the foundation shall be limited to those detailed in the MCHW clauses referenced in Figure 3.17 to Figure 3.23.

NOTE The feasibility of using site won materials (particularly soils containing organics, sulphates and/or sulphides) within the bound capping and/or subbase mixtures is dependent on designing a durable mixture. Historic lessons are that initial feasibility is best done at the design stage.

3.14 Foundation class 1 shall not be used where the pavement is designed for traffic loading greater than 20 msa.

3.15 Unbound subbase to Clause 804 (Type 2) of the MCHW [Ref 4.N] shall not be used where pavements are designed for traffic loading greater than 5 msa.

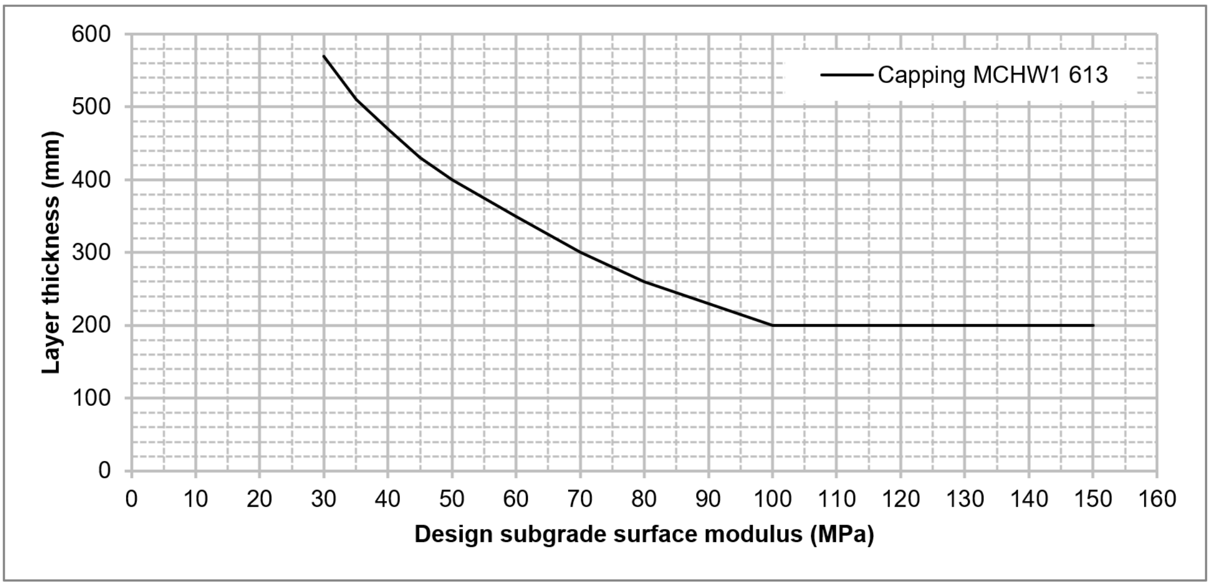
Thickness charts

3.16 Design nominal thicknesses for each layer shall be rounded up to the nearest 10 mm.

NOTE For worked examples demonstrating use of the thickness charts, see Appendix B.

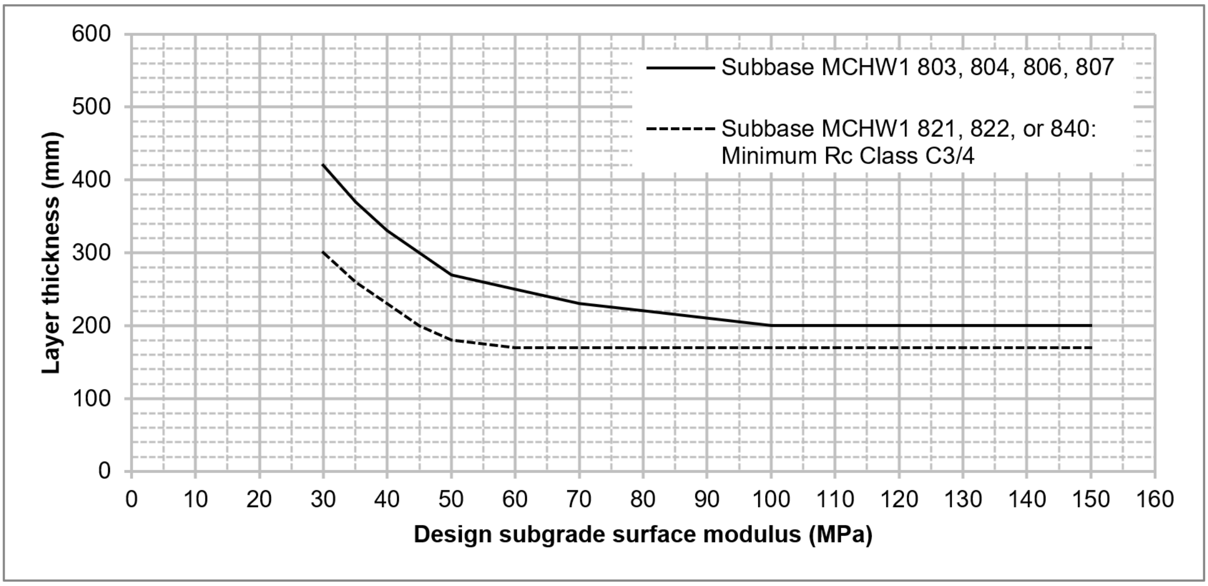
3.17 The design thickness for foundation class 1 designs shall be obtained from Figure 3.17.

Figure 3.17 Restricted design options - class 1 capping only



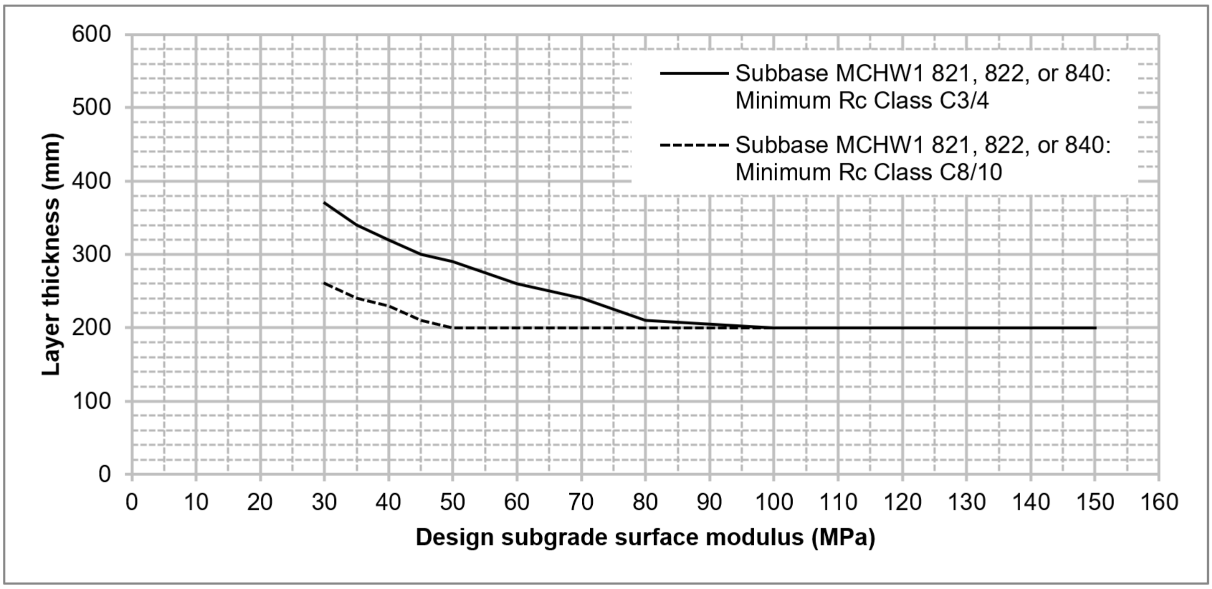
3.18 The design thickness for subbase only foundation class 2 designs shall be obtained from Figure 3.18.

Figure 3.18 Restricted design options - class 2 subbase only



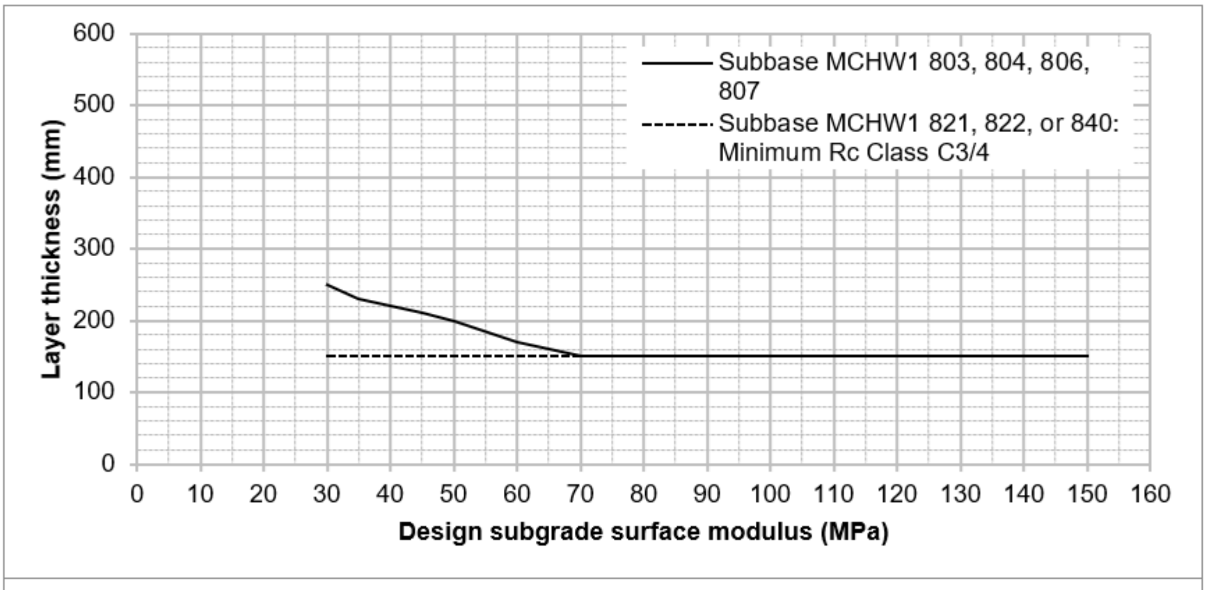
3.19 The design thickness for subbase only foundation class 3 designs shall be obtained from Figure 3.19.

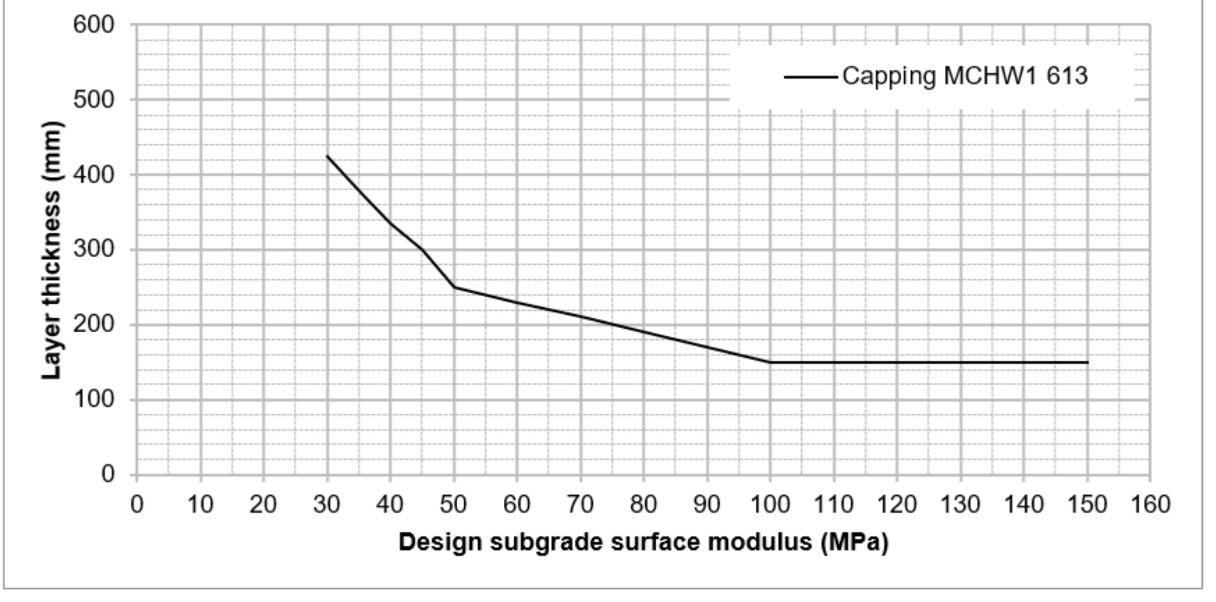
Figure 3.19 Restricted design options - class 3 subbase only



3.20 The design thicknesses for subbase on capping for foundation class 2 restricted designs shall be obtained from Figure 3.20.

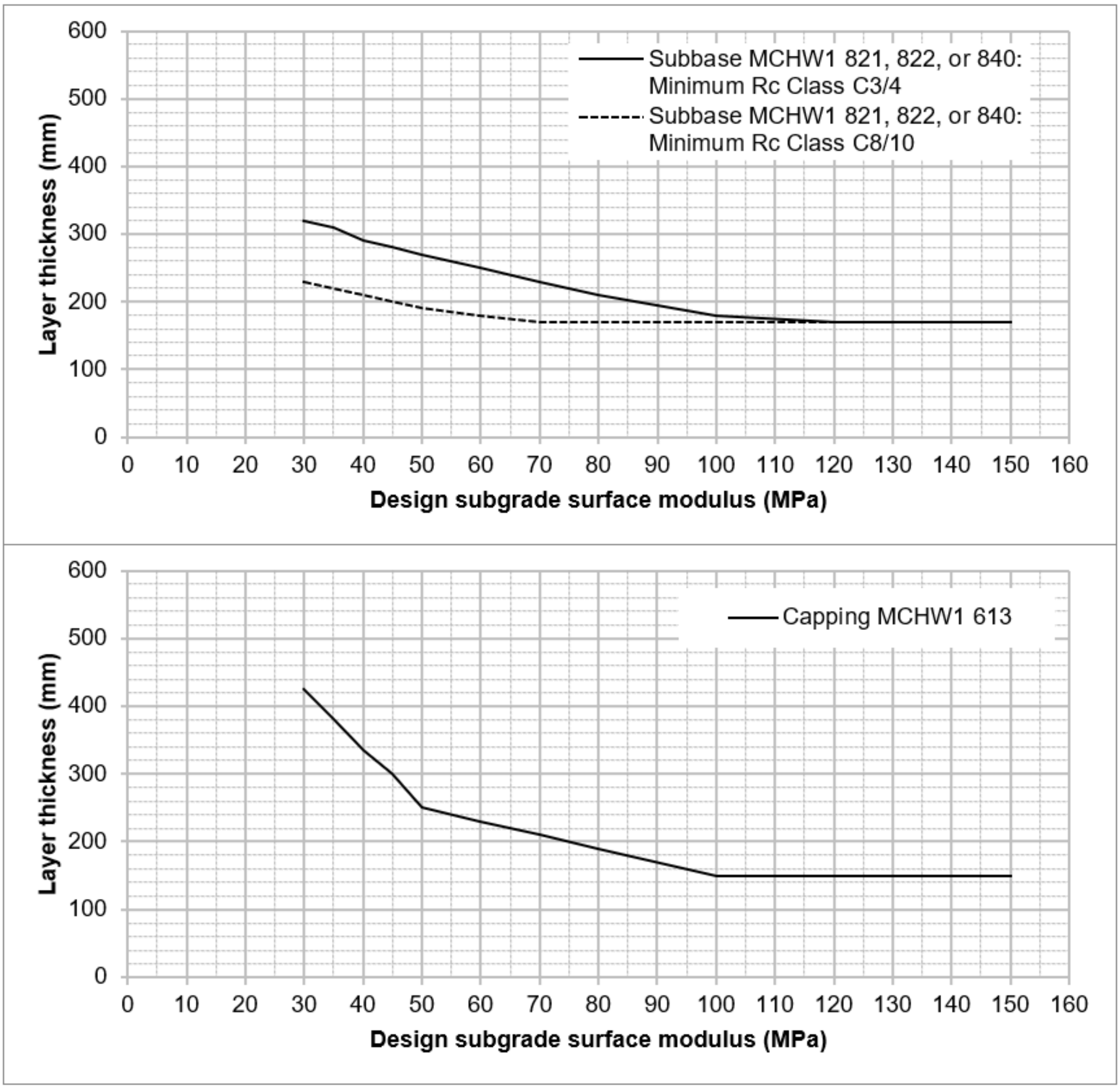
Figure 3.20 Restricted design options - class 2 subbase on capping





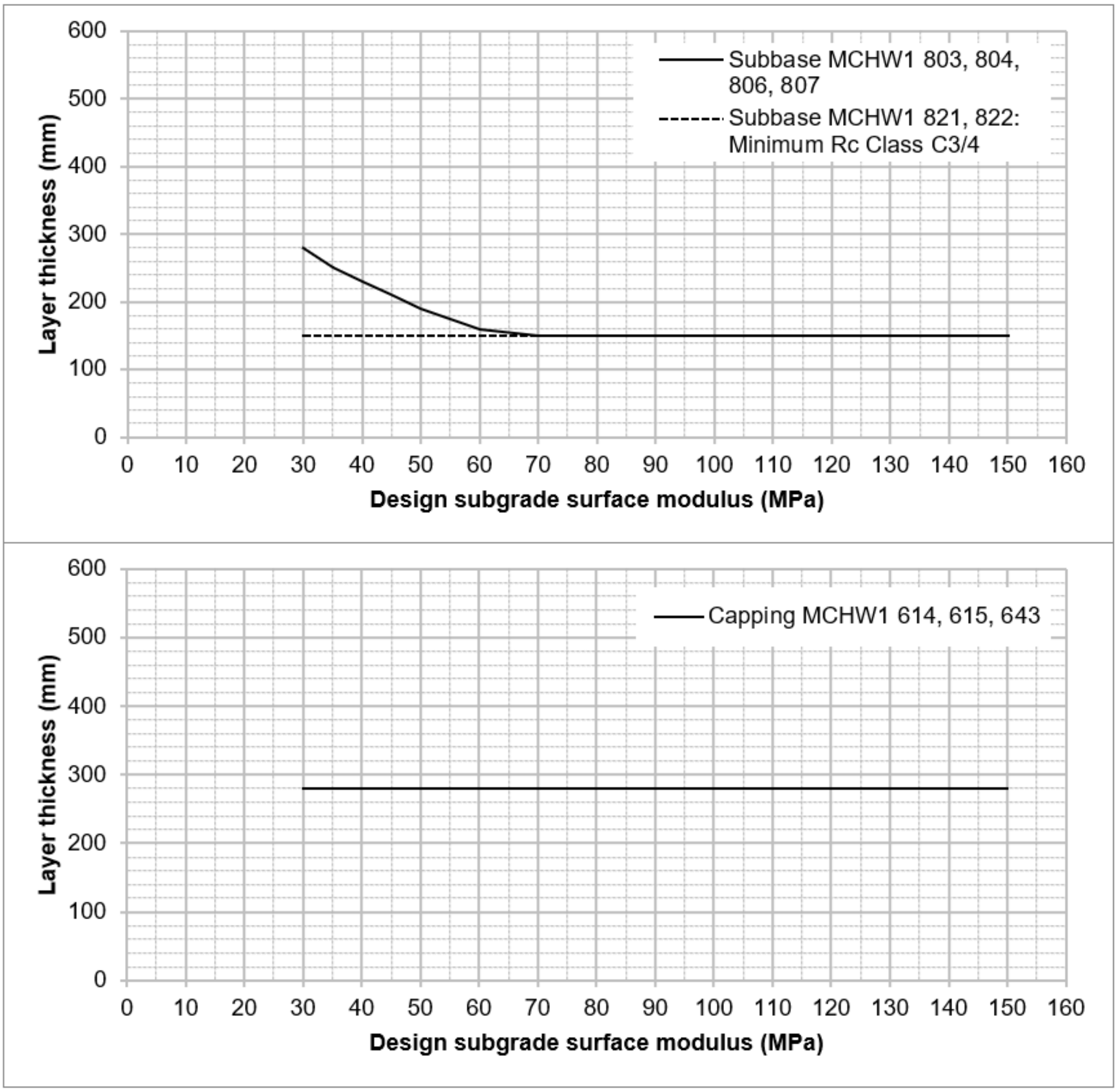
3.21 The design thicknesses for subbase on capping for foundation class 3 restricted designs shall be obtained from Figure 3.21.

Figure 3.21 Restricted design options - class 3 subbase on capping



3.22 The design thickness for subbase on a constant thickness of bound capping (in-situ stabilised soil as per Series 600 of the MCHW [Ref 4.N]) for foundation class 2 shall be obtained from Figure 3.22.

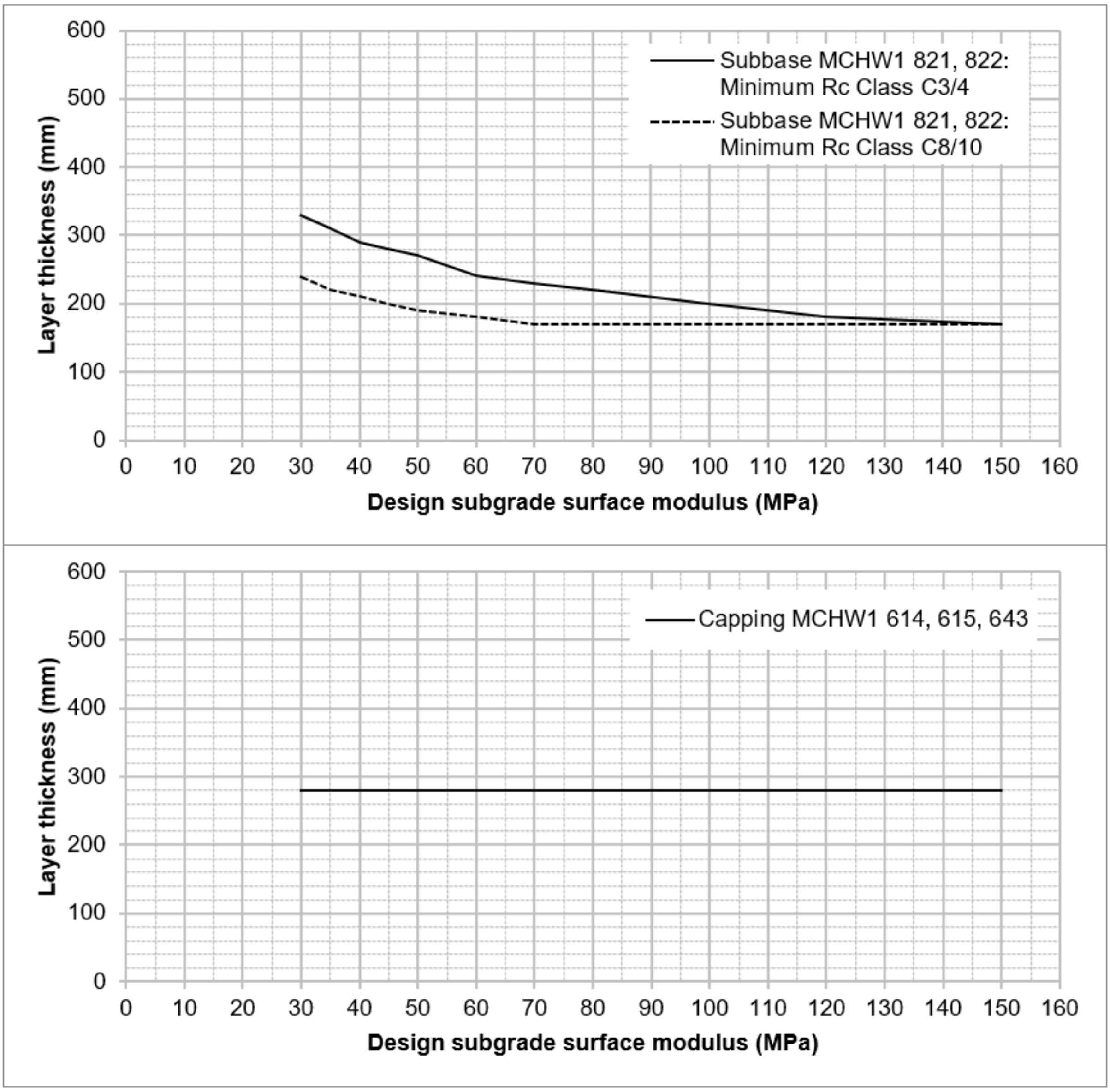
Figure 3.22 Restricted design options - class 2 subbase on bound capping



NOTE *Other constant nominal thicknesses of capping can be used via the performance foundation design approach.*

3.23 The design thickness for subbase on a constant thickness of bound capping (in-situ stabilised soil as per Series 600 of the MCHW [Ref 4.N]) for foundation class 3 shall be obtained from Figure 3.23.

Figure 3.23 Restricted design options - class 3 subbase on bound capping



Performance foundation designs

General requirements

3.24 For each foundation area and for each layer to be constructed, the following shall be detailed:

1) start and end chainage;
2) foundation class;
3) the layer stiffness; and,
4) minimum layer thicknesses.

3.25 Performance foundation designs shall be subject to performance testing in accordance with Series 800 of the MCHW [Ref 4.N].

3.26 A demonstration area to meet the requirements of the MCHW [Ref 4.N] shall confirm the performance of the foundation design.

3.27 Where the demonstration area fails to meet the requirements of the MCHW [Ref 4.N] for that foundation class, then the materials shall be modified or the foundation redesigned.

3.27.1 The foundation redesign may involve increasing foundation thickness and/or changing the materials used.

3.28 For the main works, a testing regime shall be detailed to confirm that the performance requirements of the MCHW [Ref 4.N] have been achieved.

3.29 The foundation surface modulus shall be equal to or higher than that specified in the MCHW [Ref 4.N] for the designed foundation class.

NOTE The foundation surface modulus measured in accordance with the MCHW [Ref 4.N] is for a partially confined foundation and is not to be confused with the long-term confined foundation surface modulus values within Table 3.6.

3.30 Where the foundation surface modulus is lower than that specified in the MCHW [Ref 4.N] for the designed foundation class, action shall be taken to either undertake improvement or review the foundation design.

NOTE The approach for improvement is dependent on the scale of the issue and the practical options available on site.

3.31 Where a foundation area within the main works fails to comply with the surface modulus performance measurement requirements, and the foundation is to be redesigned, the suitability of the redesigned foundation shall be confirmed with a demonstration area, specified in accordance with the MCHW [Ref 4.N].

Layer stiffness requirements

3.32 Capping layers shall be assigned a layer stiffness for use in the foundation design.

3.33 Subbase layers shall be assigned a layer stiffness for use in the foundation design.

3.34 The layer stiffness assigned to hydraulically bound mixtures for use in the foundation design shall be no more than 20% of the mixture's mean modulus of elasticity in compression when tested in accordance with the MCHW [Ref 4.N].

Thickness design requirements

3.35 The design thickness shall be derived using the layer stiffness values assigned to each layer and the procedure outlined in Section 4.

3.35.1 When the subgrade surface modulus is expected to be low at the time of construction, a capping layer should be added to provide a working platform for construction of the subsequent layers.

NOTE Foundations built on a construction subgrade surface modulus of 50 MPa or less have a relatively high risk of structural rutting during construction if the foundation does not incorporate a capping layer.

3.36 The design thickness derived shall either be subject to zero negative tolerance; or, to ensure that the design thickness is applied throughout the scheme, an additional thickness may be applied to the derived thickness.

3.36.1 Any additional thickness required may be limited by the capacity of the construction equipment to deliver the required design thickness consistently.

3.37 The minimum foundation thickness for class 1 and 2 foundations shall be 150 mm.

3.38 The minimum foundation thickness for class 3 foundations shall be 180 mm.

3.39 The minimum foundation thickness for class 4 foundations shall be 200 mm.

Widening of pavement foundations

3.40 For widening, the pavement and the foundation of the existing adjacent carriageway shall be assessed to establish the material type, condition and the thickness of each layer.

NOTE 1 The type, condition, construction thicknesses and levels of the layers in the adjacent pavement and foundation are key to the design of the widened pavement and foundation.

NOTE 2 This section only details the requirements for the pavement foundations.

3.41 For widening, the design for each foundation area shall follow either a restricted or performance foundation design approach.

3.42 The foundation design for widening shall provide continuity of drainage.

NOTE The requirement for drainage continuity can result in a thicker subbase layer than required by the foundation design.

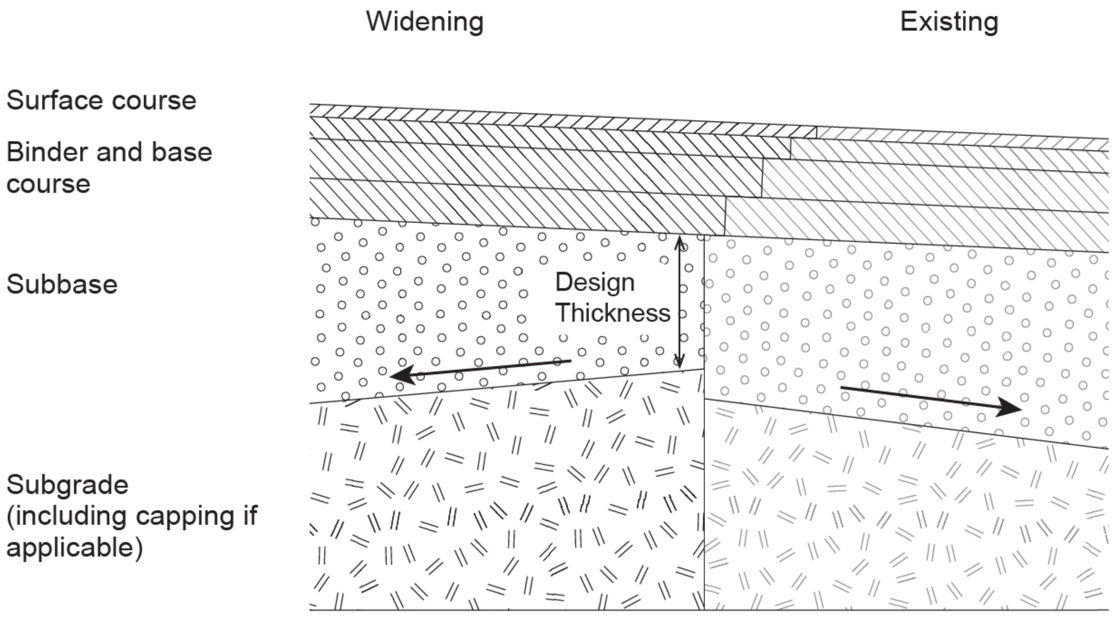
3.42.1 Continuity of drainage may be achieved by selecting appropriate:

1) materials that do not inhibit the flow of subsurface drainage through the foundation;
2) layer thicknesses;
3) crossfalls.

3.43 Edge of pavement drains shall be as detailed in pavement drainage design guidance CD 524 [Ref 2.N].

3.44 Where the existing subsurface drainage falls towards the existing pavement, the formation level within the widening shall fall in the opposite direction, away from the existing pavement, to avoid additional water contributing to the existing drainage paths (see Figure 3.44).

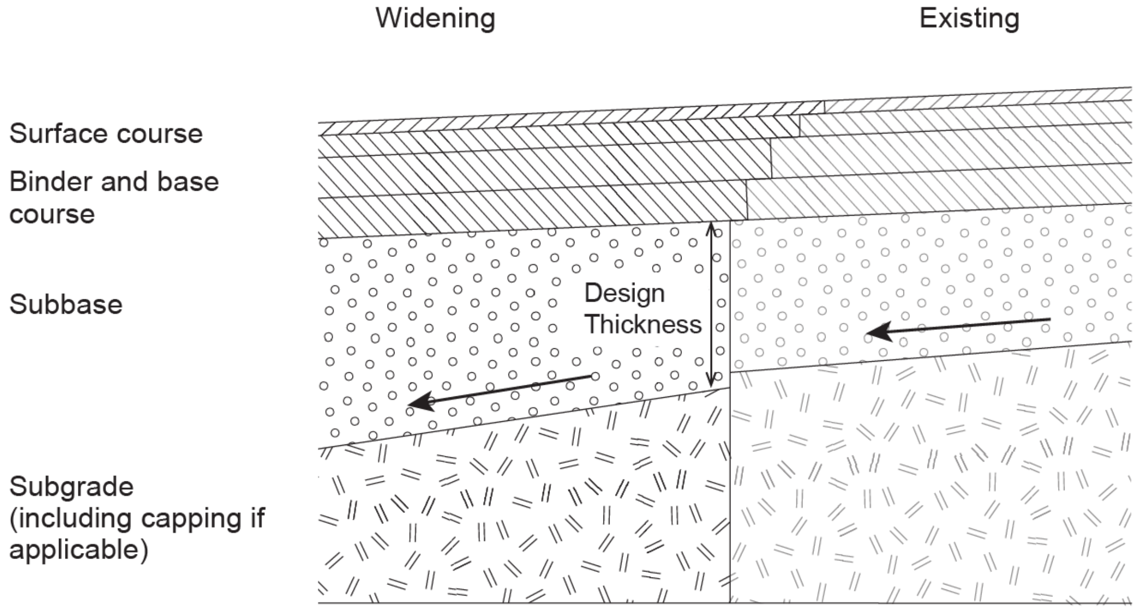
Figure 3.44 Pavement falls towards existing carriageway



NOTE Additional thickness of subbase to match the existing formation level in this scenario is not required. However, there can be practical construction benefits to doing so.

3.45 Where the existing subsurface drainage falls towards the widening, the formation level within the widening shall either match or be lower than the existing formation level (refer to Figure 3.45, for example).

Figure 3.45 Pavement falls away from existing carriageway



4. Procedure for performance foundation designs

4.1 Performance foundation design thicknesses shall be derived analytically using multi-layer linear elastic analysis.

4.1.1 Design charts for a range of layer stiffness and foundation class scenarios are contained within Appendix A and may be used to establish a performance foundation design thickness.

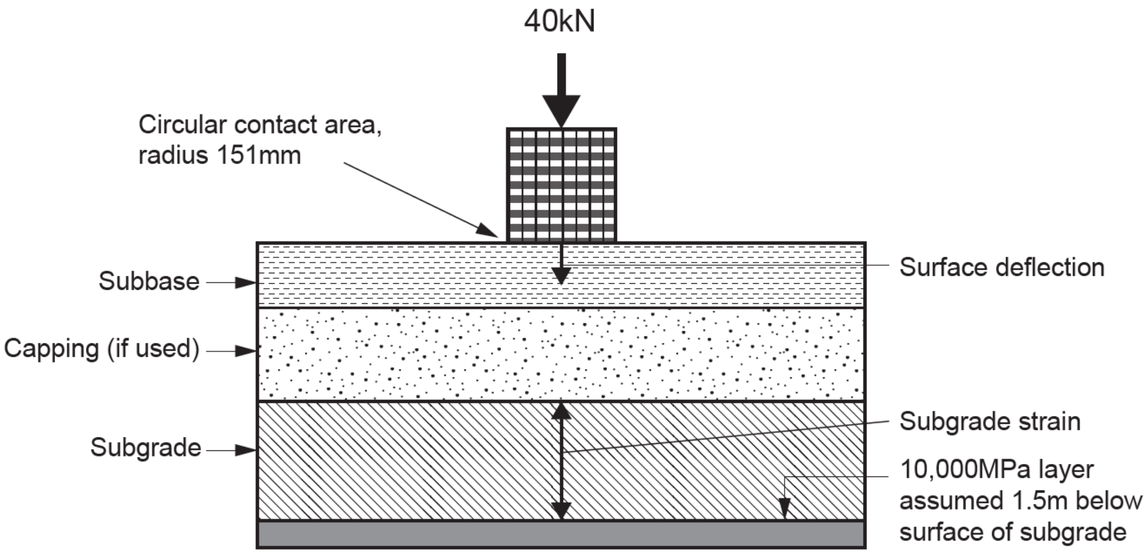
4.2 Performance design criteria of subgrade strain and surface deflection shall be as detailed in this section.

NOTE 1 Protection of the subgrade during construction (short-term) is based on the vertical compressive strain in the top of the subgrade. The structural response is limited so that excessive deformation does not occur.

NOTE 2 Support for the pavement during its design life is defined by calculating the deflection of the foundation under the action of a wheel load at the top of foundation level, shown in Figure 4.3. The deflection under a given load can be equated to a surface modulus for the foundation as a whole.

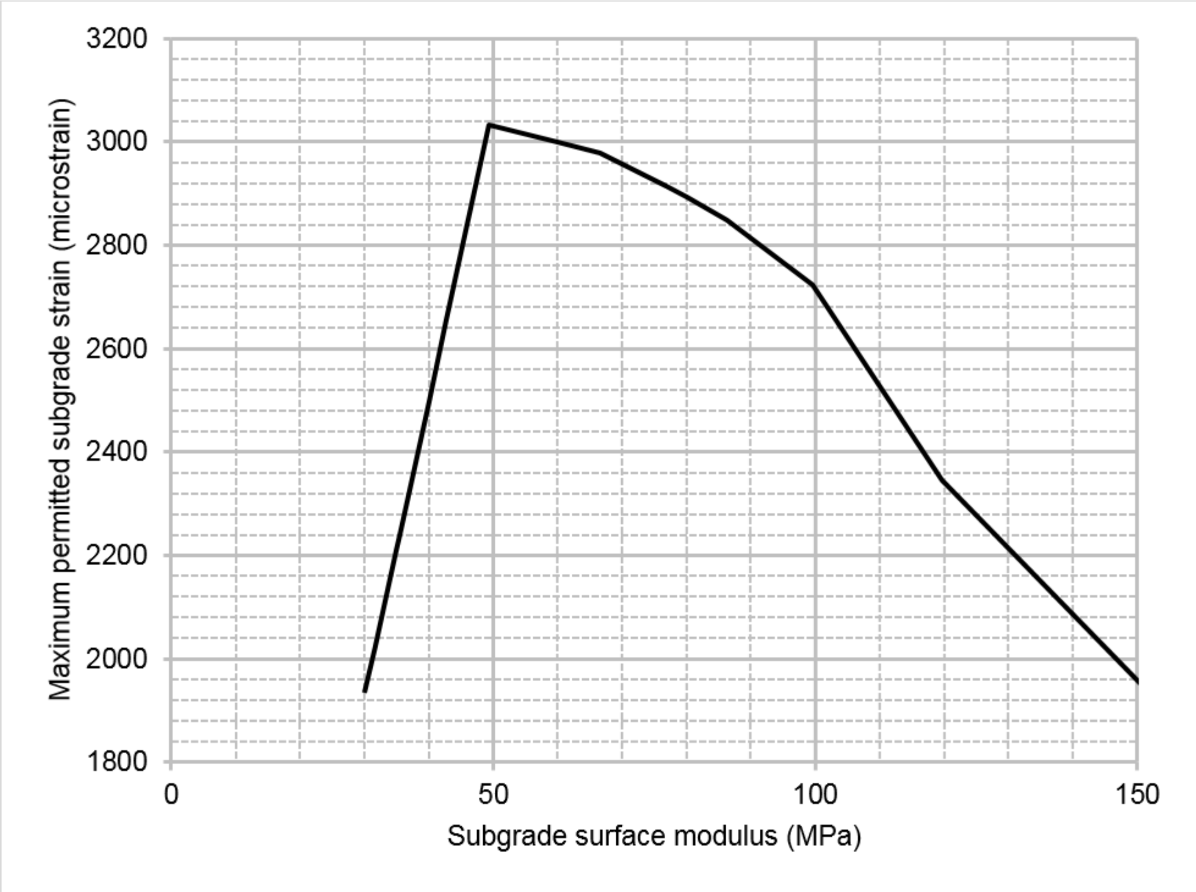
4.3 The vertical strain in the subgrade shall be calculated under the action of a standard 40 kN wheel load travelling at the top of foundation level, refer to Figure 4.3.

Figure 4.3 Input parameters for performance foundation designs



4.4 The vertical strain in the subgrade for the corresponding subgrade surface modulus value shall not exceed the limits as shown in Figure 4.4.

Figure 4.4 Subgrade strain limits for performance foundation designs



NOTE *Based on the principles presented by LR1132 [Ref 13.I], these limits assume that the foundation carries up to 1000 standard axles of traffic with no more than 40 mm deformation at the top of subbase.*

4.4.1 Trafficking at lower levels may be permitted provided the deformation limits given in the performance specification are not exceeded.

4.5 The deflection of the foundation shall be calculated under the action of a standard wheel load (40 kN load over a 151 mm radius loaded area).

4.6 The maximum deflection of the foundation for each foundation class under a standard wheel load (40 kN load over a 151 mm radius loaded area) shall be:

1) Foundation class 1 - 2.96 mm;
2) Foundation class 2 - 1.48 mm;
3) Foundation class 3 - 0.74 mm;
4) Foundation class 4 - 0.37 mm.

NOTE *These limits are based primarily on the criteria used in LR1132 [Ref 13.I] but adjusted for reasons given in PPR 127 [Ref 6.I].*

4.7 The Poisson's Ratio value used in the design for subbase materials shall be 0.35.

4.8 The Poisson's Ratio value used in the design for subgrade materials including capping and the 10,000 MPa layer assumed 1.5 m below the surface of the subgrade shall be 0.45.

5. Normative references

The following documents, in whole or in part, are normative references for this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Ref 1.N	Highways England. CD 226, 'Design for new pavement construction'
Ref 2.N	Highways England. CD 524, 'Edge of pavement details'
Ref 3.N	Highways England. GG 101, 'Introduction to the Design Manual for Roads and Bridges'
Ref 4.N	Highways England. MCHW, 'Manual of Contract Documents for Highway Works'

6. Informative references

The following documents are informative references for this document and provide supporting information.

Ref 1.I	BSI. BS EN ISO 4787, 'Laboratory glassware. Volumetric instruments. Methods for testing of capacity and for use'
Ref 2.I	BSI. BS 1377-5, 'Methods of test for soils for civil engineering purposes. Compressibility, permeability and durability tests'
Ref 3.I	BSI. BS 1377-6, 'Methods of test for soils for civil engineering purposes. Consolidation and permeability tests in hydraulic cells and with pore pressure measurement'
Ref 4.I	BSI. BS 1377-4, 'Methods of test for soils for civil engineering purposes. Part 4. Compaction related tests'
Ref 5.I	BSI. BS 5835-1, 'Recommendations for testing of aggregates. Compactibility test for graded aggregates'
Ref 6.I	TRL Ltd. Chaddock, B & Roberts, C. PPR 127, 'Road foundation design for major UK highways'
Ref 7.I	National Physical Laboratory. Kaye GWC & Laby TH. Kaye & Laby , 'Tables of physical and chemical constants and some mathematical functions'
Ref 8.I	BSI. BS EN 932-6, 'Tests for general properties of aggregates. Definitions of repeatability and reproducibility'
Ref 9.I	BSI. BS EN 932-1, 'Tests for general properties of aggregates. Methods for sampling'
Ref 10.I	BSI. BS EN 1097-3, 'Tests for mechanical and physical properties of aggregates. Determination of loose bulk density and voids'
Ref 11.I	BSI. BS EN 1097-6, 'Tests for mechanical and physical properties of aggregates. Determination of particle density and water absorption'
Ref 12.I	BSI. BS EN 1097-5, 'Tests for mechanical and physical properties of aggregates. Determination of the water content by drying in a ventilated oven'
Ref 13.I	TRL. Powell, WD, Potter, JF, Mayhew, HC & Nunn, ME. LR1132, 'The structural design of bituminous roads'
Ref 14.I	ASCE Journal of the Hydraulics Division, Vol 93, pp 137-148. Dudgeon, CR. ASCE Proc Paper 5433, 'Wall effects in permeameters'

Appendix A. Example performance foundation design charts

Design thicknesses using the procedure in Section 4 have been generated at 5 MPa increments between 30 MPa and 50 MPa and at 10 mm increments between 50 MPa and 150 MPa and have been rounded up to the nearest 10 mm.

Table A.1 Performance related design curves

Figure	Foundation class	Construction type	Layer stiffness (MPa)
A.1	1	Single layer	50, 75
A.2	2	Single layer	120, 150, 350
A.3	3	Single layer	350, 500, 1000
A.4	4	Single layer	1000, 2000, 4000
A.5	2	Subbase on capping	Capping – 75 Subbase – 120, 150, 350
A.6	3	Subbase on capping	Capping – 75 Subbase – 350, 500, 1000
A.7	4	Subbase on capping	Capping – 75 Subbase – 1000, 2000, 4000

Figure A.1 Performance design options - class 1 single foundation layer

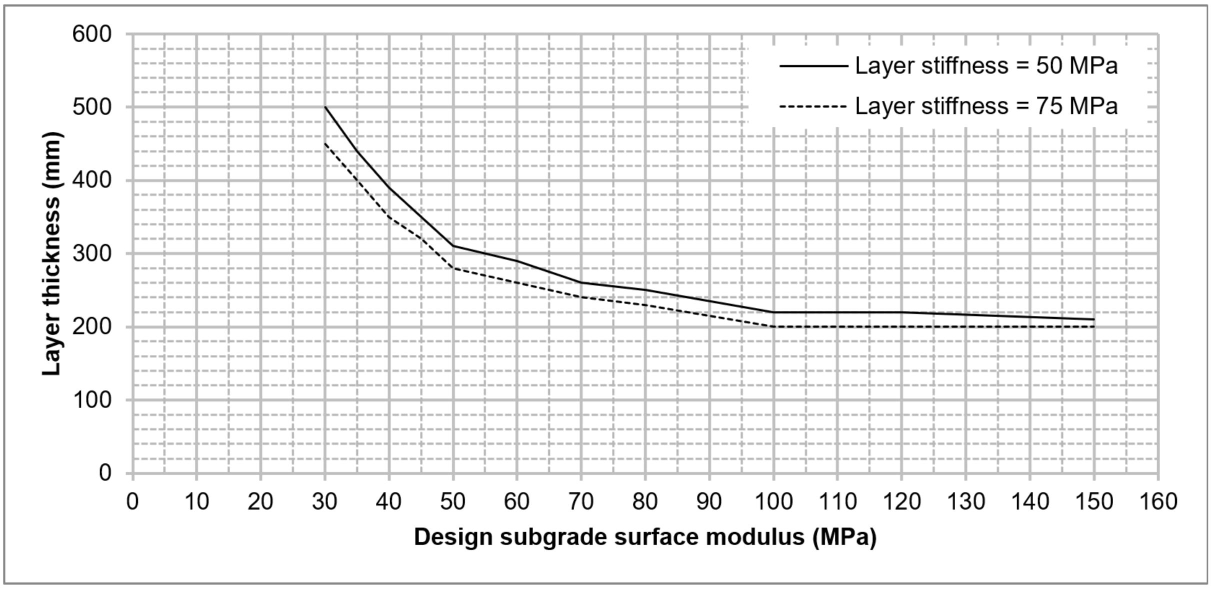


Figure A.2 Performance design options - class 2 single foundation layer

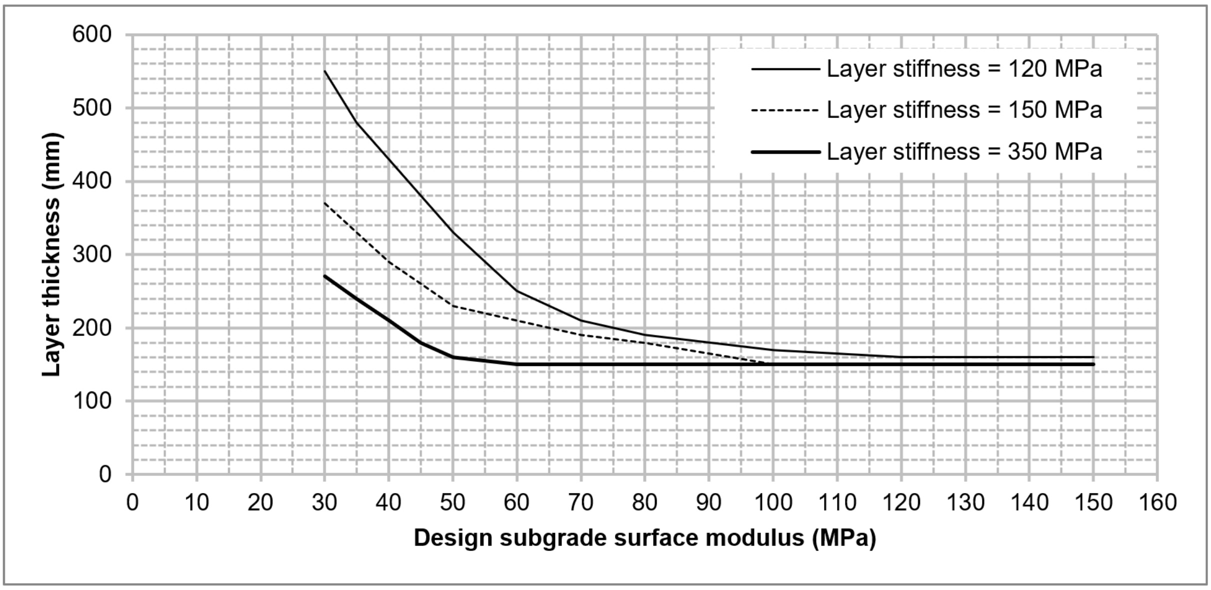


Figure A.3 Performance design options - class 3 single foundation layer

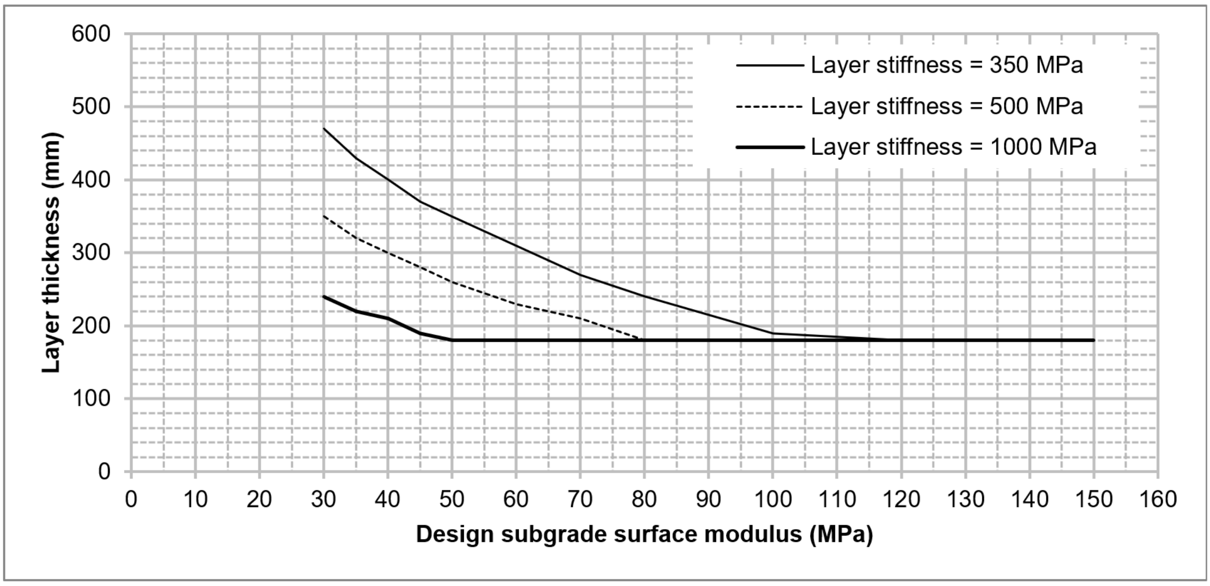


Figure A.4 Performance design options - class 4 single foundation layer

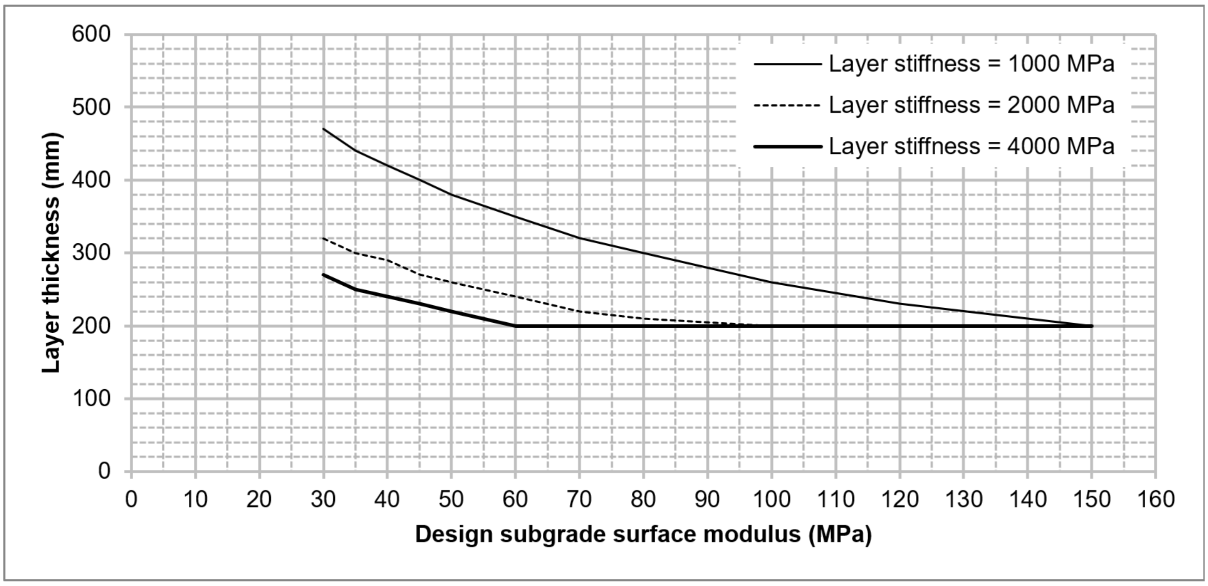


Figure A.5 Performance design options - class 2 subbase on capping

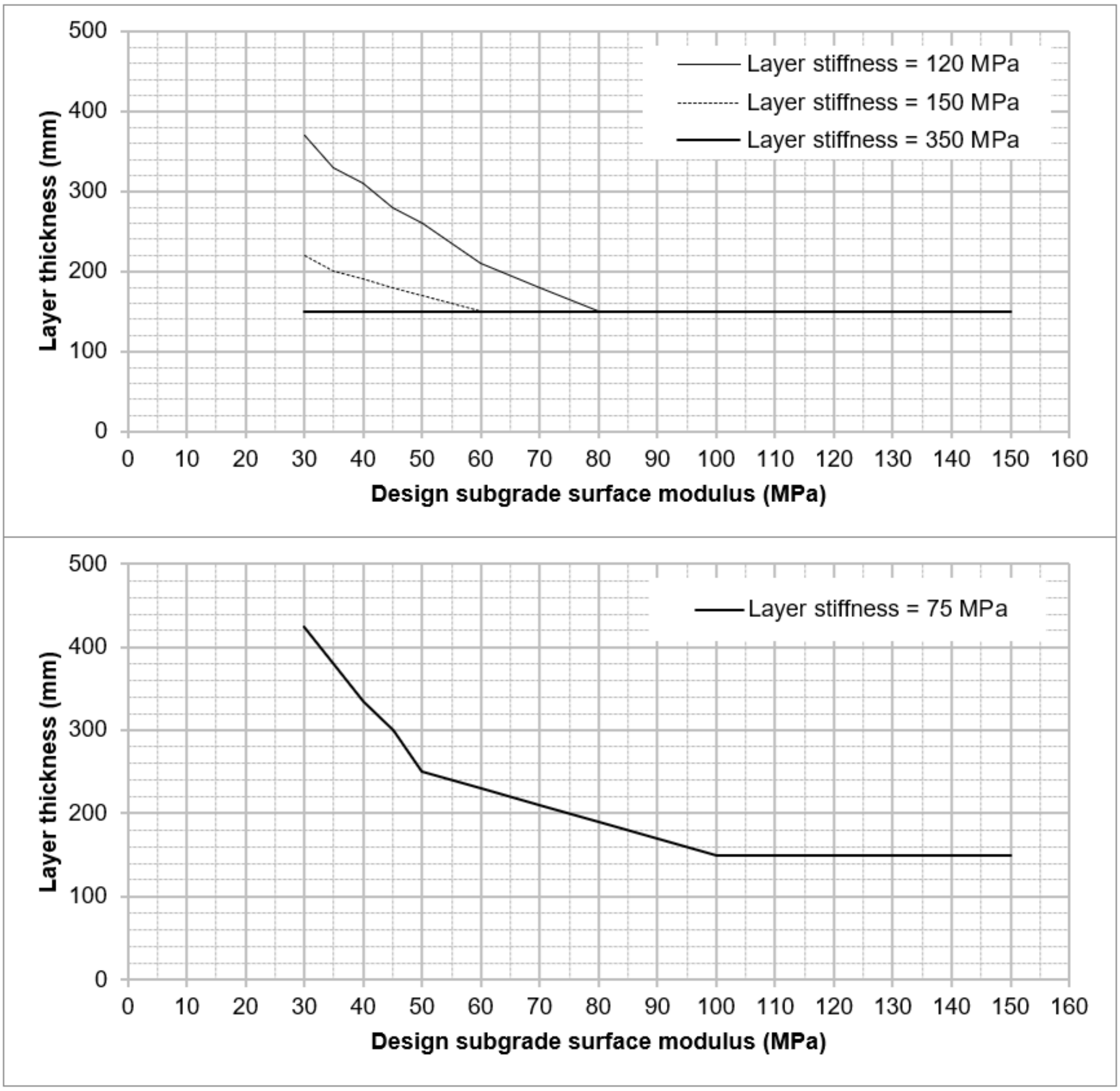


Figure A.6 Performance design options - class 3 subbase on capping

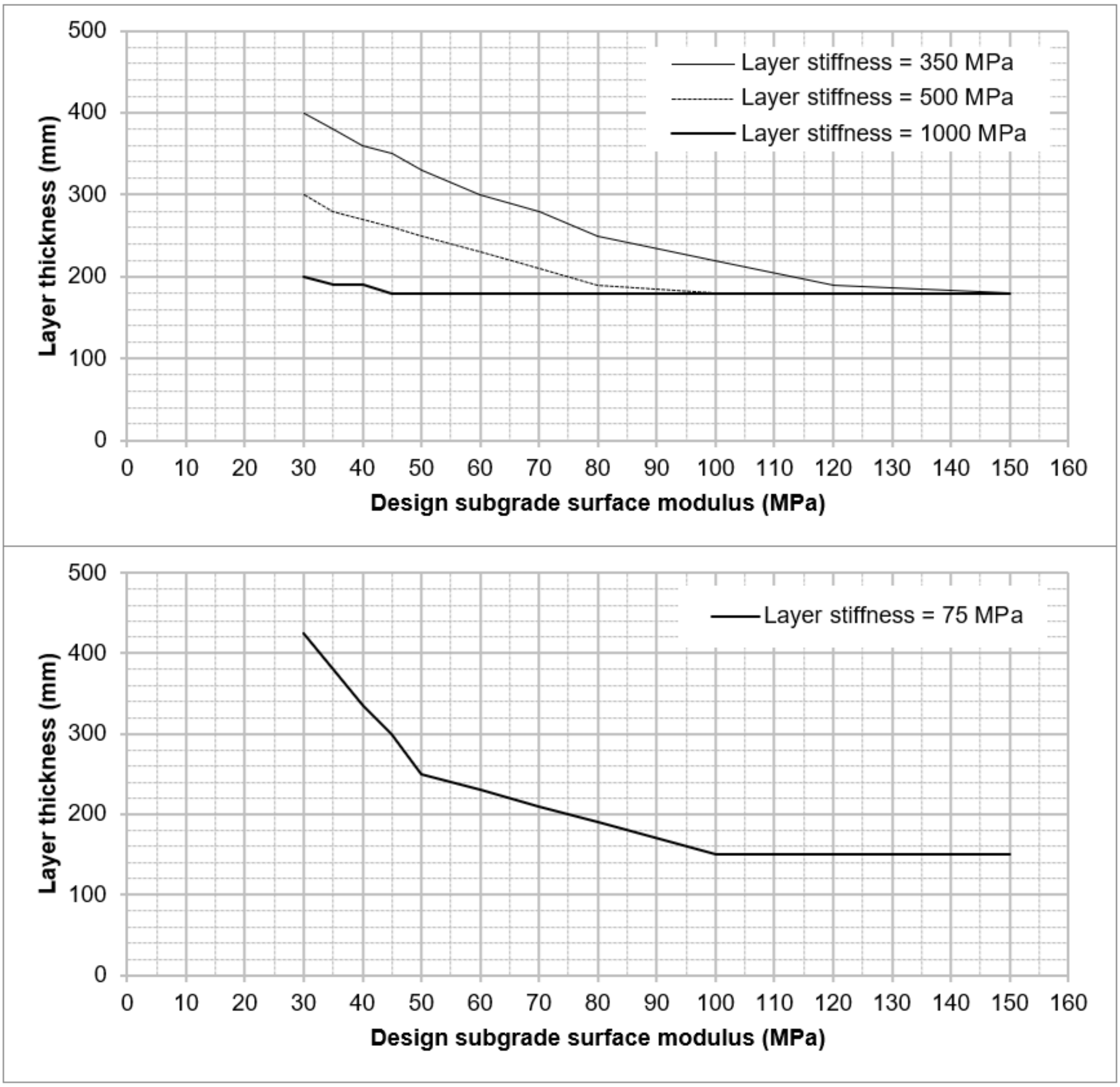
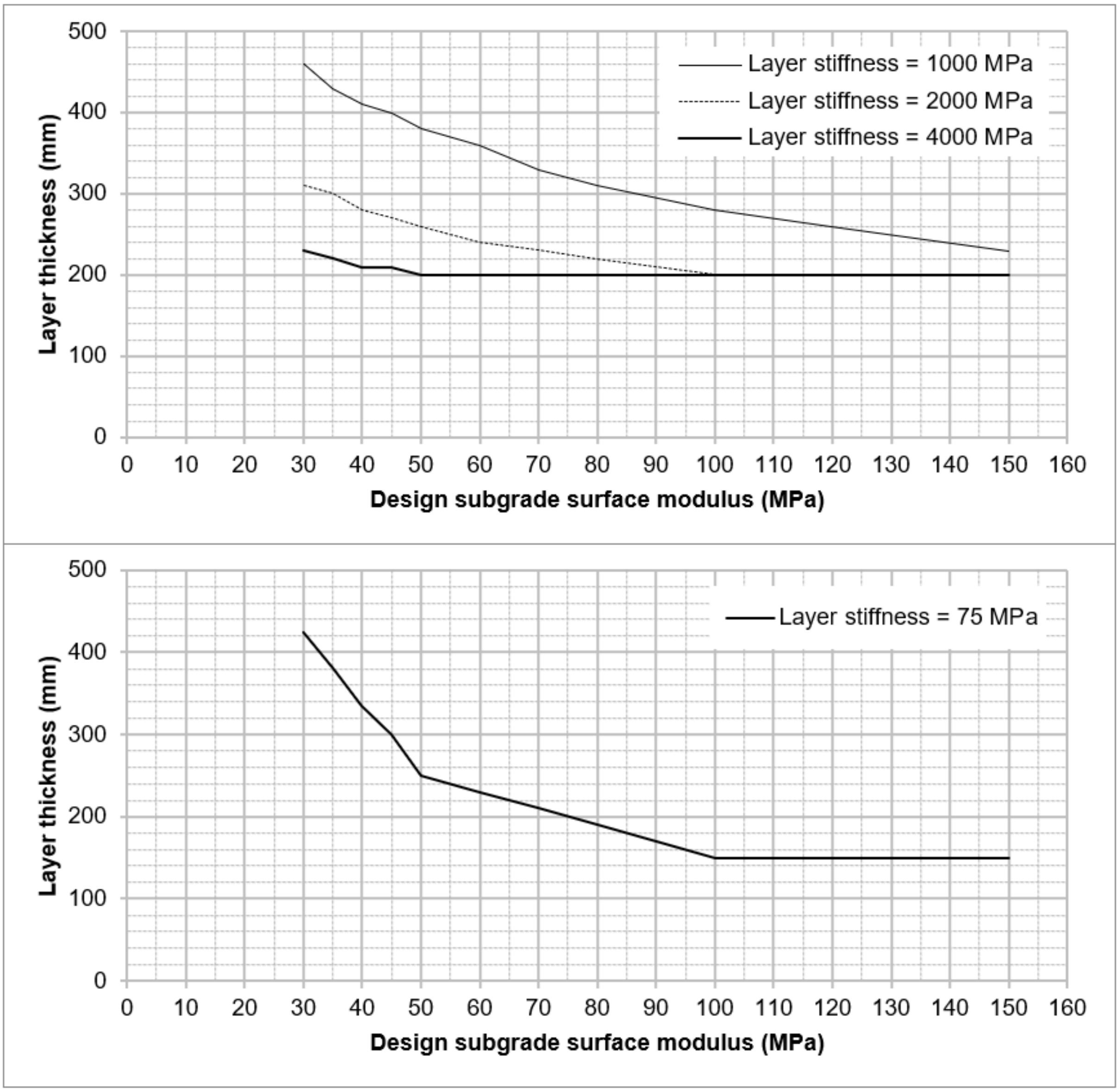


Figure A.7 Performance design options - class 4 subbase on capping



Appendix B. Worked examples

B1 Example 1 – Restricted foundation design procedure

Design factors:

1) long-term subgrade surface modulus = 35 MPa; and,
2) short-term subgrade surface modulus = 60 MPa.

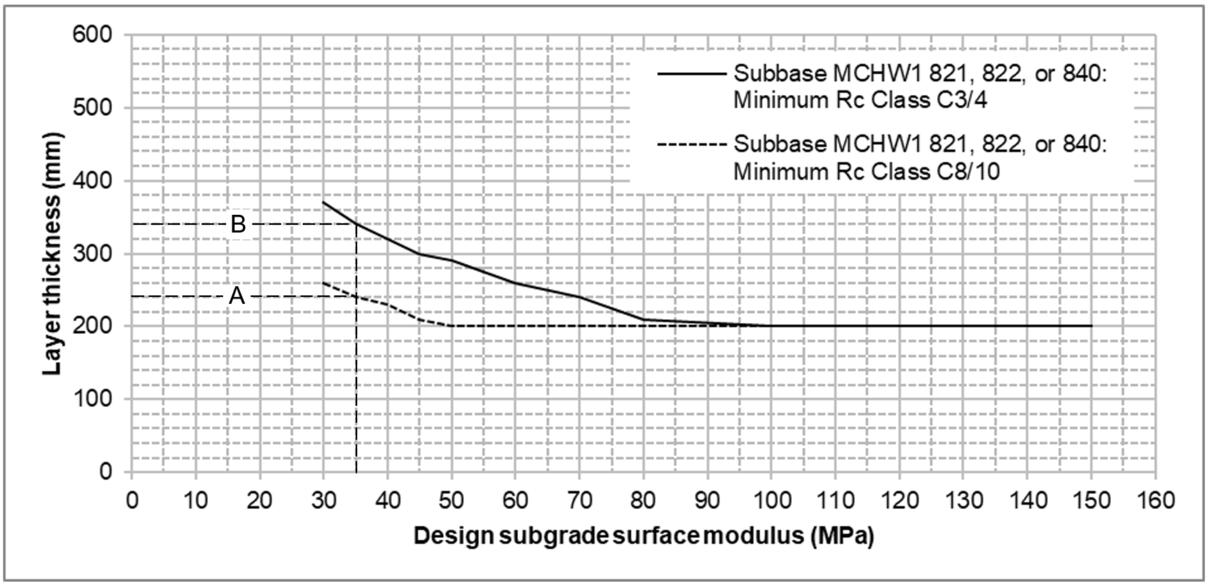
Design subgrade surface modulus = 35 MPa.

Using Figure B.1 (replica of Figure 3.19) to design a class 3 restricted subbase only foundation:

A) 240 mm MCHW 821, 822 or 840 R_c Class 8/10; or,

B) 340 mm MCHW 821, 822 or 840 R_c Class 3/4.

Figure B.1 Example 1



B2 Example 2 – Performance foundation design procedure

Design factors:

1) long-term subgrade surface modulus = 35 MPa;
2) short-term subgrade surface modulus = 60 MPa; and,
3) mean modulus of elasticity in compression (E_c) of material = 3500 MPa.

Design subgrade surface modulus = 35 MPa.

For layer stiffness take 20% E_c of material, therefore layer stiffness = 700 MPa.

Using the procedure in Section 4 to design a class 3 performance single layer foundation:

260 mm of 700 MPa subbase

B3 Example 3 – Restricted foundation design procedure for widening

Design factors:

1) long-term subgrade surface modulus = 40 MPa;

2) short-term subgrade surface modulus = 30 MPa;
3) existing adjacent pavement unbound;
4) existing pavement falls towards proposed widening;
5) existing asphalt approximately 380 mm thick, widening to match this thickness; and,
6) existing subbase approximately 160 mm thick.

Design subgrade surface modulus = 30 MPa.

Short-term subgrade surface modulus <50 MPa, capping layer required.

Formation level to match or be lower than formation under existing adjacent pavement.

Unbound materials required to ensure drainage is not inhibited.

Using Figure B.2 (replica of Figure 3.20) to design a class 2 restricted capping and subbase foundation:

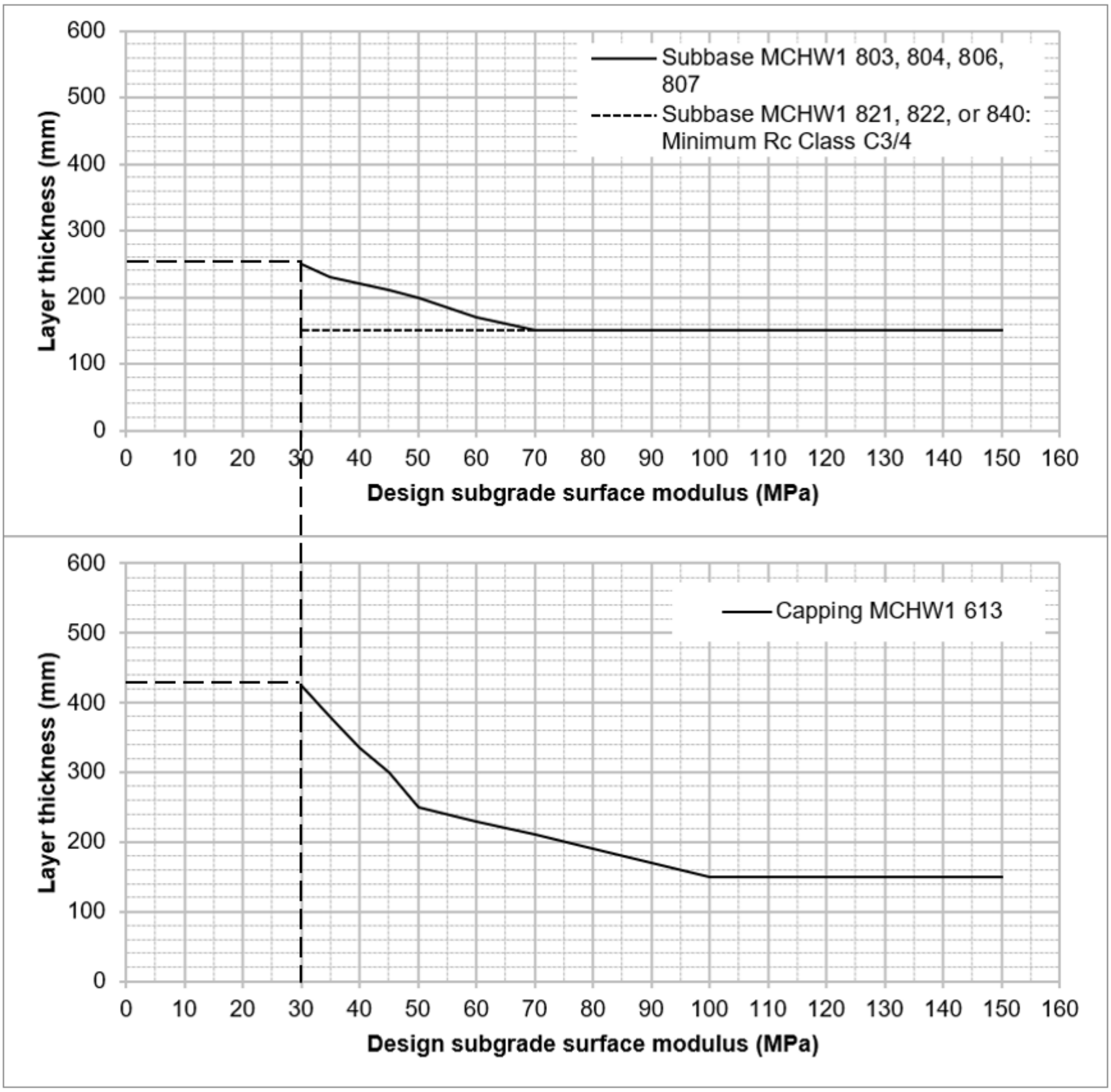
250 mm MCHW1 803, 804, 806 807 subbase

On

430 mm MCHW 613 capping

Formation level of widening lower than adjacent pavement formation so additional thickness not required.

Figure B.2 Example 3



B4 Example 4 – Performance foundation design procedure

Design factors:

1) long-term subgrade surface modulus = 40 MPa; and,
2) short-term subgrade surface modulus = 30 MPa.

Design subgrade surface modulus = 30 MPa.

Short-term subgrade surface modulus <50 MPa, capping layer specified.

Using the procedure in Section 4 and 75 MPa layer stiffness for capping and 150 MPa layer stiffness for subbase, to design a class 2 performance multi-layer foundation:

214 mm of 150 MPa subbase

on

430 mm of 75 MPa capping

Appendix C. A permeameter for road drainage layers

C1 Overview

C1.1 Introduction

Appendix C describes a box-type permeameter that can be used for testing the horizontal permeability of road drainage layers.

It describes the apparatus and sets out the test procedure.

C1.2 Scope

The test can be used to determine the horizontal permeability of embankment drainage layers, capping materials and subbases and can be used to supplement the information required by Clause 640 of the MCHW [Ref 4.N].

It is used where, subject to limitations set out below, particle sizes within the granular specimens exceed those that can be tested using methods described in BS 1377-5 [Ref 2.I] and BS 1377-6 [Ref 3.I].

Whilst the apparatus and test methods are currently the best available, as with any test procedure, there are limitations on reproducibility and repeatability. The test can only be applied to conditions of laminar flow and not to situations where high hydraulic gradients and turbulent flow might occur in practice.

C1.3 Background

Granular layers can be used to provide drainage of pavement layers beneath roads and for the relief of pore pressures within embankments. These layers need to exhibit both adequate drainage and load bearing properties. There is a conflict in that a well graded material is needed for load bearing but this is detrimental to the drainage properties.

The selection of coarse materials for use as drainage layers is usually achieved by the specification of a grading envelope. Large variations in permeability within these grading envelopes have been noted. Where there is a need to specify the permeability of such layers (e.g. according to Clause 640 of the MCHW [Ref 4.N]) the test described in Appendix C provides a mean to determine the horizontal permeability of drainage, subbase and capping materials in their compacted states.

C2 Apparatus

C2.1 Introduction

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

Figure C.1 Schematic diagram of apparatus

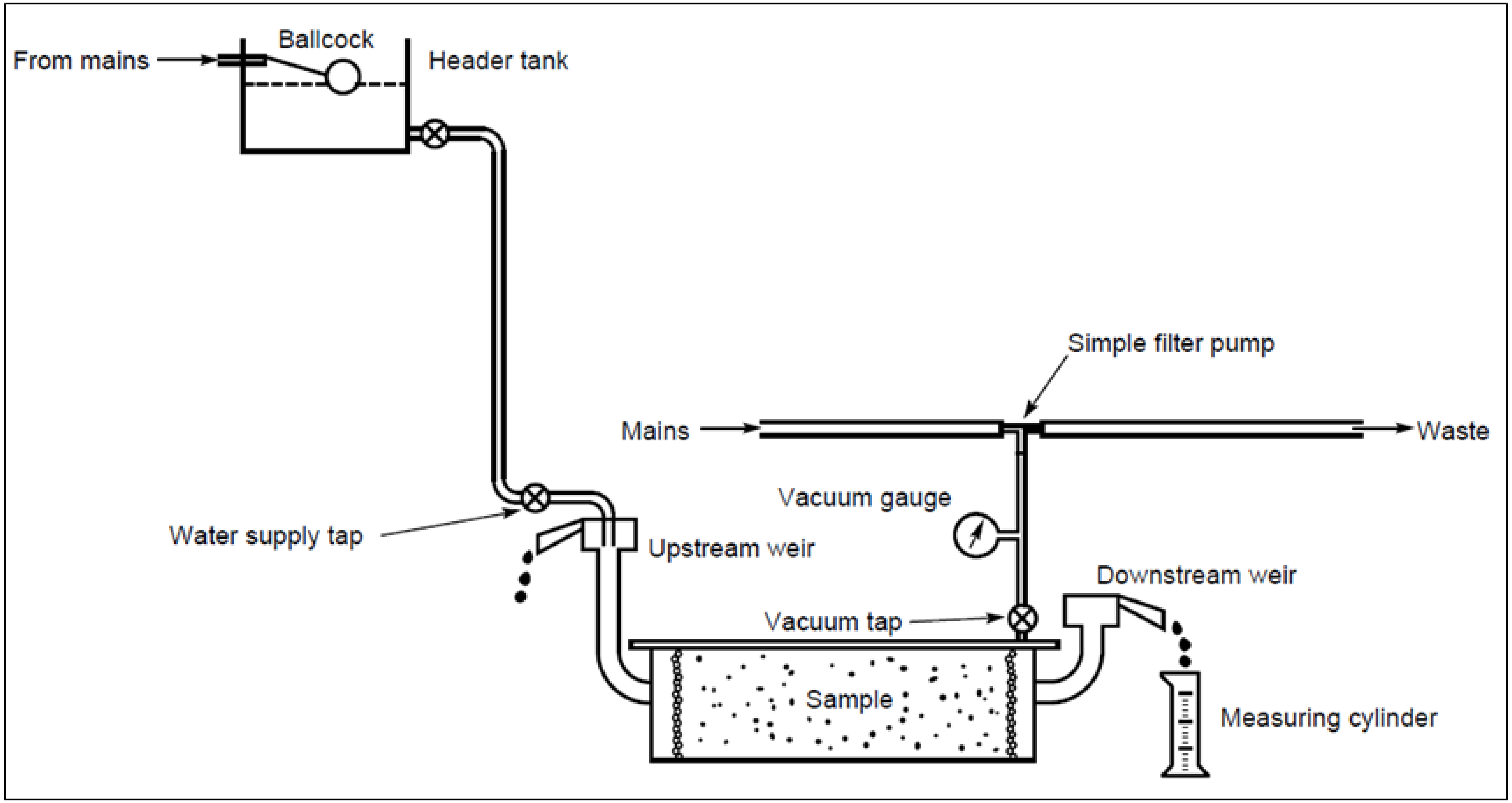


Figure C.2 Test box typical details

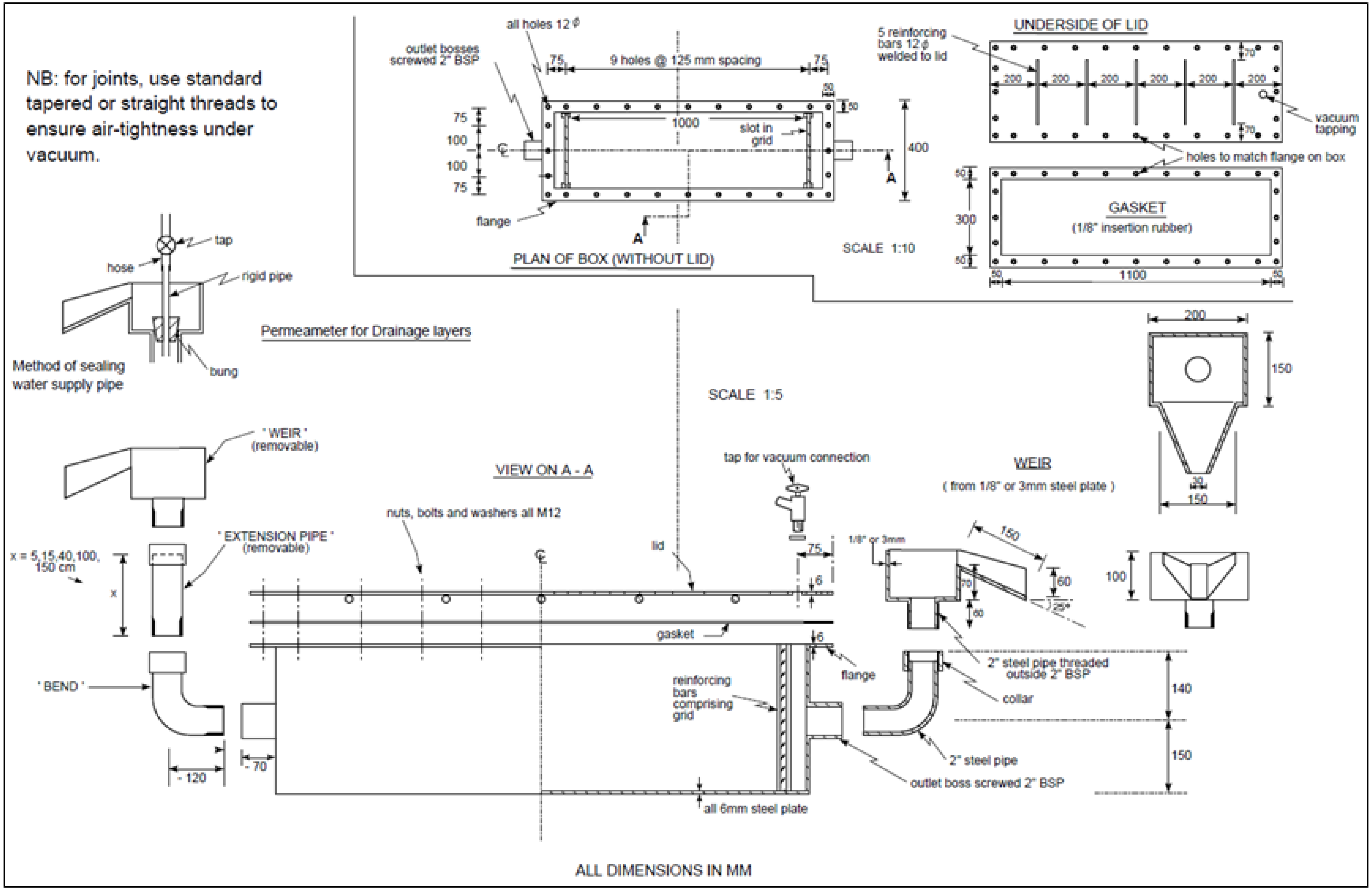
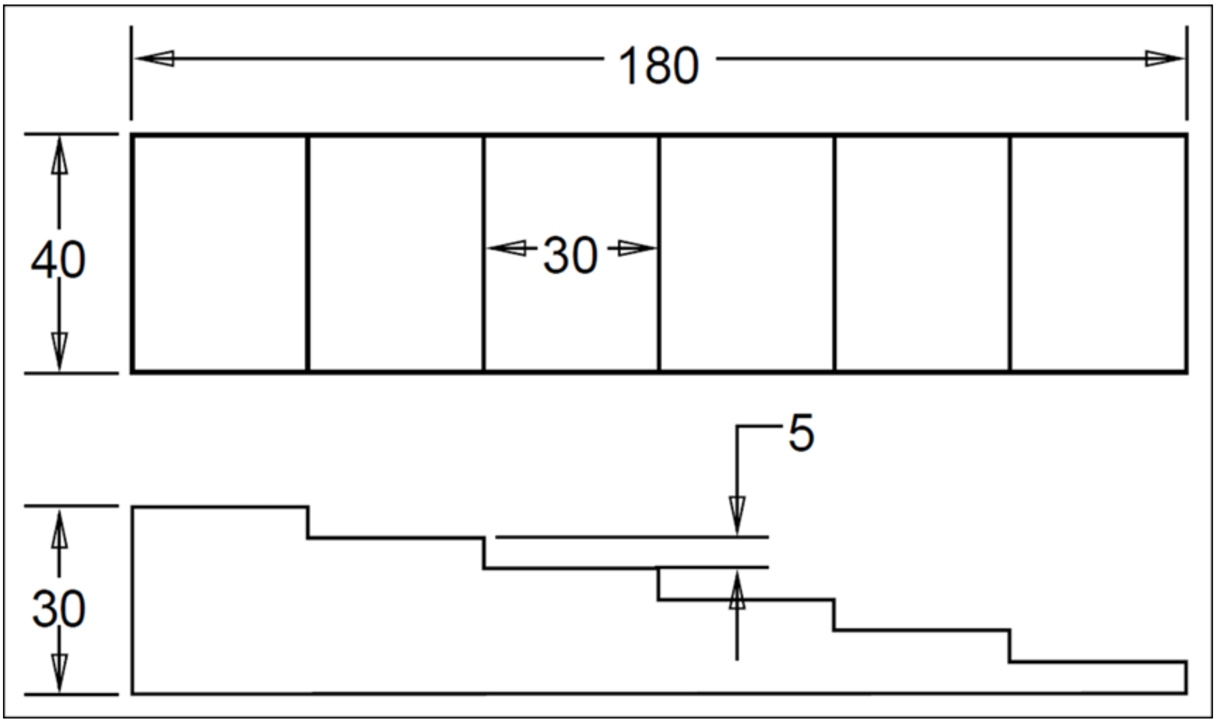


Figure C.3 Stepped wedge suggested dimensions (mm)



C2.2 Apparatus required

1) A test box as described in C2.1 and as shown in the drawing (Figure C.2) with associated extension pipes and weirs. All dimensions are suggested dimensions, hence no manufacturing tolerances are indicated.
2) A jack and suitable stepped wedges (Figure C.3) to incline the permeameter and thus achieve small differences in head.
3) About 250 kg of the material to be tested, which has been sampled in an approved manner according to BS EN 932-1 [Ref 9.I].
4) An electric vibrating hammer as called for in BS 1377-4 [Ref 4.I], Clause 3.7, but fitted with a square tamping foot of approx. 125 mm side.
5) A layer of sealed cell (impermeable) foam, such as a 12 mm non-intercellular neoprene foam sheet (NINS).
6) 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 to be calibrated and readable to 20 mm of mercury or the equivalent, or better.
7) Two rubber bungs to fit the holes in the base of each weir. One to be intact, the other to have a piece of rigid pipe (at least 7 mm internal diameter) 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 is sealed to the exposed end of the pipe.
8) A supply of settled water consisting of mains water being supplied via a ballcock to a header tank of at least 150 litre capacity. Water is 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 is referred to as the water supply tap. [Note: For tests at low hydraulic gradients, requiring smaller volumes of water, the use of de-aired water, instead of settled water, may be used].
9) Some pipe jointing compound, and pipe wrenches.

10) Manometers and scale. The manometers to 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).
11) A spirit level.
12) A metre rule with scale divisions every 0.5 mm.
13) A stopwatch, calibrated to within 1 s in 5 min.
14) 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 EN ISO 4787 [Ref 1.I].
15) A thermometer, readable to 0.1°C, calibrated against a reference standard before using.
16) Facilities for determination of water content to BS EN 1097-5 and relative density according to BS EN 1097-6 [Ref 11.I].

C3 Method of test for horizontal permeability of drainage layers

C3.1 General

This method is suitable for testing materials having median (d_{50}) particle size up to 30 mm. When compacting in layers, the layer thickness needs to be chosen in relation to the maximum particle size (d_{100}). During testing, a differential head of water is maintained across the sample by an upstream and downstream weir. This can 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.

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).

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

C3.2 Procedure

C3.2.1 Preparation

1) The box should be placed on a firm, horizontal surface allowing water to be collected or run to waste at either end.
2) The material should be weighed before it is compacted into the box to find its mass.
3) 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 water content determined from BS 1377-4 [Ref 4.I] Clause 3.7 or from BS 5835-1 [Ref 5.I].
4) Take a sample of the remaining material for water content (w) determinations according to BS EN 1097-5 [Ref 12.I], loose bulk density according to BS EN 1097-3 [Ref 10.I] and relative density G_{sa} determination according to BS EN 1097-6 [Ref 11.I].
5) Measure the dimensions of the sample, i.e. length (L), width (W) and depth (D) to an accuracy of ± 0.5 mm.
6) Fit appropriate extension pipes and weirs at either end to give a suitable head difference of 30 to 40 mm across the sample. Ensure that all joints are well tightened as they should be capable of holding a vacuum (use pipe jointing compound and PTFE tape where appropriate).
7) Place a piece of sealed cell foam of appropriate size on top of the sample.
8) 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.

9) 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.
10) 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.
11) When a vacuum of at least 7 m water (508 mm Hg) and preferably around 9.5 m water (699 mm Hg) below atmospheric has been achieved, open the water supply tap slightly, allowing water to flow in slowly and saturate the sample.
12) 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.
13) 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.
14) Remove the bungs. Fill the box until there is some water in the lower weir. Turn off the water supply tap.

C3.2.2 Testing

1) Supply the water to the higher (upstream) weir and adjust the flow throughout the test so that this weir just overflows.
2) Measure the flow rate (q) at the discharge end at 15 minute intervals.
3) Measure the head difference (ΔH) between the upstream and downstream weirs, by means of the manometers.
4) Measure the water temperature (T) at both ends of the permeameter throughout the duration of the test and calculate the average.
5) 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.
6) Observe when the discharge water appears to be clear. If it continues to be very dirty, take some samples, noting the time of sampling.
7) Results should be reported on an appropriate record sheet.
8) 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 (ΔH). The plot indicates the linear region for which Darcy's law is applicable.
9) After testing, take a representative sample of material from the permeameter for a particle size distribution analysis (wet sieving test).
10) When removing the sample from the box, take note of anything which may adversely have affected the results (e.g. evidence of piping, flow across top of sample, non-saturation of sample).

C3.3 Notes on testing errors

C3.3.1 Sampling errors

These can be overcome by rigid adherence to BS EN 932-6 [Ref 8.I].

C3.3.2 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 not necessarily complete, but usually this is a method appropriate to the volume of water required and the scale of the experiment.

C3.3.3 Non-saturation

This is potentially the greatest source of error. The saturation procedures described in part C3.2.1 should minimise the problem. If required, the degree of saturation (S_r) can be calculated by equation C.1.

Equation C.1 Degree of saturation

$$S_r = \frac{(M_w1 - M_w2) + \rho_s}{1000n}$$

where:

M_w1	is the total mass of water added (kg)
M_w2	is the mass of water required to fill box ends and fittings only (kg)
n	is porosity (%)
S_r	is the degree of saturation
V	is the volume of sample (m^3)
ρ_s	is the dry density of sample (kg/m^3)

C3.3.4 Flow around sample (piping)

Care is needed to ensure that flow does not occur over the sample. The sealed cell impermeable foam sheet provides an effective seal across the top of the specimen as the reinforcing bars on the permeameter lid press firmly into the sheet.

C3.3.5 Wall effects

ASCE Proc Paper 5433 [Ref 14.I] 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 can allow materials with d_{50} up to 30 mm to be tested.

C3.3.6 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 gives an estimate of the percentage loss of fines. Erosion of the sample and subsequent piping may occur if high flow rates are used. This can be avoided by conducting the test using lower head differences and correspondingly low flow rates.

C3.3.7 Transitional/turbulent flow

The method of test described in Section C3 with small head differences, ensures that non-Darcy flow is unlikely and that a laminar flow is obtained. The calculation procedure given below rejects data not obeying Darcy's law.

C3.3.8 Temperature effects

The dynamic viscosity of water is temperature dependent. Figure C.4 gives the ratio of dynamic viscosity of water at temperature T°C to that at 20°C, μ_T / μ_{20} , i.e. the temperature correction factor, c, used in the calculations.

C3.3.9 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. The results indicate a characteristic range rather than a single absolute value of horizontal permeability.

C4 Results calculation

C4.1 Coefficient of permeability

The coefficient of permeability, k, at any temperature T is given by equation C.2.

Equation C.2 Coefficient of permeability

$$k = \left(\frac{q}{Ai}\right)\left(\frac{10^{-6}}{60}\right)ms^{-1}$$

where:

A	is the cross sectional area (m^2)
i	is the hydraulic gradient
k	is the coefficient of permeability
q	is the steady state flow rate (ml/min)

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 C.3 and C.4.

Equation C.3 Hydraulic gradient

$$i = \left(\frac{\Delta H}{L}\right)$$

where:

i	= hydraulic gradient
L	= length of the specimen (m)
ΔH	= Head difference across specimen (mm)

Equation C.4 Flow rate per unit area

$$\frac{q_{20}}{A} = \left(\frac{q.c}{W.D}\right)$$

where:

A	is the cross sectional area (m^2)
c	is the temperature correction factor μ_T/μ_{20}, obtained from a standard chart (Figure C.4, based on Kaye & Laby [Ref 7.I])
D	is depth (m)
q	is the steady state flow rate (ml/min)
q_{20}/A	is the flow rate per unit area standardised to 20°C
W	is width (m)

q_{20}/A is plotted against i and the best straight line drawn from the origin through those points exhibiting a linear relationship. (refer to Figure C.5, plot for sample results). The gradient of this line gives k_{20}, the coefficient of permeability at standard laboratory temperature.

Figure C.4 Relationship between dynamic viscosity of water and temperature

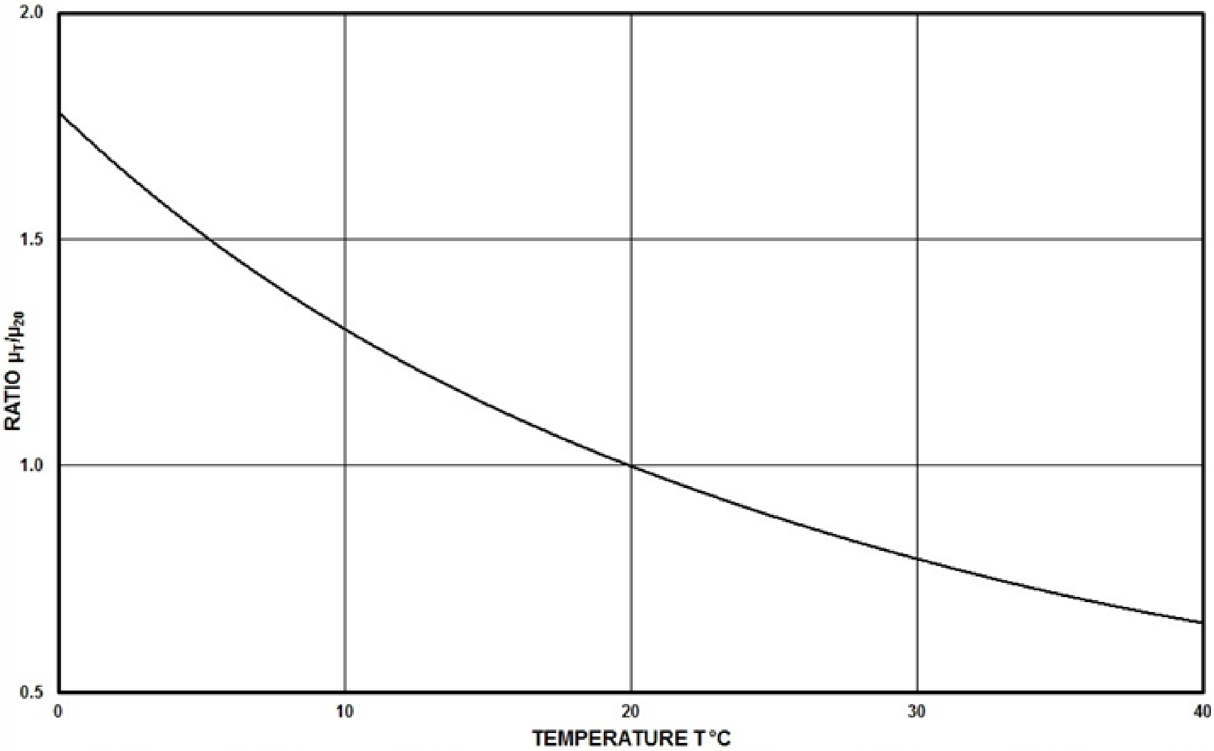
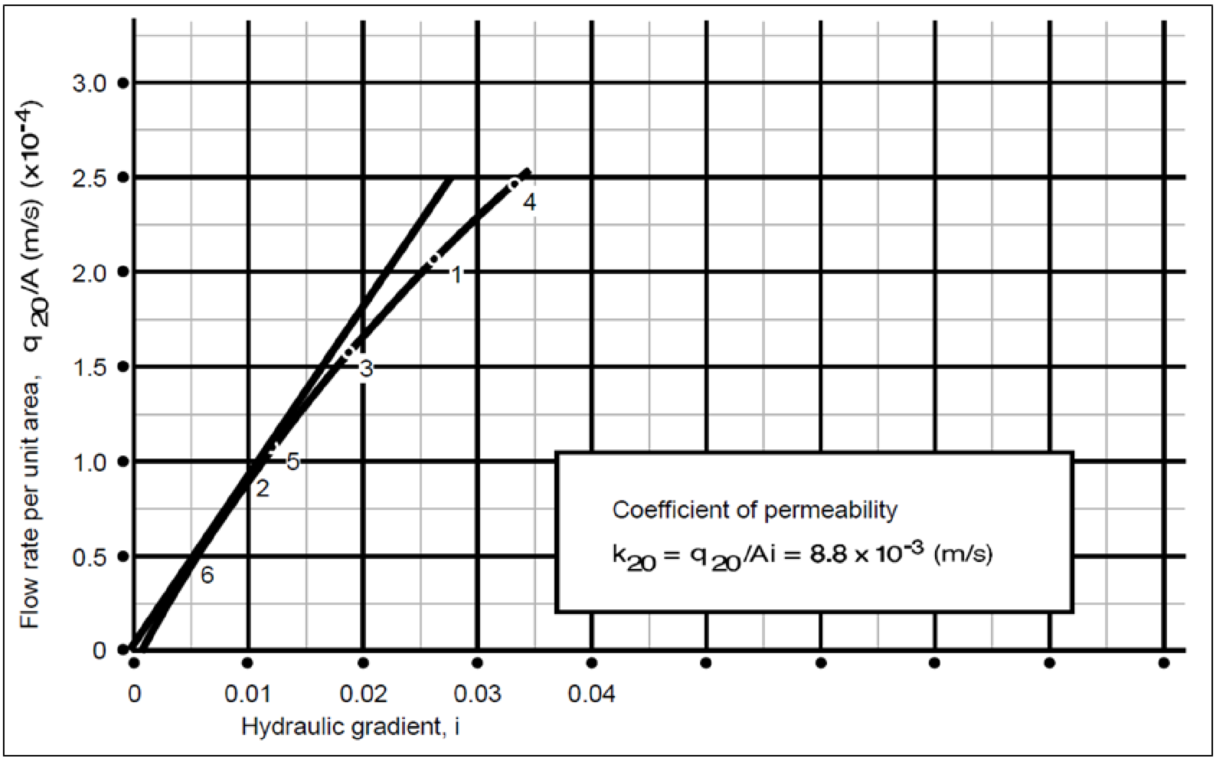


Figure C.5 Sample results plot of flow rate per unit area (q20) vs. hydraulic gradient (i)



C4.2 Total porosity

Total porosity, n, can be calculated with equation C.5 if required.

Equation C.5 Total porosity

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

where:

D	is depth (m)
G_{sa}	is the apparent relative particle density
L	is length (m)
M	is the total mass of aggregate in permeameter (kg)
n	is porosity (%)
W	is width (m)
ω	is water content (%)

C4.3 Recording of results and sample calculations

A results test sheet should be created that records all relevant data including the permeability, bulk density, water content, relative density, porosity and saturation results. For the coarse granular materials falling within the scope of the test, the values of k_{20} are normally in the range 10^{-4} m/s to 10^{-2} m/s.

C4.4 Sample results and calculation

Sample description:

Table C.1 Sample results

Specimen preparation	190 kg compacted in 5 layers at 0% water content.
Dry density	2290 kg/m³
Dimensions	Length, L = 0.934 m; Width, W = 0.300 m; Depth, D = 0.296 m; Area, A = W x D = 0.089 m²
Apparent relative particle density (G_{sa})	2.82 (measured);
Water absorption (WA)	2.9%
Total porosity, n	18.9%

Test results and determination:

Table C.2 Sample calculation

Test number	**1**	**2**	**3**	**4**	**5**	**6**
Head difference, ΔH (mm)	24.5	8.3	17	32	10.5	3.3
Hydraulic gradient, ΔH /L	0.026	0.0089	0.018	0.034	0.0112	0.0035
Steady state flow rate, q (ml/min)	899	429	706	1091	476	158
Temperature (°C)	12.75	13.5	13.25	13.25	13.25	13.5
Temperature correction factor, c	1.21	1.18	1.19	1.19	1.19	1.18
Flow rate per unit area Q_{20}/A = qc x10^{-6} / 60A m/s	2.03 x10^{-4}	0.95 x10^{-4}	1.56 x10^{-4}	2.43 x10^{-4}	1.06 x10^{-4}	0.35 x10^{-4}

Notification

This document was notified in draft to the European Commission in accordance with Technical Standards and Regulations Directive 2015/1535/EU.