INTERIM ADVICE NOTE 73/06

DESIGN GUIDANCE FOR ROAD PAVEMENT FOUNDATIONS (DRAFT HD25)

SUMMARY

This interim advice note provides design guidance for road pavement foundations.

INSTRUCTIONS

This IAN takes immediate effect. It supersedes the current HD 25/94 and includes new Manual of Contract Documents for Highways Works Specification for Highway Works Clauses 890 to 896 and the Notes for Guidance. It should be read in conjunction with HD 26/06

Contents

Section

Section 1. Background

This Interim Advice Note provides design guidance for road pavement foundations. Road pavement upper layers are now subject to new design methods and criteria that have been published in HD 26/06. This revised design criteria are based on a new classification for road pavement foundations that are separated into 4 Classes. The design guidance contained in this Interim Advice Note (presented as the draft HD 25) defines the 4 Classes of foundations and describes the methods to be used in their design and the testing regime associated with the design. It is published in this interim form to ensure that all road pavements may be designed in a coordinated manner using both HD 26/06 and the guidance in this IAN. The guidance has been produced in the form of a draft standard that will eventually replace the existing requirements that are set out in HD 25/94 together with draft Specification clauses that will be included in the MCHW. The Standard HD 25/94 (DMRB 7.2.2) is now withdrawn. The new foundation classes are presented in two forms, ‘performance designs’ allow a wide use of materials together with measures and testing to ensure design requirements are met and also ‘restricted designs’ are included for smaller schemes where limited options are available and performance testing may not be appropriate. The Guidance is included in this Interim Advice Note in 3 sections

Section 4. Draft Standard HD 25. ‘Pavement Foundations
Section 5. Draft Specification Clause 890 to 896
Section 6. Draft Notes for Guidance Clauses NG890 to NG896

Section 2. Implementation

This Interim Advice Note shall be used forthwith on all future schemes for the construction, implementation, improvement and maintenance of trunk roads. It shall apply also to all those schemes that are in preparation provided that, in the opinion of the Overseeing Organisation, this will not result in significant additional expense or delay progress. Design Organisations shall confirm its application to particular schemes with the Overseeing Organisation.

Section 3. Departures from Standard

The design guidance for pavement foundations included in this Interim Advice Note is separated into two separate chapters. The designs included in Chapter 4 on Restricted Designs may be used by designers without reference to the Overseeing Organisation. The designs included in Chapter 5 on Performance Designs should be referred to the Overseeing Organisation for approval under the Departure from Standards procedure. It is the intention that this will be required for an interim period until the guidance is published as a Standard in the DMRB and the Specification/Notes for Guidance clauses are published in the MCHW.

Section 4. Draft Design Standard HD 25 Pavement Foundations

Replaces previous HD 25/94

Contents

Chapter 1. INTRODUCTION

General

1.1 The main purpose of the 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.

Scope

1.2 This Part covers the design of pavement foundations in order to achieve the Foundation Classes called up in HD26.

1.3 The four Foundation Classes are defined by the Surface Modulus value (see Paragraph 1.11 for definition) at top of foundation level used for design purposes, as follows:

- Class 1 – 50MPa
- Class 2 – 100MPa
- Class 3 – 200MPa
- Class 4 – 400MPa

1.4 The materials covered by this Part are the subgrade, either natural ground or compacted fill, unbound capping materials and stabilised capping materials as defined in Series 600 of the Specification (MCHW1), or hydraulically bound subbase layers (including stabilised soils) or granular subbase mixtures as defined in Series 800 of the Specification.

1.5 Two design approaches are presented. The first allows a limited number of 'Restricted Designs' to be applied for Foundation Classes 2 and 3 and is particularly intended for use on schemes of limited extent. The designs are conservative, making allowances for uncertainty in material performance and also construction level tolerances.

1.6 The second approach is for 'Performance Designs'. It covers all four Foundation Classes and provides more flexibility to the designer. Although a design method is provided with examples for the four foundation classes, the criteria for construction of an acceptable foundation must be the measure of its constructed performance. Until publication of this standard in the Design Manual for Roads and Bridges, all foundations designed in this category will be subject to approval under a Departure from Standards.

1.7 Performance Designs recognise that not all materials within a particular category in the Specification necessarily have equal engineering properties; for example rock mineralogy is known to affect strength and stiffness of an unbound layer. The resulting designs are minimum thickness requirements and level tolerances must be added when specifying construction thickness requirements. It is for use in connection with the 'Performance Specification' for foundation materials given in Draft Clauses 890 onwards in Section 5 of this Interim Advice Note.

1.8 The important role of drainage in achieving good long-term pavement performance is also highlighted and key requirements given.

1.9 Issues with regard to frost penetration are also covered.

1.10 A chapter on in-situ test methods is included for general information. The particular tests required by the Performance Specification are detailed in annexes.

Definitions

1.11 The following expressions used in this standard are defined below. Also see Figure 1.1.

Stiffness Modulus: The ratio of applied stress to induced strain.
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 with contributions from all underlying layers.
Layer Modulus: The 'stiffness modulus' assigned to a given foundation layer; for hydraulically bound materials this will take account of degradation due to cracking.
Element Modulus: The modulus of elasticity measured in a laboratory test; for hydraulically bound materials it is generally significantly greater than the layer modulus.

1.12 Great care should be taken not to confuse the layer modulus with the foundation surface modulus, values will not generally be similar. For example, a Class 2 foundation with 100MPa Foundation Surface Modulus may comprise an upper layer with a layer modulus of 150 MPa over a subgrade with a modulus of 50 MPa.

1.13 Hydraulically Bound Mixtures (HBMs) in this document have, in places, been separated into 'Cement Bound materials' where the primary binder for the aggregate is Cement and 'Other HBMs' where other primary binders may be used although some cement may also be part of the mixture.

Implementation

1.14 This Draft HD 25 shall be used forthwith on all schemes for the construction, improvement and maintenance of trunk roads including motorways, currently being prepared provided that, in the opinion of the Overseeing Organisation, this would not result in significant additional expense or delay. Design organisations should confirm its application to particular schemes with the Overseeing Organisation.

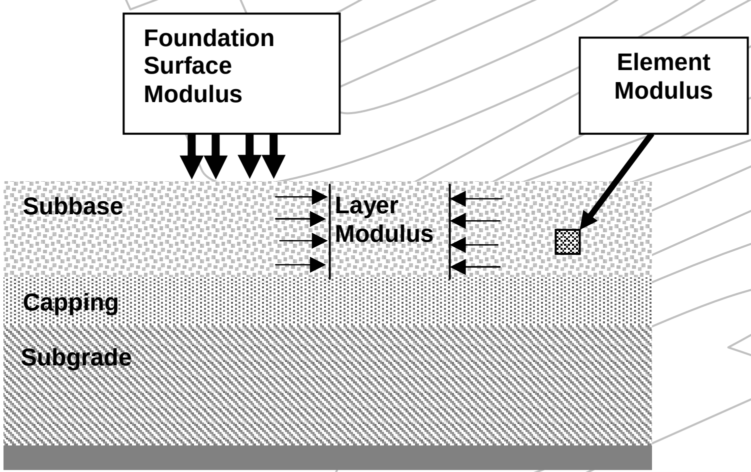


Figure 1.1 Modulus Definitions

Chapter 2. ROLE OF FOUNDATION

During Construction

2.1 The stresses in the foundation are relatively high during construction, although the number of stress repetitions from construction traffic is relatively low and traffic is not so channelised as normal traffic during the service life of the pavement.

2.2 During pavement construction, it is expected that loads will be applied to the foundation due to delivery vehicles, asphalt pavers and other construction plant. At any level where such loading is applied, the strength has to be sufficient to withstand the load without any damage occurring that might adversely influence the future performance of the pavement.

2.3 Foundation layers also have to be either protected from or of sufficient durability to withstand environmental effects from rain, frost, high temperature etc, without sustaining damage.

2.4 Damage may take the form of rutting or other uneven deformation, cracking in hydraulically bound mixtures (including stabilised soils) or other forms of degradation.

2.5 The designs given in this Draft HD 25, in conjunction with the tests and material restrictions given in the Specification, are intended to ensure that, under normal construction conditions, such damage is avoided.

2.6 The foundation also has to be of sufficient stiffness for the upper pavement layers to be placed and compacted to a high standard. This places a lower limit on the permitted foundation stiffness.

In Service

2.7 During the life of a pavement, its foundation has to be able to withstand large numbers of repeated loads from traffic. It is also likely to experience ingress of water, particularly as the upper pavement materials begin to deteriorate towards the end of their design lives.

2.8 It is essential that the Stiffness Modulus of the foundation, relating to the choice of Foundation Class, is maintained throughout the life of the pavement. If this is not the case, fatigue failure of the upper pavement may occur more rapidly than the designer has assumed.

2.9 It is also essential that excessive deformation does not accumulate within the foundation under repeated traffic loading, since this is a potential source of wheelpath rutting at the pavement surface.

2.10 In part, achieving the necessary foundation stiffness and avoiding foundation deformation depend on constructing and maintaining an effective drainage system – see Chapter 6; however, they also depend on appropriate foundation design and compliance with the Specification.

Chapter 3. CHARACTERISATION OF MATERIALS

General

3.1 The primary material characteristic used in foundation design is Stiffness Modulus. For subgrades, this property is difficult to measure reliably and consistently so historically in the UK California Bearing Ratio (CBR) has been used as an indirect measure. The approximate relationship between the two is explained in Paragraph 3.9. Both properties are referred to in this document. Generally for issues related to specification and measurement of subgrade, CBR is used and for issues related to design, stiffness modulus is used.

3.2 The Stiffness Modulus relating to the Foundation Class is the modulus applying in the long term (in-service condition).

3.3 Stiffness Modulus varies according to the stress conditions applying and for unbound and lightly bound materials also varies according to the moisture state of the material.

3.4 An unbound material which is confined by overlying pavement layers will often appear stiffer than the same material when unconfined. This means that the Stiffness Modulus apparent during construction will tend to be lower than the Stiffness Modulus expected in service.

3.5 Since a 'cracked' state is assumed for the in-service condition of hydraulically bound mixtures (HBMs), the initial 'uncracked' or 'less cracked' material at the time of construction may have a higher Stiffness Modulus.

3.6 An unbound material at high moisture content can appear significantly less stiff than a drier material. This means that the Stiffness Modulus apparent during construction will be significantly affected by the weather conditions applying at the time and the effectiveness of the drainage system, and often may not reflect the longer term in-service condition (at equilibrium moisture content).

3.7 Some of the HBMs permitted by the Specification are relatively slow curing. This means that the Stiffness Modulus apparent during construction will be significantly less than that achievable in the longer term. However, such materials are susceptible to damage, both during construction and in service, which may result in their expected long-term Stiffness Modulus being reduced.

Subgrade Characterisation

3.8 The primary measure of subgrade 'quality' for pavement design purposes is Stiffness Modulus since the stiffness of the subgrade is a major contributor to the stiffness of the foundation as a whole, which in turn defines Foundation Class.

3.9 The California Bearing Ratio (CBR) is traditionally used as an index test for subgrade strength, but it should be recognised that there is no definitive relationship between CBR and Stiffness Modulus (*E*). The following equation has been derived from work on certain UK soils (Powell et al, 1984) and may be used to give an estimate of Stiffness Modulus, acknowledging a degree of uncertainty.

$$E = 17.6\ (CBR)^{0.64} \quad \text{MPa}$$

3.10 The foundation designs in Chapter 4 and the example designs in Chapter 5 are intended to ensure adequate performance in both the short and long term. The lowest value of design subgrade Stiffness Modulus (normally measured by CBR) must therefore be used for the design process.

3.11 In selecting the design Stiffness Modulus value for the subgrade, consideration must be given to the likely moisture conditions applying during construction, assuming that appropriate precautions are taken against excessive disturbance, as demanded by the Specification.

3.12 The designer must also consider the likely long-term equilibrium moisture condition, making reasonable allowance for moisture ingress through the pavement, but assuming drainage is correctly installed as designed. For some soils, determination of the Moisture Condition Value (MCV) may also be useful, (further information in TRL Report 273(1997)).

3.13 The following techniques may be used to estimate subgrade Stiffness Modulus to assist in the design process. It is recommended that a range of tests is carried out for each area of the scheme. Some tests may not be appropriate for all types of soils.

a) CBR tests, either in situ or in the laboratory (refer to BS 1377(1990));
b) Dynamic Cone Penetrometer (DCP) testing in situ (refer to Annex A);
c) Dynamic Plate Test (DPT) testing in situ directly on the subgrade (refer to Annex B);
d) Falling Weight Deflectometer (FWD) testing of an existing pavement (refer to HD29 (DMRB 7.3.2));
e) Triaxial testing of unbound material laboratory specimens for stiffness (refer to BS EN 13286-7, 2004)
f) Springbox testing of laboratory specimens (refer to Annex C);
g) Estimation based on description and Plasticity Index (PI) using Table 3.1.

3.14 CBR values can be measured in the laboratory on recompacted specimens, in accordance with BS1377 (1990), during the site investigation stage and when the equipment and experience are available. Tests should be carried out over a range of conditions to reproduce, as far as possible, the conditions of moisture content and density which are likely to be experienced during construction and in the completed pavement. Cohesive soils should be compacted to not less than 5% air voids to reproduce the likely conditions on site. Equilibrium moisture content can be deduced from measurements on a suction plate (Black and Lister, 1979).

3.15 For design, the CBR must be estimated before construction commences. For fine-grained soils in-situ CBR values can however be measured for checking purposes in pits or in demonstration areas during construction. Equilibrium CBR values require the testing of existing pavements and HA44 (DMRB 4.1.1) suggests a suitable procedure. Plate bearing tests are necessary for coarse materials (BS5930, 1981 – see also Chapter 7).

3.16 In-situ cone penetrometer, DCP, DPT and FWD testing is particularly appropriate in major reconstruction or widening cases, where an existing road has been present over the same subgrade materials long enough for equilibrium moisture conditions to develop. However, caution must be exercised if the testing is carried out during the summer months when moisture levels are likely to be lower; in this case additional laboratory testing at higher moisture content may be advisable, especially if construction is likely to occur over winter months when it is assumed that the soil is wetter.

3.17 FWD testing of an existing pavement has the further advantage that the stress condition generated in the subgrade is close to that induced by a moving heavy goods vehicle.

3.18 Laboratory testing has the advantage that realistic conditions of moisture and 'disturbance' can be simulated. This is particularly appropriate when assessing materials to be used as embankment fill or capping.

3.19 The Springbox has the advantage that stress conditions approximately representative of those occurring beneath a pavement can be applied.

3.20 If Table 3.1 is to be used but the full information called for is not available, then certain assumptions can be made. The worst condition of a 'high water table' can be taken together with 'average construction conditions', (i.e. carried out according to the Specification). The pavements discussed in this Section vary between 'thick' and 'thin' constructions; interpolation between the CBR values relating to 'thick' and 'thin' construction is permitted. Background information on this table is available in HA44 (DMRB 4.1.1).

3.21 Where a Performance Design is used, the short-term CBR (Stiffness Modulus) must be checked during construction and appropriate action carried out if the design assumption is not satisfied. However, it is the designer's responsibility to evaluate the likely long-term value.

Soil	PI (%)	High Water Table						Low Water Table					
		Poor Construction Conditions		Average Construction Conditions		Good Construction Conditions		Poor Construction Conditions		Average Construction Conditions		Good Construction Conditions	
		Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick
Heavy Clay	70	1.5	2	2	2	2	2	1.5	2	2	2	2	2.5
	60	1.5	2	2	2	2	2.5	1.5	2	2	2	2	2.5
	50	1.5	2	2	2.5	2	2.5	2	2	2	2.5	2	2.5
	40	2	2.5	2.5	3	2.5	3	2.5	2.5	3	3	3	3.5
Silty Clay	30	2.5	3.5	3	4	3.5	5	3	3.5	4	4	4	6
Sandy Clay	20	2.5	4	4	5	4.5	7	3	4	5	6	6	8
	10	1.5	3.5	3	6	3.5	7	2.5	4	4.5	7	6	>8
Silt*	-	1	1	1	1	2	2	1	1	2	2	2	2
Sand (poorly graded)	-	---20---											
Sand (well graded)	-	---40---											
Sandy Gravel (well graded)	-	---60---											

* estimated assuming some probability of material saturating

Notes:
1. A high water table is 300mm below formation or subformation
2. A low water table is 1000mm below formation or subformation
3. A thick layered construction is a depth to subgrade of 1200mm
4. A thin layered construction is a depth to subgrade of 300mm

Table 3.1 Equilibrium Subgrade CBR Estimation

Subgrade with low CBR (CBR < 2½ % or Stiffness Modulus <30Mpa)

3.22 The minimum permitted subgrade Stiffness Modulus is 30MPa (approximately 2.5% CBR). Where a subgrade has a lower natural Stiffness Modulus it is considered unsuitable support for a pavement foundation since it would tend to deform under construction traffic. It must therefore be improved using one of the options given in the following paragraphs.

3.23 The material at the surface can be removed and replaced by a more suitable material; if the depth of relatively soft material is small, all can be replaced but it may only be necessary to replace the top layer. The thickness removed will typically be between 0.5 and 1.0m. Although the new material may be of good quality, the subgrade should be assumed to be equivalent to one of 30MPa Stiffness Modulus, in order to allow for movements in the soft underlying material. If capping is used, a total construction thickness of about 1.5m will often result. A geosynthetic may also be useful.

3.24 If the soil is cohesive, a lime treatment may be appropriate, subject to soil suitability being shown. Details of various soil treatments are given in HD44 (DMRB 4.1.1). The overlying pavement foundation should again be designed for a 30MPa subgrade.

3.25 If the soil is reasonably permeable, a deeper than normal drainage system may be considered, together with a system of monitoring the improvement expected. Design of the main foundation may then be based on whatever conditions are achievable in the time available.

Foundation Layer Characterisation

3.26 In order to make use of the performance based designs in Chapter 5, it is necessary to assign a long-term Stiffness Modulus to each foundation layer.

3.27 The following techniques may be used to estimate the Stiffness Modulus of pavement foundation materials.

a) Falling Weight Deflectometer testing (refer to HD29 (DMRB 7.3.2));
b) Dynamic Plate Testing of compacted trial layers (refer to Annex B). Note that lightweight test devices may not be suitable for thicker stiffer foundations;
c) Modulus of Elasticity testing of laboratory specimens of HBM mixtures in compression (refer to BS EN 13286-43:2003);
d) Springbox testing of laboratory specimens of unbound or lightly bound materials (refer to Annex C);
e) Estimation using the advice given in Table 3.2.

3.28 FWD derived stiffnesses are applicable in major reconstruction or widening schemes where an existing foundation layer is to be retained in the rehabilitated pavement. In most such cases the FWD will allow derivation of a composite Stiffness Modulus for the foundation as a whole, and it will neither be practical nor necessary to separate out the Stiffness Moduli of individual layers.

3.29 Use of the Dynamic Plate Test (DPT) has the advantage that the same test is called up for compliance assessment by the Performance Specification clauses. The test can be carried out either on a small trial site or in a suitably sized (minimum 1m square) container in the laboratory. The advantage is that the material can be compacted in a realistic manner. However, the modulus will be the ‘unconfined’ value, which for unbound materials is typically only about 60% of that expected when ‘confined’ beneath a finished pavement. Furthermore it will be affected by the substrate upon which the layer is compacted such that the material stiffness will be either low or high depending on whether the substrate stiffness is respectively low or high relative to the material layer stiffness. Test applicability is restricted to unbound or lightly bound materials.

3.30 The only permitted laboratory test for Modulus of Elasticity of HBM mixtures is the Compression Test, one of three described in BS EN 13286-43. It is appropriate for those materials which have sufficient strength to remain intact during the test. However, the resulting Stiffness Modulus is that applying to a small intact and very well compacted specimen of material, whereas the condition in situ may be less dense and is likely to include significant cracking due to shrinkage and temperature fluctuation. For these reasons, no more than 20% of the measured laboratory Stiffness Modulus may be taken for long-term design in the case of cement bound mixtures. For other HBMs, no more than 10% of the laboratory value should be used unless well-documented evidence demonstrates that other values can be justified and in such circumstances, a Departure from Standards will be required. This assumes that no abnormal damage is caused to the material during construction.

3.31 The derivation of a long-term in-situ design Stiffness Modulus of HBM from laboratory stiffness testing using the factors in the previous paragraph does not guarantee that the Surface Modulus requirements of the Performance Specification (see Chapter 5) will be achieved in practice.

3.32 Springbox testing has the advantage that it allows a small sample of unbound or lightly bound material to be tested under approximately realistic stress conditions and under appropriate (normally soaked then drained) moisture conditions.

3.33 The values given in Table 3.2, which are derived principally from experience of FWD test data, are for general guidance only and are suited to preliminary design when detailed choice of material has not been made. In reality, there is a considerable range of possible Stiffness Modulus for each material. For example, the Stiffness Modulus of a Type 2 subbase is not necessarily less than that of a Type 1, but the value given in the table recognises the greater uncertainty inherent in a Type 2 material. The long-term stabilised capping modulus takes account of likely deterioration during the life of a pavement.

Material	Condition	Estimated Stiffness Modulus - Design Value (MPa)
Granular capping	-	75
Stabilised capping	Early life (e.g. 2 months)	300
	Long-term	100
Subbase Type 3	-	140
Subbase Type 2	-	130
Subbase Type 1	-	150
Subbase Type R	-	180
Hydraulically Bound Subbase (all Classes)	-	Not suitable for estimation

Table 3.2 Indicative Stiffness Moduli for Pavement Foundation Layers

Chapter 4. RESTRICTED DESIGNS

Applicability

4.1 The designs given in this chapter are intended for use in cases where it is inappropriate to carry out the range of compliance testing required by the Performance Specification, owing to the size of the scheme. For this reason they are conservative and recognize the greater uncertainty present in material properties when subjected to more limited testing.

4.2 Designs are not included for Foundation Class 4 since it is considered essential to measure the properties of such a foundation during construction to give adequate assurance that the appropriate long-term Stiffness Modulus will be achieved.

4.3 The designs given for Foundation Class 3 are restricted to those using a cement bound granular mixture (CBGM A or CBGM B C8/10) subbase, acknowledging the greater uncertainty present with other HBMs and the consequent need for testing to be carried out.

4.4 The designs for Foundation Class 2 allow the use of granular subbase Types 1, 3 and Cat B or CBGM A or CBGM B, C3/4 or C5/6. Granular subbase Type 2 may only be used for design traffic levels up to 5msa.

4.5 Designs are included for Foundation Class 1, but these are not permitted for use on Trunk Roads including Motorways. This is because of the increased likelihood of damage during construction. Assurance against this would require performance related testing to be carried out.

Restricted Designs

4.6 The subgrade design strength or Stiffness Modulus must be estimated in accordance with one or more of the techniques detailed in Paragraph 3.13. The foundation design must be based on the lower of the short-term CBR and the predicted long-term equilibrium CBR value. Where the natural subgrade has a CBR value less than 2½ % (Stiffness Modulus less than 30MPa), it must be improved as described in paragraphs 3.22 to 3.25.

4.7 The CBR value on which the design is based must be verified by testing in each area of the site before foundation construction starts. Required thicknesses for Restricted Designs are shown in Figures 4.1 and 4.2.

4.8 Class 1 foundation designs, for non Trunk Road pavements only, may make use of any of the capping options given in Table 6/1 in Series 600 of the Specification (MCHW 1). Finished surface of the foundation must meet the criteria for subbase in the Specification Series 700 (MCHW 1).

4.9 For Class 2 foundations, there are four different design options depending on whether unbound or bound subbase is chosen and whether a capping is used.

4.10 The CBR scales provided in Figures 4.1 and 4.2 are for consistency with previous standards. The relationship assumed is that given in paragraph 3.9.

4.11 Thicknesses are to be rounded up to the nearest 10 mm.

4.12 Thicknesses derived for these 'Restricted' Designs may be specified as construction thicknesses. Allowance for permitted level tolerances has already been made in deriving the designs.

Design Examples 1

Subgrade Stiffness Modulus for design estimated as 40MPa (approximately 3.5% CBR); the following Restricted Design options exist:

Foundation Class 1 (for non Trunk Road pavements):
- Figure 4.1 gives 465mm of capping
- Round up to 470mm for design

Foundation Class 2 (Types 1, 2, 3 or CAT B subbase):
- Figure 4.1 gives 385mm
- Round up to 390mm for design

Foundation Class 2 (CBGM A or B, C3/4 or C5/6):
- Figure 4.1 gives 305mm
- Round up to 310mm for design

Foundation Class 2 (Types 1, 2, 3 or CAT B subbase on capping):
- Figure 4.2 gives 515mm in total and 228mm of capping
- Round to 290mm subbase and 230mm capping for design

Foundation Class 2 (CBGM A or B, C3/4 or C5/6, on capping):
- Figure 4.2 gives 487mm in total and 228mm of capping
- Round to 260mm subbase and 230mm capping for design

Foundation Class 3 (CBGM A or B C8/10):
- Figure 4.1 gives 305mm
- Round up to 310mm for design

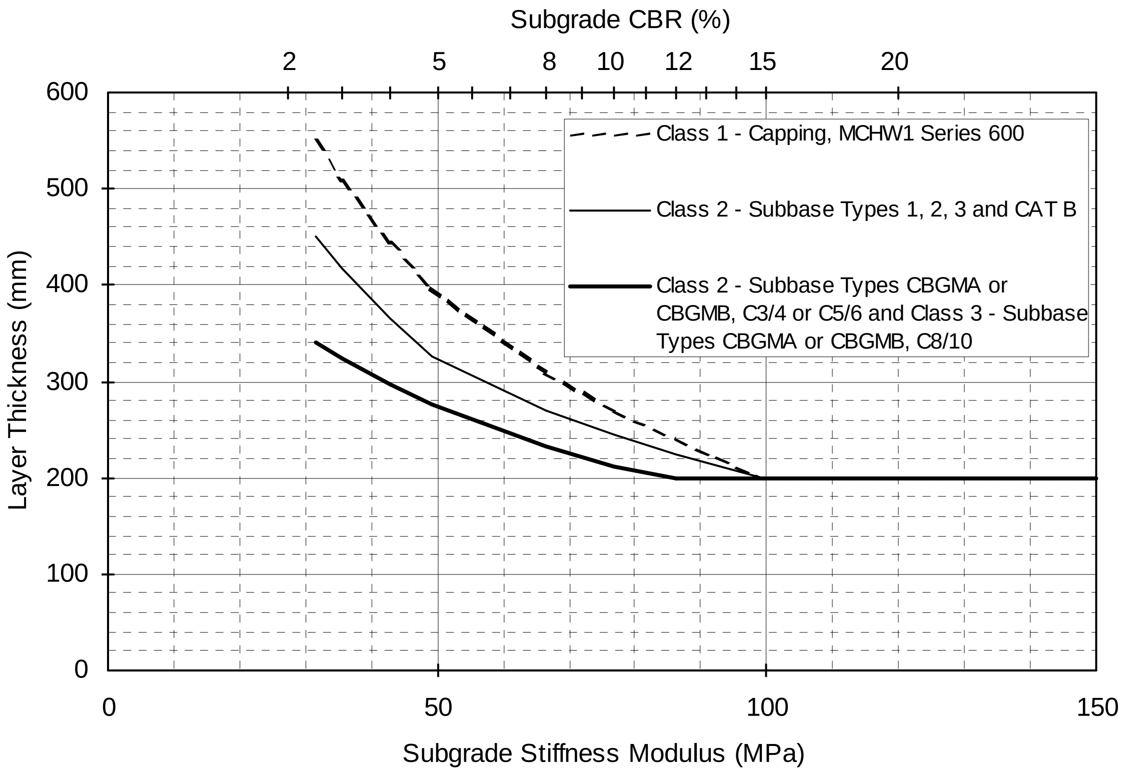


FIGURE 4.1 Restricted Design Options – Subbase or Capping only

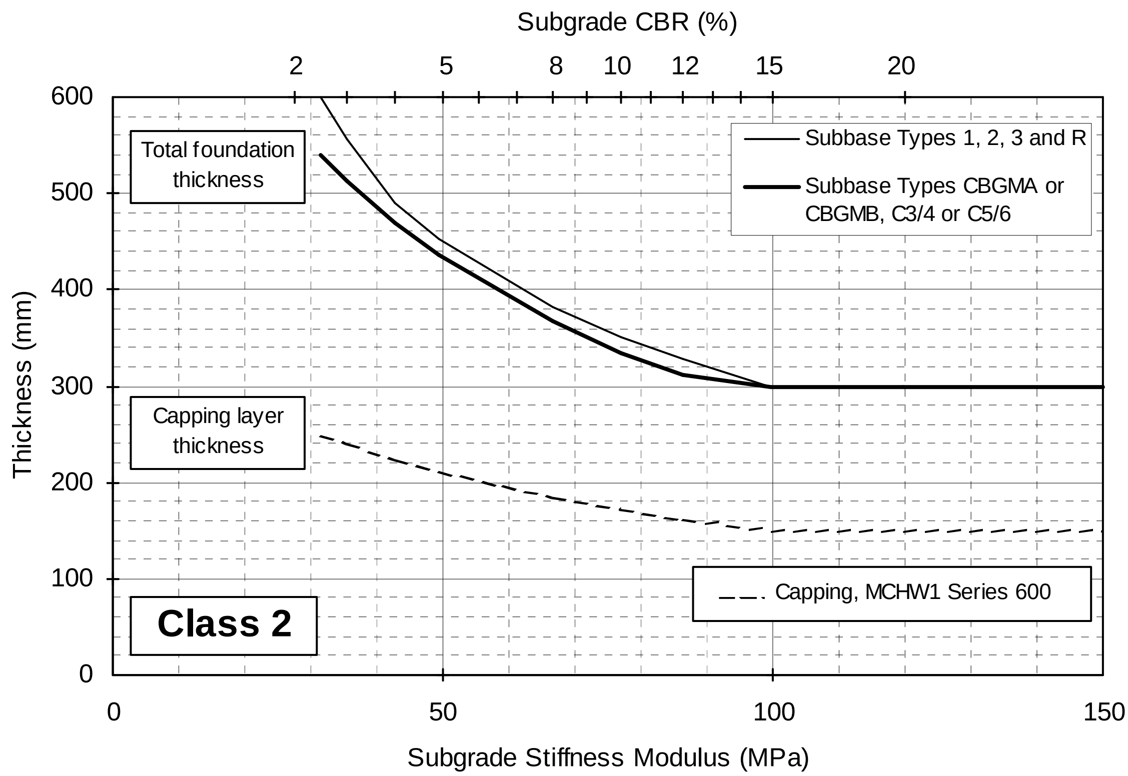


FIGURE 4.2 Restricted Design Options – Class 2 Subbase on Capping

Chapter 5. PERFORMANCE DESIGNS

Overview of Design Approach

5.1 The intention of a performance based foundation design, known here as a 'Performance Design', is to enable the efficient use of materials. As a consequence of producing an engineered solution, sufficient testing needs to be carried out on the materials comprising the pavement foundation, both in the laboratory and in situ, to provide assurance that the properties required by the design assumptions will be achieved, both during construction and in service.

5.2 Although a design method is provided with examples and formulae for the four foundation classes, the criteria for construction of an acceptable foundation must be the measure of its constructed performance. Until publication of this standard in the Design Manual for Roads and Bridges, all foundations designed in this category will be subject to approval under a Departure from Standards. This chapter must be used in conjunction with the 'Performance Specification' presented in Draft Clauses 890 to 896 in Section 5 of this Interim Advice Note.

5.3 Performance Designs are carried out based on an assessment of the Stiffness Modulus of each component foundation material and thicknesses are calculated using a multi-layered linear elastic model. The basis of the modelling is indicated in Figure 5.1.

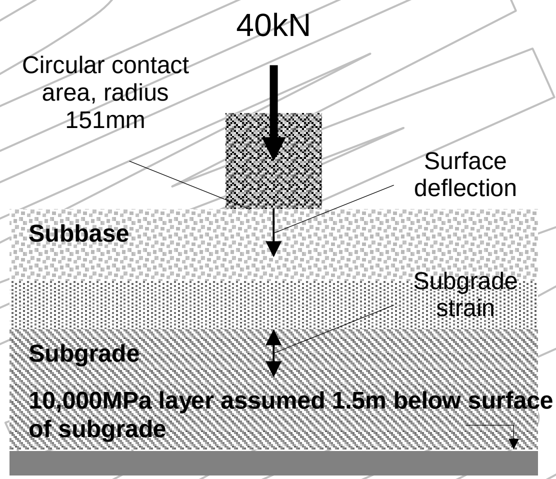


Figure 5.1 Basis of Foundation Designs

5.4 The designs presented in this Part have been derived from a consideration of three different criteria (Chaddock and Roberts, 2006), namely:

- Protection of the subgrade during construction;
- Provision of adequate support stiffness to the overlying pavement layers;
- Practical minimum layer thicknesses for construction.

The practical minimum thicknesses have been taken as 150mm for all materials in a Class 1 or 2 foundation, 175mm for subbase materials in a Class 3 Foundation and 200mm for materials in a Class 4 Foundation. The reason for the increase in minimum thicknesses for bound materials relates to their relatively greater sensitivity to variations in thickness. It is of high importance that these materials should not crack during construction beyond the levels assumed in the design.

5.5 Soil cement materials as described in Clause 840 of the Specification (MCHW 1) must not be used in any structural layer of a Foundation Class 4.

Design Thicknesses

5.6 As for standard designs, the minimum subgrade Stiffness Modulus permitted is 30MPa (approximately 2.5% CBR). Where the natural subgrade has a Stiffness Modulus less than 30MPa (approximately 2.5% CBR), it must be improved as described in paragraphs 3.22 to 3.25.

5.7 There are a large number of possible designs for each combination of subgrade Stiffness Modulus and Foundation Class.

5.8 The designs given in this Chapter are based on the method described in Chaddock and Roberts (2006). The example designs are shown in Figures 5.2 to 5.5 for single material type (either capping or subbase) designs and Figure 5.6 for Foundation Class 2 subbase on capping designs and give examples of design thicknesses for a range of possible material layer Stiffness Moduli. Interpolation between the lines shown is permitted. Equations for these example designs have been provided following Figure 5.6. Whatever design method is used, the acceptability of the foundation is to be based on its performance following construction measured by the required testing protocol.

5.9 Examples of designs with subbase on capping for Foundation Classes 3 and 4 have not been presented in this Chapter, as these would not usually show any advantage over the subbase only designs. They may be worthwhile in practical terms to enable construction plant to lay the foundation and the necessary compaction to be achieved in the designed layers.

5.10 The thicknesses determined using the Performance Design examples in this Chapter are minimum thickness values. Allowance for permitted level tolerances must be added when specifying construction thicknesses and layer thicknesses are then to be rounded up to the nearest 10mm. The completed surface of all foundations must meet the criteria in the Specification Series 700 (MCHW 1).

Design Examples 2

Subgrade Stiffness Modulus for design estimated as 35MPa (approximately 3% CBR)

Options covered by Figures 5.2-5.6:

Foundation Class 1 (Capping only; Figure 5.2):
- 460mm of 50MPa material
- 390mm of 75MPa material
- 365 (→370) mm of 100MPa material

Foundation Class 2 (Subbase only; Figure 5.3):
- 320mm of 150MPa material
- 290mm of 200MPa material
- 265 (→270) mm of 250MPa material

Foundation Class 2 (Subbase on 75MPa capping; Figure 5.6):
- 475 (→480) mm total; → 240mm of 150MPa material + 240mm capping
- 410mm total; → 170mm of 200MPa material + 240mm capping
- 392 (→400) mm total; → 160mm of 250MPa material + 240mm capping

Foundation Class 3 (Subbase only; Figure 5.4):
- 315 (→320) mm of 500MPa material
- 247 (→250) mm of 750MPa material
- 216 (→220) mm of 1000MPa material
- 175 (→180) mm of 2000MPa material

Foundation Class 4 (Subbase only; Figure 5.5):
- 435 (→440) mm of 1000MPa material
- 300mm of 2000MPa material
- 245 (→250) mm of 3000MPa material
- 200mm of 5000MPa material

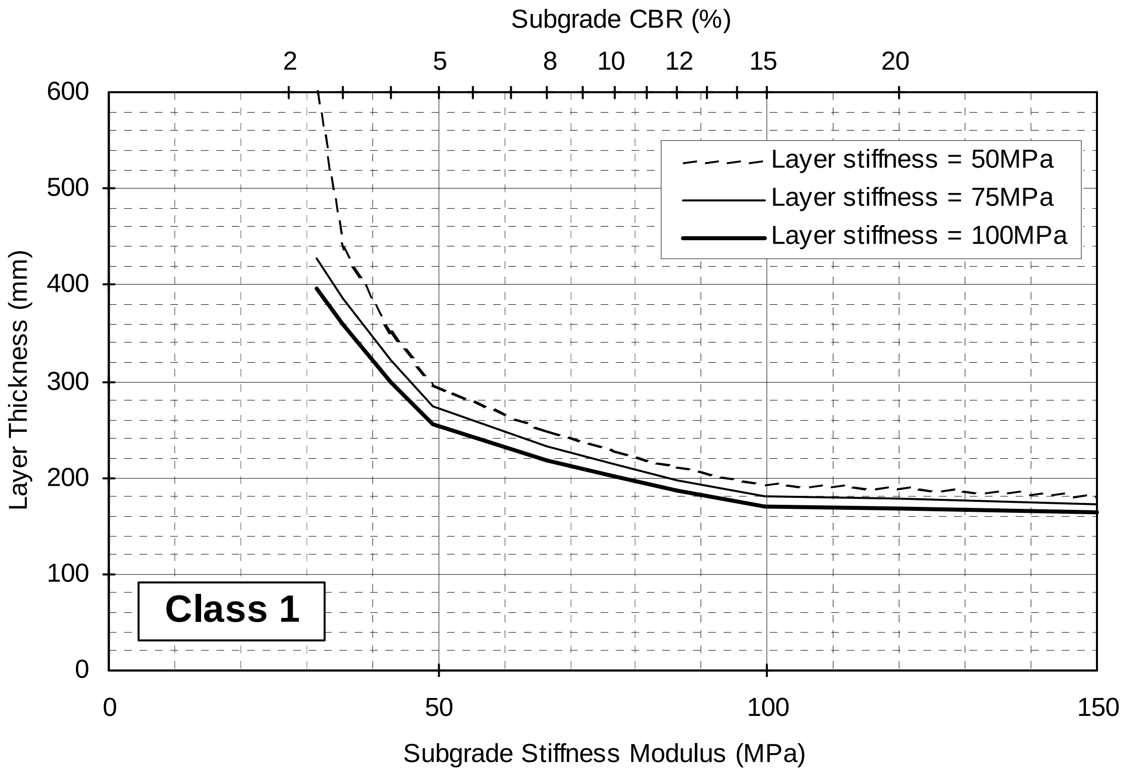


FIGURE 5.2 Class 1 Designs – Single Foundation Layer

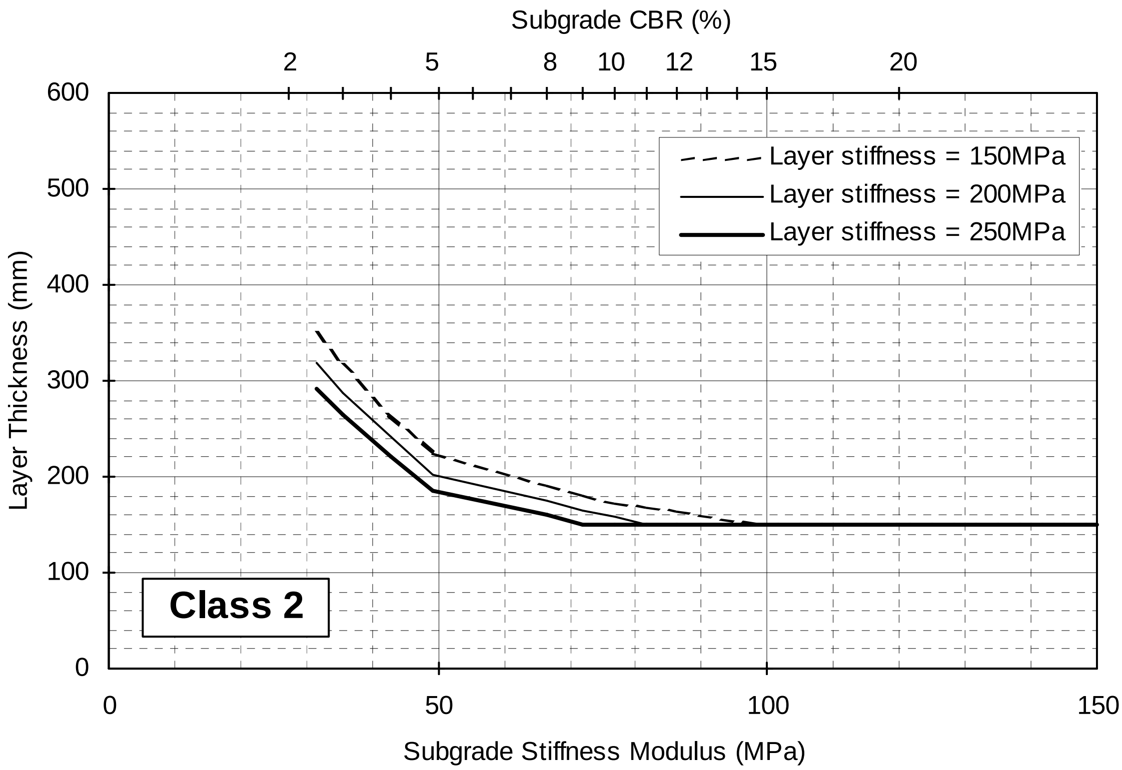


FIGURE 5.3 Class 2 Designs – Single Foundation Layer

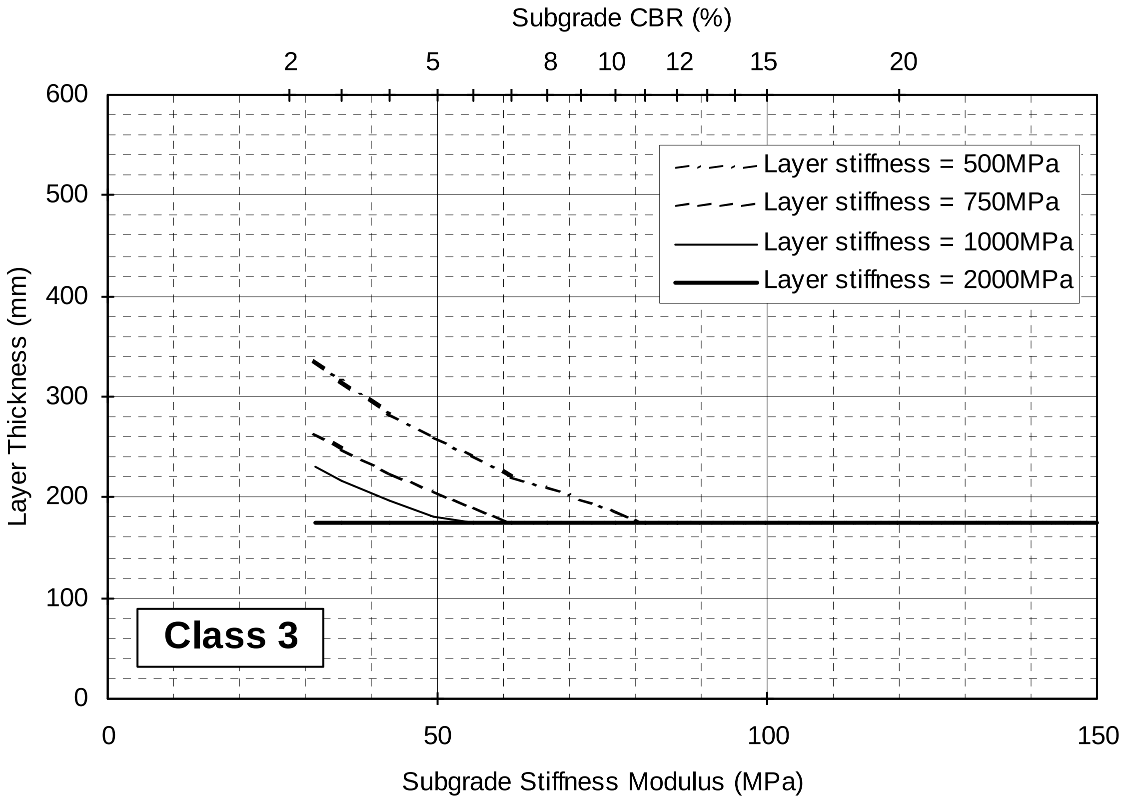


FIGURE 5.4 Class 3 Designs – Single Foundation Layer

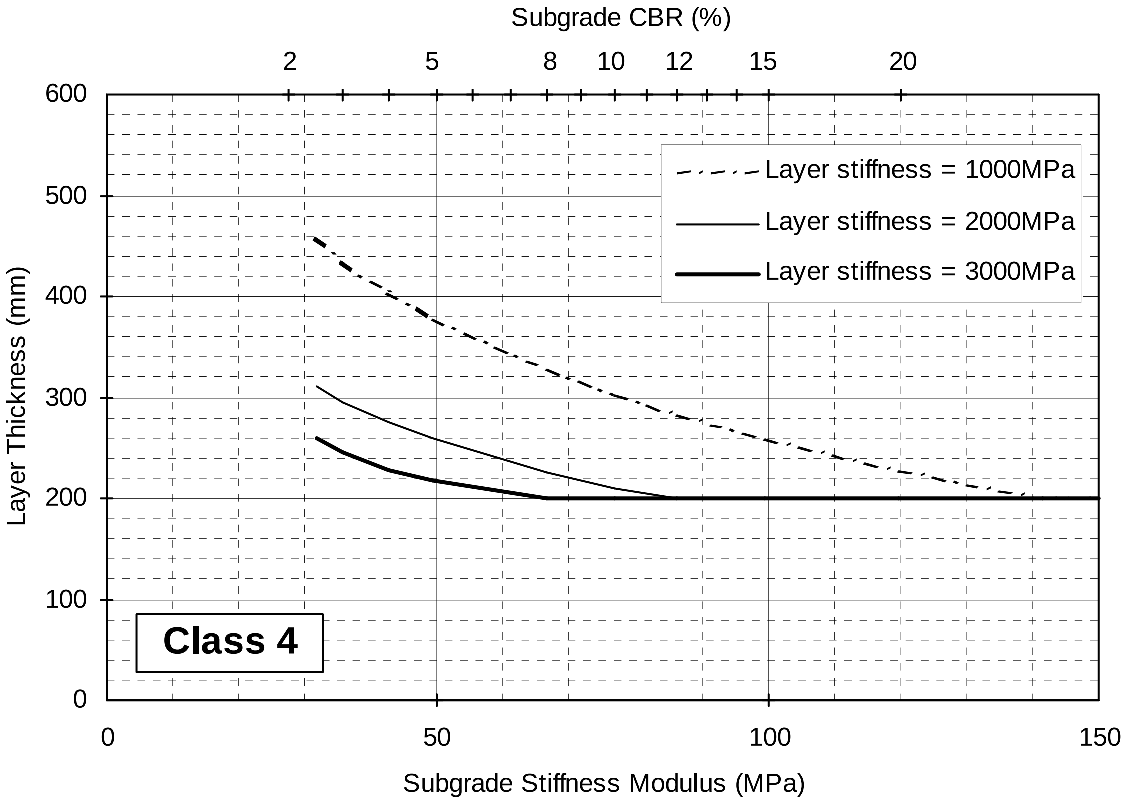


FIGURE 5.5 Class 4 Designs – Single Foundation Layer

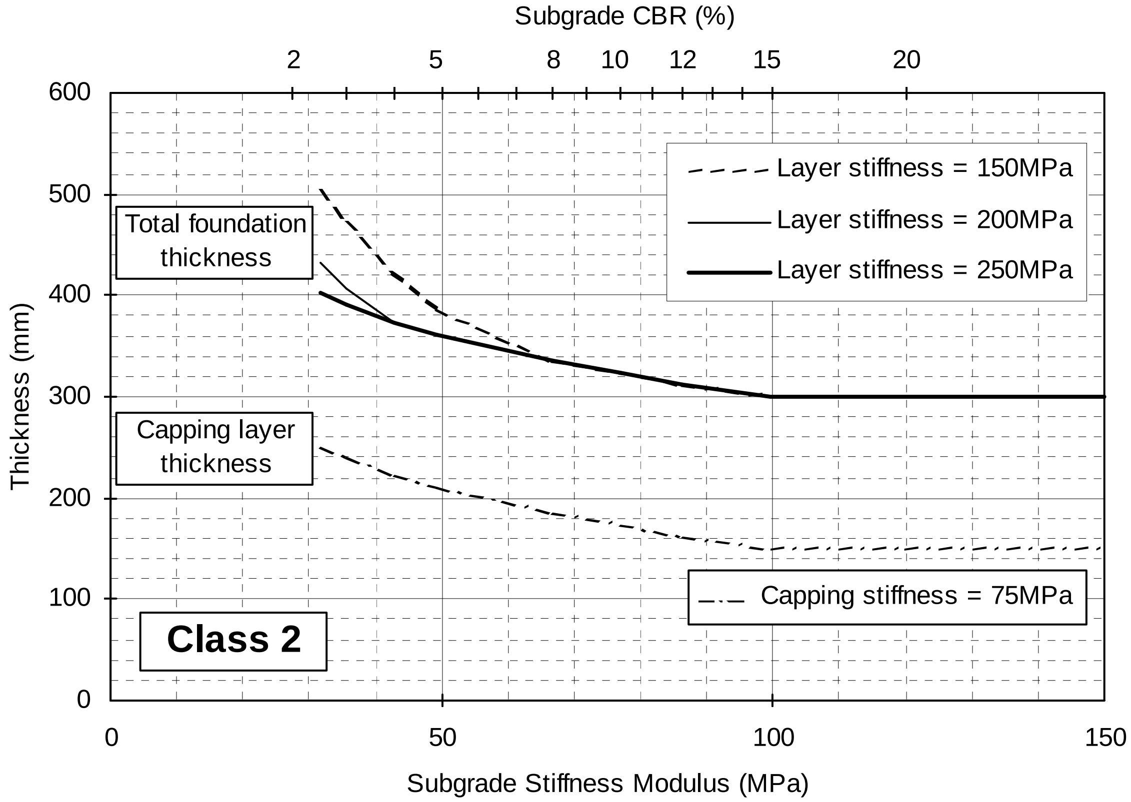


FIGURE 5.6 Class 2 Designs – Subbase on Capping

Design Equations

The following equations derived in the same way as the design charts (Figures 5.2 to 5.6) provide an alternative method to calculate foundation layer thicknesses.

The following abbreviations have been used:

H_{Cap} (mm) is capping thickness, E_{Cap} is capping layer stiffness (MPa)
H_{SB} (mm) is sub-base thickness, E_{SB} is sub-base layer stiffness (MPa)
CBR is the California bearing ratio of the subgrade (%).
(S) and (D) denotes whether the thicknesses where determined using the subgrade strain criterion (S) or the deflection criterion (D).

Subbase or Capping only designs

Foundation Class 1 **(Capping only)**

For subgrade CBR >2½ % ≤5%

$$H_{Cap}(S) = 1.845 \times 10^{3}.E_{Cap}^{-0.250}(1 - 0.395.E_{Cap}^{-0.025} Ln(CBR))$$

For CBR >5% ≤15%

$$H_{Cap}(S) = 1.016 \times 10^{3}.E_{Cap}^{-0.214}(1 - 0.230.E_{Cap}^{-0.026} Ln(CBR))$$

Mininum value for $H_{Cap} = 150mm$

Valid range: CBR 2½ to 15%
Capping layer modulus 55 to 100MPa

Foundation Class 2

For subgrade CBR >2½ % ≤ 5%:

$$H_{SB}(S) = 9.25 \times 10^{2}.E_{SB}^{-0.202} - 69.\ Ln(CBR))$$

For subgrade CBR >5% ≤30%

$$H_{SB}(S) = 2.85 \times 10^{3}.E_{SB}^{-0.341}(1 - 0.316.E_{SB}^{0.021} Ln(CBR))$$

Minimum value for $H_{SB} = 150mm$

Valid range: CBR 2½ to 30%
Subbase layer modulus 150 to 250 MPa

Foundation Class 3

$$H_{SB}(D) = 8.44 \times 10^{3}.E_{SB}^{-0.480}(1.0 - 0.261.E_{SB}^{-0.008}.Ln(CBR))$$

Minimum value for $H_{SB} = 175mm$

Valid range: CBR 2½ to 30%
Subbase layer modulus 500 to 2,000MPa

Foundation Class 4

$$H_{SB}(D) = 1.53 \times 10^4 . E_{SB}^{-0.4833} (1.0 - 0.234 E_{SB}^{-0.025} . Ln(CBR))$$

Minimum value for $H_{SB} = 200mm$

Valid range: CBR 2½ to 30%
Subbase layer modulus 1,000 to 5,000 MPa

Subbase on Capping Design

Foundation Class 2

Capping thickness:

$$H_{Cap} = 3.01 \times 10^2 - 56.Ln(CBR))$$

Minimum value for $H_{Cap} = 150mm$

Subbase thickness:

$$H_{SB}(S) = 8.27 \times 10^4 .(0.4123 Ln(E_{Cap}) - 1) E_{SB}^{-(0.2075+0.1933 Ln(E_{Cap}))} - 21.39 . E_{Cap}^{1.745} . E_{SB}^{(0.271-0.335 Ln(E_{Cap}))} Ln(CBR))$$

Minimum value for $H_{SB} = 150mm$

Valid range: CBR 2½ to 30%
Capping layer modulus 50 to 100 MPa
Subbase layer modulus 150 to 250 MPa

Analytical Designs

5.11 Alternative design options may be calculated analytically using a multi-layer linear elastic analysis package. In such cases, the designer must show that all the design criteria given in the following paragraphs (subgrade strain, surface deflection and practical thickness limits) are met.

5.12 Protection of the subgrade during construction (short term) is based on the calculation of the maximum vertical strain in the subgrade under the action of a standard 40kN wheel load travelling at the top of foundation level, as shown in Figure 5.1. Trafficking at lower levels is permitted, but only so long as the deformation limits given in the Performance Specification are not exceeded.

5.13 Limits on the maximum permitted subgrade strain vary according to the Stiffness Modulus of the subgrade, as shown in Figure 5.7. These limits are based primarily on the criteria used in Powell et al (1984) but adjusted for reasons given in Chaddock and Roberts (2006).

5.14 Adequate support is defined by calculating the deflection of the foundation under the action of a wheel load (or Dynamic Plate load) at top of foundation level, also shown in Figure 5.1. The deflection under a given load can be equated to a Surface Modulus for the foundation as a whole. The following are the maximum deflections permitted for each Foundation Class under a standard wheel load (40kN load over a 151mm radius loaded area).

- Class 1 – 2.96mm
- Class 2 – 1.48mm
- Class 3 – 0.74mm
- Class 4 – 0.37mm

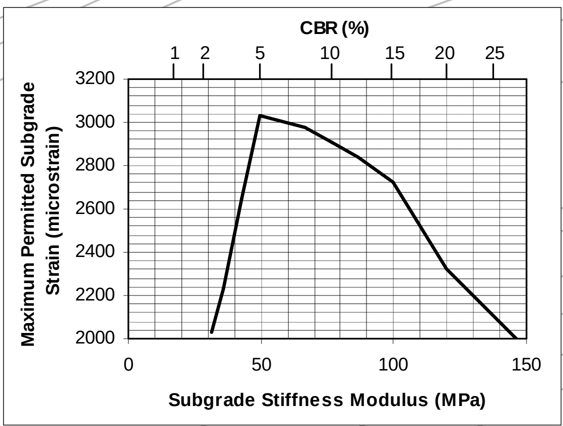


Figure 5.7 Subgrade Strain Limits

5.15 The limiting thicknesses given in paragraph 5.4 apply to all Performance Designs, including analytical designs.

Design Example 3

Subgrade Stiffness Modulus for design estimated as 50MPa (approximately 5% CBR)

Design a composite Class 4 foundation with 200mm of HBM upper subbase of design Stiffness Modulus 1500MPa over a HBM lower subbase of Stiffness Modulus 500MPa.

Limits applying:

1) Minimum lower subbase thickness = 150mm
2) Maximum surface deflection under a standard 40kN load = 0.37mm
3) Maximum vertical compressive strain in the subgrade = 3030με

Theoretical requirements:

1) 150mm minimum
2) 193mm of lower subbase gives 0.37mm surface deflection
3) 0mm of lower subbase gives < 3030με vertical compressive strain in subgrade

Resulting design:

Take greatest figure = 193 (→200) mm of HBM lower subbase.

Performance Specification Overview

5.16 This section is included in order to explain the way in which the Performance Specification operates and its interaction with the Performance Designs presented here. Figure 5.8 is a summary flowchart of the sequence of procedures. A complete flowchart is given in Annex D.

5.17 The Performance Specification requires a number of checks, tests and measurements to be carried out during construction of the pavement foundation. The principal tests called for are as follows:

- Either CBR or Surface Modulus at top of exposed subgrade, immediately prior to placement of overlying layers
- Surface Modulus and material density in each layer at each stage of foundation construction, in a designated Demonstration Area
- Material density in each layer at each stage of foundation construction, throughout the Works
- Surface Modulus at top of foundation level, immediately prior to construction of an overlying layer, throughout the works.

Material properties are to achieve the values as required by the Specification (MCHW 1) or the stated design values.

5.18 Table 5.1 gives Target and Minimum Stiffness Moduli for each Foundation Class. Definitions of fast and slow curing are given in Series 800 of the Specification and relate to binder type and content. Surface Modulus is measured using the Dynamic Plate Test (refer to Annex B). As explained in Chapter 3, the results from this test will generally be different from the long-term design value. The results are also expected to contain significant scatter due to subgrade variability and because foundation layer materials generally have not been through the same level of production controls as plant mixed bound materials used in the pavement layers. The Specification takes both these effects into account by defining a 'Target' value and an absolute 'Minimum' value. The Target values for unbound materials will therefore be lower than the expected long-term stiffness under confined conditions. For bound materials, on the other hand, the value in the short term will tend to be higher than the design value because of the deterioration expected during the life of the pavement.

Quantity	Surface Modulus (MPa)			
	Class 1	Class 2	Class 3	Class 4
Foundation Class (Stiffness Modulus used in Design)	**50**	**100**	**200**	**400**
Target	Unbound: **40** Bound: **50**	Unbound: **80** Bound: **100**	Fast curing: **300** Slow curing: **150**	Fast curing: **600** Slow curing: **300**
Minimum	**25**	**50**	Fast curing: **150** Slow curing: **75**	Fast curing: **300** Slow curing: **150**

Table 5.1 Top of Foundation Surface Modulus Requirements

5.19 For Demonstration Areas, the designer must specify the age at which Surface Modulus testing is to be carried out. This will normally be 24 hours in the case of unbound mixtures, 7 days in the case of cement bound mixtures and 28 days in the case of other HBMs. Normally, testing in the main works is carried out immediately prior to the foundation being covered by pavement layers. If the required foundation surface stiffness modulus will not be achieved in the main works because of the construction programme adopted then a Departure from the values given in Table 5.1 may be sought.

Subgrade Assessment

5.20 It is the responsibility of the designer to quote either a Target CBR or a Target Stiffness Modulus against which the subgrade material encountered on site can be judged.

5.21 In setting these targets, the designer should be aware of the differences likely between the different methods of CBR assessment, in particular between laboratory testing in a confining mould and in-situ where no such confinement is present but where a surcharge may be specified. If a Stiffness Modulus target is specified, the difference between the confined and unconfined properties of most soils as outlined in paragraph 3.29 should be borne in mind.

5.22 Where the Target CBR or Surface Modulus value is not achieved, the Performance Specification makes provision for re-evaluation of the design or remedial action to the subgrade or foundation where necessary.

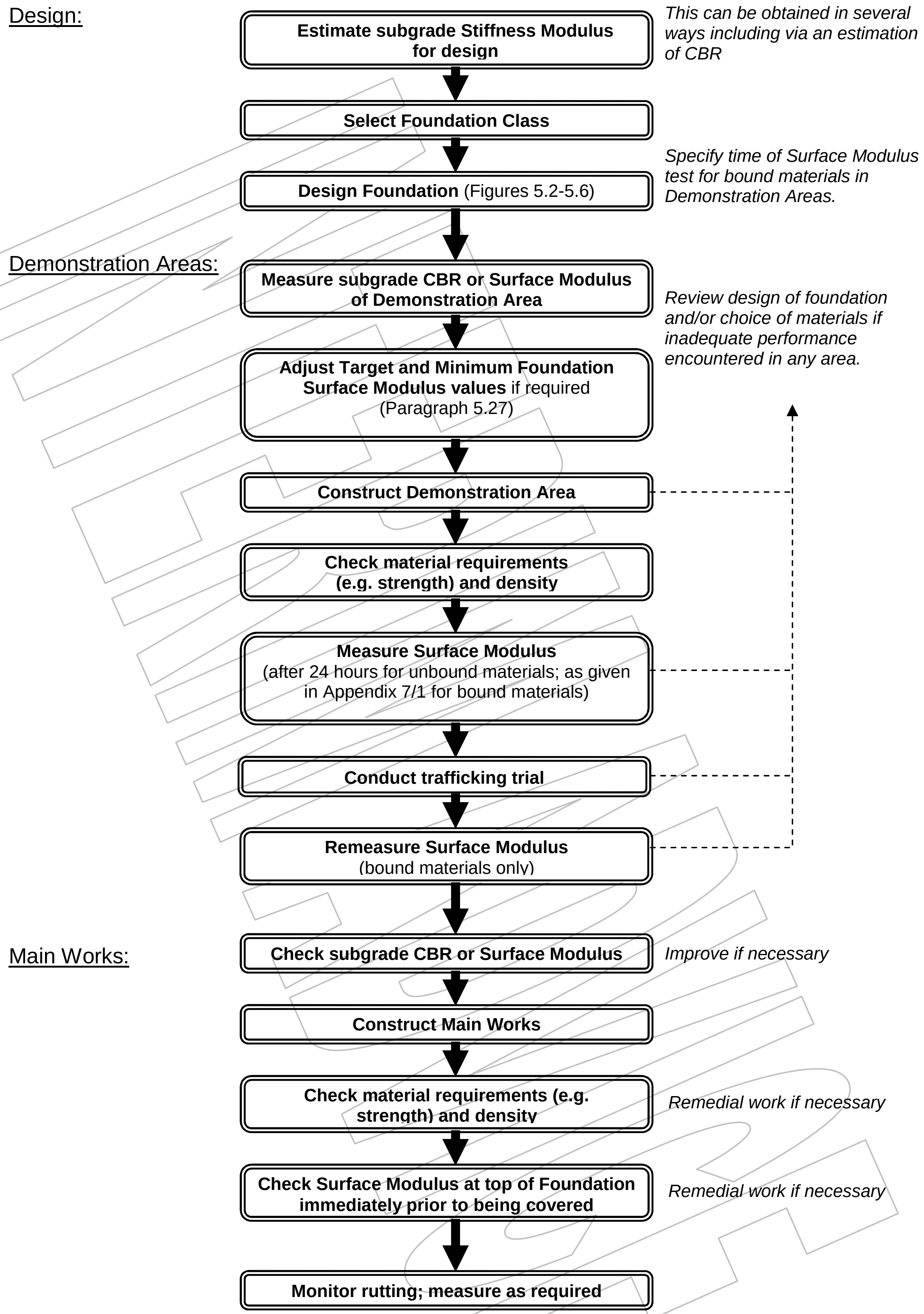


FIGURE 5.8 Summary Flowchart of Performance Design and Specification

Foundation Assessment – Demonstration Areas

5.23 The reason for Demonstration Areas is so that material production and layer constructability are proved prior to construction of the Main Works. This involves checking compliance with material specification (e.g. gradation limits, compressive strength), compaction (i.e. density) and Stiffness Modulus.

5.24 The Performance Specification requires that each stage of construction (i.e. any level at which compaction is carried out) is subject to a Demonstration Area and that the following tests are carried out:

- Either subgrade CBR or Stiffness Modulus
- Density after compaction
- Laboratory tests on samples of HBM material, in accordance with the requirements of the relevant material specification clauses
- Surface Modulus measurement on the layer subject to Demonstration

5.25 The density and strength test requirements are to prove compliance with the relevant material and construction specifications.

5.26 At intermediate foundation levels, the Surface Modulus measurements are for information only, since the Performance Specification requirement is at top of foundation level. However, it is intended that these measurements, in conjunction with those on the subgrade beneath the Demonstration Area, provide warning of any potential problem and the information required to address that problem, reducing the danger of encountering inadequate performance at top of foundation level.

5.27 At top of foundation level, the Surface Modulus requirement is defined according to Foundation Class and the required values are given in Table 5.1. The Demonstration Area gives the opportunity to check the value achieved in the context of the actual subgrade CBR or Stiffness Modulus at that location for increased assurance of the correctness of the design. To make the adjustment that allows for a higher actual subgrade CBR (or stiffness modulus) at the demonstration area than that used as a basis for the design, the required foundation stiffness modulus (both target and minimum) is multiplied by the following factor:

$$\text{Factor} = 1 + k \times \text{Ln (Subgrade Ratio)}$$

where 'Subgrade Ratio' is the actual subgrade CBR or Stiffness Modulus divided by the design value and k = 0.28 when working with CBR or 0.43 when working with Stiffness Modulus.

5.28 Failure to meet the required Target and/or Minimum values in a Demonstration Area does not in itself constitute non-compliance, but it warns of the likelihood of non-compliance when tested immediately prior to construction of an overlying layer. It also warns of the possibility of non-compliance in the Main Works, especially where the subgrade is less stiff than in the Demonstration Area.

5.29 Trafficking trials are required to be carried out in Demonstration Areas at top of foundation level. The relevant requirements of the Performance Specification (See Section 5 of this IAN) are

- a limit on rut depth, applying throughout the Works, which depends on foundation thickness and whether the foundation is bound or unbound, and
- a requirement that the Surface Moduli measurements after trafficking are greater than the target and minimum values in Table 5.1.

It is intended that Demonstration Areas are used to establish whether there is any likelihood of significant ruts or stiffness loss developing. Trafficking trials are also strongly advised at any stage of foundation construction where significant construction traffic and/or when adverse weather conditions are likely to occur.

Foundation Assessment – Main Works

5.30 Material strength testing of HBMs and density measurement for all foundation materials are required throughout the Main Works to prove compliance with material specification and compaction clauses.

5.31 Surface Modulus testing at top of foundation level is required immediately prior to being covered by pavement layers (i.e. no more than 24 hours prior to pavement layer construction) and must meet the requirements given in Table 5.1 or those values as amended by Departure from Standard if bound materials are tested before the ages given in Paragraph 5.19.

5.32 In cases where the foundation is to remain exposed for a long period, an earlier check is advised (but is not required by the Performance Specification) to give assurance that no problem is likely.

5.33 The rut limit given in the Performance Specification is not accompanied by any specific testing requirement. Measurements will therefore only be taken where visual appearance leads to the suspicion that the limit has been exceeded.

5.34 The following two examples are provided to demonstrate the use of Performance Designs.

Example 4. Use of Performance Specification: Class 2 Foundation

Design

A Designer estimates the short term CBR for a site as 4% and the long term CBR as 7%. Taking the lower of the two values, the design is based on 4% CBR or approximately 43MPa.

The Designer wishes to use a Type 1 subbase complying with the Specification Series 800 over a locally won capping material. The Designer estimates that the Stiffness Modulus of the Type 1 is 150MPa and the Stiffness Modulus of the capping material is 75MPa. Using a layered linear elastic analysis, the Designer estimates that the design requires 211mm of capping and 123mm of subbase. As the minimum thickness permissible for Type 1 is 150mm, he adjusts the design to 200mm of capping and 150mm of Type 1 subbase (total 350mm). Construction thicknesses are selected taking into account permitted level tolerances.

Demonstration Area

The Demonstration Area is constructed on site in order that the design assumptions can be checked. Using Table 5.1 the requirements at the top of the foundation for a Class 2 unbound foundation are a Target Value of 80MPa and a Minimum Value of 50MPa (assuming the design CBR is correct).

The subgrade in the Demonstration area is checked and is found to be at the design CBR of 4%. Construction of the Demonstration Area proceeds to prove the production and placement process for the capping and subbase material. The density and material properties are checked against the requirements of the relevant clauses of Specification Series 600 and 800. The constructed layer thicknesses comply with the design requirements. After a specified time period Dynamic Plate Tests are carried out at top of foundation and the results compared to the Target and Minimum values. It is found that the Demonstration Area does not achieve the Target Value of 80MPa. The Designer asks for the locally won capping material to be tested in the laboratory using the Springbox. The results show that the capping has a stiffness of 50MPa rather than 75MPa that had been assumed. The design is recalculated to be 185mm of capping and 185mm of subbase (total 370mm). A second Demonstration Area is constructed and the Target and Minimum Values are achieved. A trafficking trial is then undertaken to check deformation susceptibility.

Main Works

The values from the Dynamic Plate Tests are satisfactory and the design is taken forward for the Main Works. The Target and Minimum Values are those given in Table 5.1 (i.e. 80MPa and 50MPa).

During the Main Works, subgrade CBR must be assessed every 60m. If the CBR falls below the value assumed in the design (i.e. 4%) appropriate remedial action must be taken. Density and material properties of the subbase and capping must comply with the appropriate clauses of Specification Series 600 and 800.

Example 5. Use of Performance Specification: Class 4 Foundation

Design

A Designer estimates the short term CBR for a site as 5% and the long term CBR as 8%. Taking the lower of the two values, the design is based on 5% CBR or approximately 50MPa.

The Designer wishes to use a slag bound mixture (SBM) complying with the Specification Series 800 as subbase. A laboratory investigation has been carried out using the static stiffness modulus apparatus after curing the SBM for 28 days at 40^{o}C (BS EN 13286-43). The results gave an average Modulus of Elasticity for the SBM of 10,000MPa. The Designer takes 10% of this value for his calculations (i.e. 1,000MPa) to take account of degradation and likely in-situ density (see Para 3.30). Using Figure 5.5, the Designer estimates that a layer thickness of 380mm of SBM is required. Construction thicknesses are selected taking into account permitted level tolerances.

Demonstration Area

The Demonstration Area is constructed on site in order that the design assumptions can be checked. Using Table 5.1 the requirements at the top of the foundation for a Class 4 slow curing foundation are a Target Value of 300MPa and a Minimum Value of 150MPa (assuming the design CBR is correct).

The subgrade in the Demonstration area is checked and is found to have a CBR of 7% following a recent dry spell. Therefore the top of foundation Target Value and Minimum Value must be adjusted, using Paragraph 5.27:

Adjusted Target Value $= 300 \times [1+0.28\times\ln(7/5)]$
$= 328$MPa

Adjusted Minimum Value $= 150 \times [1+0.28\times\ln(7/5)]$
$= 164$MPa

Construction of the Demonstration Area proceeds to prove the production and placement process for the SBM. The constructed layer thicknesses comply with the design requirements. Testing is undertaken as required by the Specification Series 800 for density and compressive strength or tensile strength and stiffness.
After a specified time period (generally 28 days for slow-curing mixtures) Dynamic Plate Tests are carried out at top of foundation. A trafficking trial is then undertaken to check deformation susceptibility and stiffness loss. Dynamic Plate Tests are repeated and the results compared to the adjusted Target and Minimum values and the results compared to the adjusted Target and Minimum values. The results are found to be satisfactory.

Main Works

The design is taken forward for the Main Works. Having proved the adequacy of the design assumptions in the Demonstration Area, the Target and Minimum Values revert back to those given in Table 5.1 (i.e. 300MPa and 150MPa).
During the Main Works, subgrade CBR must be assessed every 60m. If the CBR falls below the value assumed in the design (i.e. 5%) appropriate remedial action must be taken. Density and material properties of the SBM must comply with the appropriate clauses of Specification Series 800.

Chapter 6. DRAINAGE AND FROST

Drainage

6.1 It is of vital importance to keep water out of the subbase, capping and subgrade, both during construction and during the service life of the pavement.

6.2 During construction every effort should be made to protect the subgrade by constructing foundation layers before rain can soften it. The Performance Specification provides a means of quantifying whether the actions, or omissions, of the contractor have contributed to the degradation of the foundation. Installing deep subgrade drains and sloping the formation to shed water could also prevent problems due to excess water not only during construction but also in the completed pavement.

6.3 In the long term, infiltration of water through the pavement should be minimised by good design, construction and maintenance and an escape route for water that succeeds in entering the foundation should also be provided (Figure 6.1).

6.4 Wherever possible, the foundation drainage should be kept separate from pavement run-off drainage in all new construction and in reconstruction work. There should always be a down-slope route from the subbase to the drain. Further details are given in HD44 (DMRB 4.1.1).

6.5 In reconstruction and widening projects it is necessary to maintain the continuity of drainage from existing capping and subbase materials to adjacent new materials, using appropriate thicknesses and crossfalls.

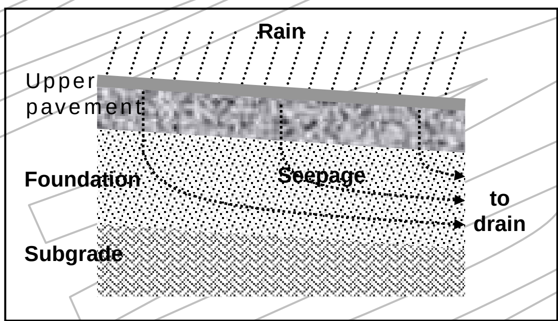


FIGURE 6.1 Foundation Drainage

6.6 A granular aggregate drainage blanket (Specification Series 600) of thickness at least 150mm and not more than 220mm may be used to drain water that infiltrates through the pavement. In order to stop pore clogging by fines from other adjacent layers, geosynthetic separators may be used when those layers are constructed of fine soil or fine capping. The drainage layers so formed may be treated as capping for structural design purposes.

6.7 When the water table is high and especially when the subgrade is moisture sensitive with a Plasticity Index < 25, slot drains as detailed in the Highway Construction Details, can be beneficial. The drain is placed below the bottom of capping (or subbase if no capping is used), to drain any water that may permeate through these materials. Deeper drains can be beneficial in drying and strengthening these, and some other soil types.

6.8 It is useful to check the speed at which water can drain out of a granular subbase as a result of ingress due, perhaps, to a cracked or damaged pavement or a surcharging drain. A procedure for calculating this is given in Jones and Jones (1989a) along with a means of estimating ingress through cracks in the bound layers. On this basis it may be possible to specify a permeability value. Care should be taken to ensure that the value required does not conflict with any limitations imposed by a specified grading, see Jones and Jones (1989b).

6.9 If it is necessary to determine the permeability of the subbase or capping material, this must be done on the full grading, at the correct density under a low hydraulic head. A suitable permeameter and procedure is described in HA41 (DMRB 4.1.3).

6.10 Drainage of the subbase may be omitted only if the underlying materials (capping, subgrade) are more permeable than the subbase, and the water table never approaches the underside of foundation closer than 300mm.

Frost Protection

6.11 For routine cases all material within 450mm of the road surface shall be non frost-susceptible as required by the Specification Series 700 and tested according to BS812: Part 124 (1989).

6.12 This requirement can be over-severe in some places (e.g. coastal areas) and may be reduced to 350mm if the Mean Annual Frost Index (MAFI) of the site is less than 50. Advice on the frost index for any particular area may be obtained from the Met Office and further information from TRL Report RR45 (1986).

6.13 The frost index, is defined as the product of the number of days of continuous freezing and the average amount of frost (in degrees Celsius) on those days.

Chapter 7 IN-SITU TESTING

7.1 The two reasons for testing pavement foundation layers are to check compliance with the Specification during construction and in pavement assessment. Also see HD30 (DMRB 7.3.3). This chapter introduces the different test devices, including those specified in the Performance Specification (Draft Clauses 890 to 896). It is for general information and advice only and does not comprise part of the Overseeing Organisation’s requirements although some tests are included in the Performance Specification.

Density Testing (Figure 7.1)

7.2 The sand replacement test involves excavating and weighing material removed from a small hole and refilling the hole with a uniform sand. The volume of the hole is calculated from the mass of sand used. The water replacement test is similar except that a plastic liner filled with water is used to determine the volume. The equipment for either is transported by vehicle. The tests are time-consuming (up to 1 hour) and thus expensive, and operator sensitive. However, they do give a direct means of measuring density, which can then be compared with values obtained in the laboratory or in trials.

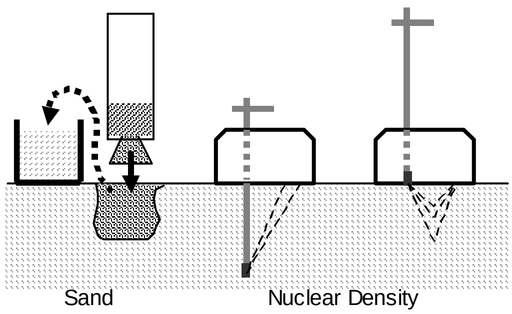


FIGURE 7.1 Density Testing Apparatus

7.3 An alternative is nuclear density testing. A radiating source is applied to the material. The amount of radiation detected decreases in proportion to the bulk density of the material between source and receiver. To determine the moisture content another source sends out radiation intercepted by hydrogen atoms in the test material. The dry density is calculated from the bulk density and the moisture content. If the material being tested is carbonaceous, care is required in interpreting the moisture content and dry density obtained. Testing is extremely rapid (less than 5 minutes) and a reading may be repeated readily. The machine is portable. Calibration is required for each soil or aggregate that is to be tested.

7.4 It should be noted that two modes of nuclear density are possible. The quickest and easiest is ‘backscatter’ mode, which is influenced only by the density of the top 100-150mm of material and is most heavily influenced by material very near the surface. ‘Transmission’ mode provides a more representative density result. Other portable non-destructive test methods are now available.

California Bearing Ratio

7.5 The California Bearing Ratio (CBR) test involves the insertion of a 50mm diameter plunger into the ground surface at a rate of 1mm per minute, whilst the load is recorded. Surcharge rings can be placed around the plunger to simulate an overburden. A laboratory version of the same test is available in which the sample tested is constrained within a 152.5mm diameter mould. The load at penetrations of 2.5 and 5mm is compared with the result for a standard aggregate and the ratio given as a percentage. The test is not suitable for coarse aggregates because the plunger and aggregate particles will be of similar size. The test measures neither Stiffness Modulus nor Shear Strength directly – giving a somewhat combined measure of both. It takes around half an hour on site and between 1 and 2 hours in the laboratory and there is a large body of experience of its use.

7.6 There are several variants on the CBR test; laboratory, field, with surcharge, saturated etc. In the context of this document the laboratory CBR with a surcharge to simulate the appropriate vertical overburden stress of the case being considered should be taken as the standard method used. The appropriate moisture content and wetting or drying condition is also important. Laboratory CBR results for granular soils are often higher than those in the field due to mould confinement effects. The test is penetration controlled and so does not model the stress level imposed by traffic. CBR is an empirical test and is best measured as initially intended although other test devices such as the cone penetrometer, the Dynamic Cone Penetrometer and the Plate Bearing Test can be used to determine approximate estimates of CBR.

Cone Penetrometers

7.7 Various sizes of static field cone penetrometer for insertion into a test material exist for the rapid approximate assessment of CBR. In general they only cover a fairly low CBR range and are therefore applicable to soft and medium fine grained subgrades.

7.8 The Dynamic Cone Penetrometer (DCP – Figure 7.2) is similar to other field cone penetrometers except that it is driven into the ground under the action of a weight dropped onto an anvil. It is therefore suited to stronger and coarser materials than other penetrometers. The rate of penetration into the ground can then be related approximately to CBR. The standard equipment and its interpretation are given in Appendix A.

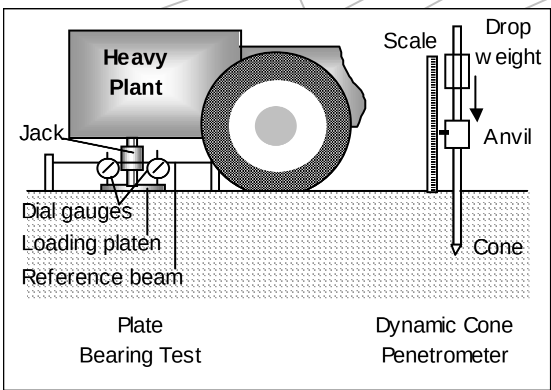


FIGURE 7.2 Plate Bearing Test and DCP

Plate Bearing Test (Figure 7.2)

7.9 This test is described in detail in BS1377 (1990) and involves placing a circular plate on a foundation layer. Its use for testing is described in the Specification Series 600 (MCHW 1). For use on pavement foundation materials, there is no need for removal of surface material or for non-vibratory compaction.

7.10 An approximate empirical relationship with CBR can be made as follows:

$$CBR = 6.1 \times 10^{-8} \times (k_{762})^{1.733} \quad \%$$

where k_{762} is the modulus of subgrade reaction, defined as the applied pressure under the loading platen divided by the displacement (normally 1.25mm) with a plate of 762mm (30 inch) diameter. Figure 7.3 allows conversion for other plate sizes.

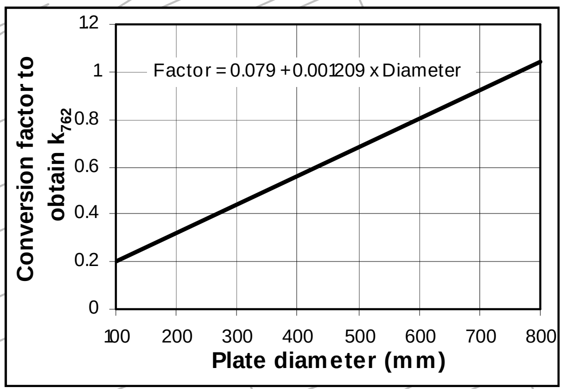


FIGURE 7.3 Conversion Factors for Smaller Plate Sizes

7.11 The test is laborious to set up and carry out and requires a lorry or excavator to provide the reaction force. The speed of loading is slow giving poor simulation of traffic loading.

Dynamic Plate Tests

7.12 These tests involve placing a circular plate on a foundation layer and dropping a weight onto a platen. Usually a damping mechanism is incorporated to control the loading time. The area of loading and applied stress may be readily controlled. Appendix B gives details of the standard test and its interpretation. The Falling Weight Deflectometer (FWD) measures the stress applied and the resulting deflection of the foundation at several radial positions up to several metres from the loading plate. Interpretation is generally in terms of the Stiffness Modulus of each foundation layer but is not straightforward and should be carried out by an experienced pavement engineer. If only the central deflection is used to determine a Surface Modulus for the foundation, then interpretation can be carried out as for other Dynamic Plate tests. Lightweight dynamic plate apparatus may not be suitable to test thicker stiffer foundations.

Chapter 8 REFERENCES

1979
Black W.P.M and Lister N.W: "The strength of clay fill subgrades, its prediction in relation to road performance". Report LR 889, TRRL

1984
Powell W.D, Potter J.F, Mayhew H.C and Nunn M.E, "The Structural Design of Bituminous Roads". Report LR1132; TRRL

1989
Jones, H.A and Jones, R.H, 1989(a). Horizontal permeability of compacted aggregates, Proc. 3rd Int'l Symp. Unbound Aggregates in Roads (UNBAR3), Univ. of Nottingham, pp 70-77.

Jones, R.H and Jones, H.A, 1989(b). Granular drainage layers in pavement foundations. Proc. 3rd Int'l Symp. Unbound Aggregates in Roads (UNBAR3), Univ. of Nottingham, pp 55-69.

1997
Matheson G.D and Winter M.G, Use and application of the MCA with particular reference to glacial tills. TRL Report 273, Transport Research Laboratory, Crowthorne.
2000

Chaddock, B.C.J and Schoepe, B, 2000. The hydraulic and structural behaviour of unbound granular sub-base layers, Proc. 5th Int'l Symp. Unbound Aggregates in Road Construction (UNBAR5), Univ. of Nottingham, pp 297-305.

2005
Edwards, J.P., Thom, N.H. Fleming, P.F. and Williams, J., 2005. "Accelerated Laboratory Based Mechanistic Testing of Unbound Materials within the Newly Developed NAT Springbox". Transportation Research Record. Issue Number 1913. Journal of the Transportation Research Board. ISBN 0309093864

2006
Chaddock, B.C.J and Roberts, R. Road foundation design for major UK roads. Unpublished Report UPR/IE/028/06. Transport Research Laboratory, Crowthorne.

.

ANNEX A: DYNAMIC CONE PENETROMETER

Equipment Specification

A.1 Dynamic Cone Penetrometer testing of subgrade (or fill) materials must be carried out using a device incorporating an 8kg steel drop weight falling vertically through 575mm and making contact with a relatively light steel anvil. This anvil shall be rigidly attached, via steel rods (less than 20mm diameter), to a 20mm diameter 60^{o} steel cone, which is thus driven vertically into the ground.

FIGURE A.1 The Dynamic Cone Penetrometer

A.2 Exceptionally, other dynamic cone equipment may be used providing it has been calibrated against equipment meeting the requirements of Paragraph A.1, on the type of materials present.

Test Procedure

A.3 For subgrade assessment the result for each test shall be expressed as the 50th percentile penetration rate in millimetres per blow between 50mm and 300mm of penetration from top of subgrade level. However, if the penetration rate falls to less than 2mm per blow, then the test should be aborted and a further test attempted nearby.

Calculation of CBR

A.4 Cone penetration rate expressed as mm/blow can be converted to a CBR value using the following relationship developed by the Transport Research Laboratory:

$$\text{Log}_{10}\,(\text{CBR}) = 2.48 - 1.057 \times \text{Log}_{10}\,(\text{mm/blow})$$

Usage

A.5 The Dynamic Cone Penetrometer may also be used through many other materials, particularly in a composite foundation, to measure both their CBRs and layer thicknesses. However, this strength measure will not normally be specified for materials overlying the subgrade since results are highly dependent on particle size and can therefore, without calibration to specific materials, be misleading. The DCP can be a useful additional measure for assessment of Demonstration Areas, and is particularly valuable for evaluating the properties of an existing pavement foundation.

ANNEX B: DYNAMIC PLATE TEST

Equipment Specification

B.1 Surface Modulus testing shall be carried out using a Dynamic Plate Test device, which has been properly calibrated to the manufacturer's specification; this includes the Falling Weight Deflectometer (FWD) as well as lightweight devices. The FWD may be more appropriate for the higher Foundation Classes.

B.2 The equipment shall be capable of delivering a load pulse of peak magnitude in the range 4-15kN of total duration 15-60msecs to a rigid circular plate of 300mm diameter. Both the applied load and the transient deflection, measured directly on the tested surface, shall be measured. The deflection measurement transducer shall be capable of measuring deflections up to 2000 microns.

FIGURE B.1 Dynamic plate Test

B.3 If any equipment is proposed which does not fully comply with these requirements, it may be permitted at the discretion of the Overseeing Organisation, provided that it is carefully calibrated against other compliant equipment, for the specific types of material and layer thickness encountered on the site. This calibration would normally be carried out as part of the Demonstration Area testing.

Testing Procedure

B.4 The peak stress applied during each test shall be within the range 50-200kPa. A peak stress of 100kPa should normally be targeted, unless the deflection measurement typically falls outside the range 100-1000 microns. For very stiff foundations, it may be necessary to increase the applied stress in order to achieve a realistically measurable deflection.

B.5 At each test point, 3 initial seating drops shall be carried out, to bed the plate into the surface, except that this may be reduced to 1 seating drop in the case of tests on bound layers. Three further drops shall then be carried out. The results (measured load and deflection) from the last set of three drops shall be averaged to give the Surface Modulus applicable to that test point.

Surface Modulus Computation

B.6 The Surface Modulus shall be computed at each point tested, using the following formula:

$$E = \frac{2 \times (1 - \nu^2) \times R \times P}{D}$$

where: E = Surface Modulus (MPa)
ν = Poisson's Ratio (default = 0.35)
R = Plate Radius (= 150mm)
P = Contact Pressure (kPa)
D = Deflection (microns)

ANNEX C: SPRINGBOX

Equipment Specification

C.1 The Springbox equipment (Edwards et al, 2005a) is a suitable tool for testing unbound granular and weak hydraulically bound mixtures. It consists of a steel box containing a cubical sample of material, of edge dimension 170mm, to which a repeated load can be applied over the full upper surface. One pair of the box sides is fully restrained and the other is restrained through elastic springs, giving a wall stiffness of 10-20kN per mm.

C.2 The equipment shall include a system by which a realistic level of compaction can be applied to the test material, by means of a vibrating hammer.

C.3 The equipment shall also include a facility to introduce water to the sample or drain water from its underside.

C.4 Loading takes the form of repeated vertical load applications of controlled magnitude at a frequency of at least 1Hz and no greater than 5Hz. Load capacity shall be equivalent to a vertical stress of at least 150kPa.

C.5 Measurements of both vertical and horizontal (spring restrained) deflection shall be made, with at least 2 measurement transducers for each measure. In the case of vertical deflection measurement, the equipment shall allow the transducers to make direct contact with the specimen, via holes in the loading platen.

Test Procedure – Stiffness Modulus

C.6 At least 3 test specimens should be manufactured to derive a Stiffness Modulus of a particular pavement foundation material.

C.7 Unless justification is provided for use of an alternative regime, specimens shall be soaked by applying water to the surface for at least 96 hours and then allowed to drain for a further 24 hours before testing. A shorter soaking period may reasonably be permitted when testing relatively permeable materials.

C.8 Each test specimen shall be subjected to at least 100 load applications at the chosen stress level. Multiple stress level applications are permitted on a single sample, provided that the stress level increases throughout the testing sequence.

C.9 It is recommended that a minimum seating stress of 10kPa and a vertical cyclic stress level of 35kPa is used for deriving a short-term Stiffness Modulus applicable to direct trafficking or testing in-situ; a cyclic stress level of 150kPa is considered suitable to simulate the long-term confined conditions applying beneath a completed pavement construction. Neither stress condition replicates the real situation perfectly and the recommendations made here are based on current experience (Edwards et al, 2005a).

FIGURE C.1 Springbox

C.10 The Stiffness Modulus shall be computed from deflection measurements averaged from the last 10 load pulses.

Stiffness Modulus Computation

C.11 The following calculation, which assumes a coefficient of wall friction of 0.38, shall be used to determine Stiffness Modulus unless justification can be provided for the use of an alternative assumption.

Step 1 $\nu = [-b + \sqrt{(b^2 - 4ac)}]/2a$

where:

ν = Poisson's Ratio
$a = 0.928\sigma_1\varepsilon_1 - 1.452\sigma_1\varepsilon_2 + 0.312k\varepsilon_1\varepsilon_2 - 0.928k\varepsilon_2^2$
$b = 0.738\sigma_1\varepsilon_1 - 0.452\sigma_1\varepsilon_2 - 0.688k\varepsilon_1\varepsilon_2 - 1.308k\varepsilon_2^2$
$c = 0.19\sigma_1\varepsilon_1 + \sigma_1\varepsilon_2 - k\varepsilon_1\varepsilon_2 - 0.38k\varepsilon_2^2$
ε_1 = Vertical Strain (positive)
ε_2 = Horizontal Strain (negative)
σ_1 = Vertical Stress (kPa)
k = Spring stiffness (kPa for 100% strain)

Step 2 $\sigma_3 = \nu\,(1.19\,\sigma_1 + k.\varepsilon_2) / (1 - 0.19\,\nu)$

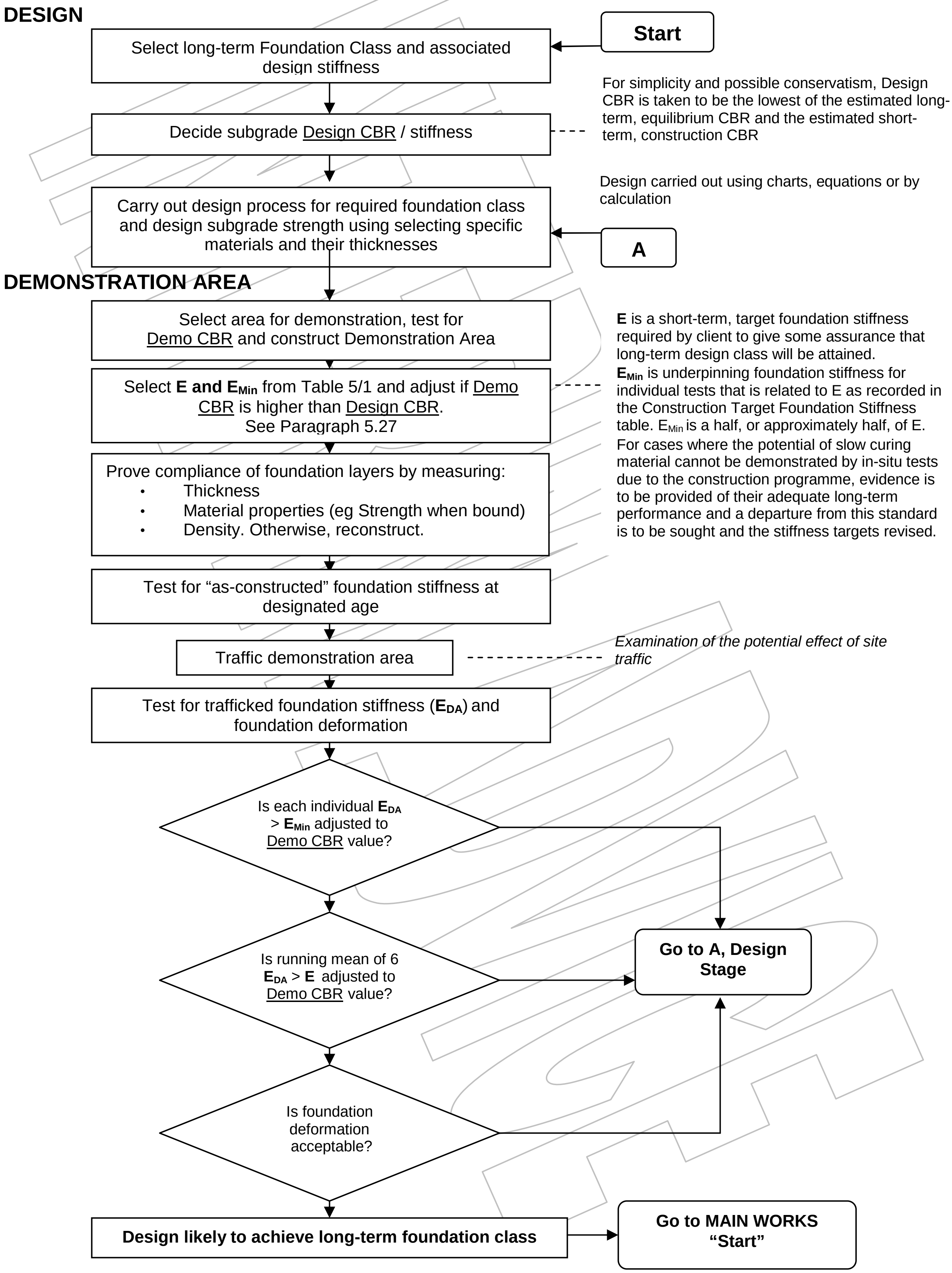
where: σ_3 = Horizontal Stress (restrained direction)

Step 3

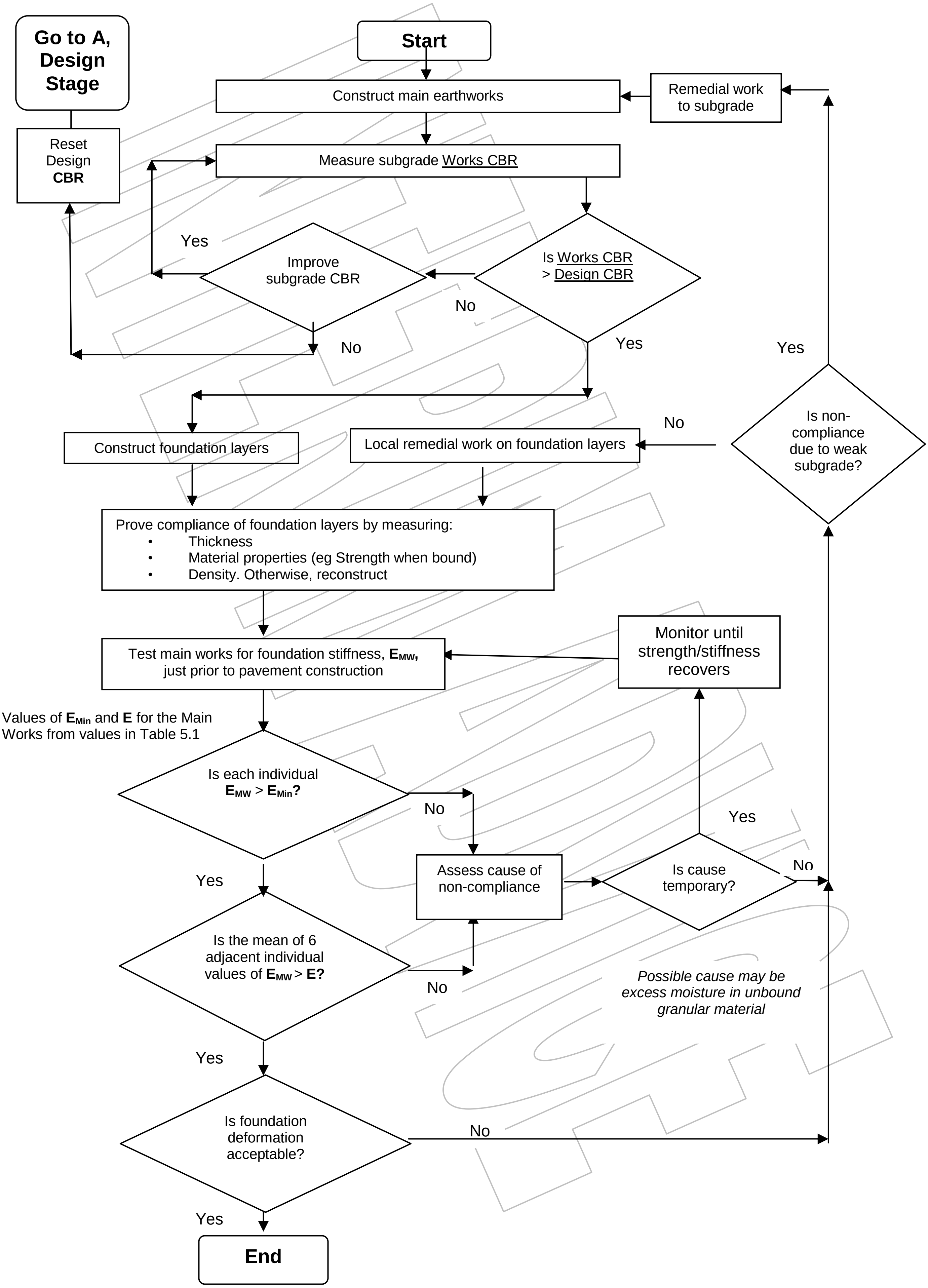
$$E = [\sigma_1\,(1 - 0.19\,\nu) - 1.19\,\sigma_3.\nu - k.\nu.\varepsilon_2] / (1000\,\varepsilon_1)$$

where: E = Stiffness Modulus (MPa)

ANNEX D: FLOWCHART



MAIN WORKS


Go to A, Design Stage
Start
Construct main earthworks
Remedial work to subgrade
Reset Design CBR
Measure subgrade Works CBR
Yes
Improve subgrade CBR
Is Works CBR > Design CBR
No
No
Yes
Yes
Is non-compliance due to weak subgrade?
No
Construct foundation layers
Local remedial work on foundation layers
Prove compliance of foundation layers by measuring:
• Thickness
• Material properties (eg Strength when bound)
• Density. Otherwise, reconstruct
Monitor until strength/stiffness recovers
Test main works for foundation stiffness, EMW, just prior to pavement construction
Values of EMin and E for the Main Works from values in Table 5.1
Is each individual EMW > EMin?
No
Yes
Yes
Assess cause of non-compliance
Is cause temporary?
No
Is the mean of 6 adjacent individual values of EMW > E?
No
Possible cause may be excess moisture in unbound granular material
Yes
Is foundation deformation acceptable?
No
Yes
End

Section 5. Draft Specification Clauses

890 Performance Related Specification for Foundations

General

1 This Performance Related Specification for Foundations must be used for 'Performance Designs' in accordance with the draft HD25 (February 2006). It demands concentrated testing within a Demonstration Area (Clause 891), prior to regular testing within the Permanent Works (Clause 892). Testing includes CBR Strength Measurement (Clause 893), Density Measurement (Clause 894), Surface Stiffness Modulus Measurement (Clause 895), and Wheelpath Deformation Measurement (Clause 896).

2 The foundations within a site shall be divided into Areas (or groups of Areas), defined in Appendix 7/1 or the Contract Specific Drawings, that are constructed with similar materials and thicknesses on a characteristic subgrade (or compacted fill) Design CBR strength value.

3 It is the responsibility of the Designer to state in Appendix 7/1, for each characteristic subgrade, the estimated long-term equilibrium CBR strength and the short-term construction CBR strength. The subgrade CBR strength value assumed for the design is taken to be the lowest of these two values. Guidance is provided in HD25.

4 Each Foundation Area shall be assessed separately for compliance with this specification.

5 The foundation structure in each Foundation Area shall be classified in Appendix 7/1 as either a Foundation Class 1, 2, 3 or 4 (i.e. with a design surface stiffness moduli of 50MPa, 100MPa, 200MPa and 400MPa, respectively). The foundation structure in each Foundation Area, comprising material types, long-term design stiffnesses, and calculated minimum layer thicknesses, shall also be detailed in Appendix 7/1.

6 The various performance tests, the spacing between successive in situ measurements, and compliance requirements for the results of the CBR strength, density, surface stiffness modulus tests and deformation measurements, are detailed in Clauses 891 and 892 for each 'stage' of construction. A 'stage' is defined as any level at which compaction is carried out, as follows:

(i) Top of Subgrade
(ii) Top of Intermediate Foundation Layer(s)
(iii) Top of Foundation

7 The design procedure for identifying available foundation materials and their performance characteristics, and calculating a combination of minimum layer thicknesses in order to provide a particular long-term Foundation Class surface stiffness modulus (E_{FC}), is detailed in HD25/06 (DMRB 7.2.2.2)

8 Design foundation surface stiffness modulus (E) performance requirements for each Foundation Class and for particular material family types (i.e. unbound/bound, slow/fast curing, and low/high strength materials) when overlying subgrade at the Design CBR strength, are tabulated in HD25/06 (DMRB 7.2.2.2) for the following situations:

- Long-term Foundation Class (E_{FC})
- Short-term foundation stiffness target (^{C}E) to be exceeded by the running mean of six consecutive measurements
- Short-term, minimum foundation stiffness target ($^{C}E_{Min}$) to be exceeded by all individual measurements.

9 Short term subgrade CBR values to be considered as weak areas, requiring treatment prior to construction of the next ‘stage’, are defined by values less than the Design CBR.

Materials

10 The foundation shall comprise ‘standard’ materials that comply with the material specifications that are called up or given in Appendix 7/1. Material specifications for a Contractor’s proposed alternative must be approved by the Overseeing Organisation.

11 All unbound foundation materials, whether complying with clauses in Series 600 or 800 of the Specification, or a permitted Contractor’s alternative, shall comply with the general requirements given in Clause 801, sub-Clauses 2, 3, 7 and 8 and with Clause 802, sub-Clauses 1-4, except that thicknesses of up to 250mm may be used for layers other than the uppermost foundation layer.

12 All bound foundation materials to Clauses 821, 822, 823, 830, 831, 832, 834 and 840 of the Specification, or a permitted Contractor’s alternative hydraulically bound mixture (HBM), shall also comply with the requirements of Clauses 810, 811, 812, 813, 814, 815, 816, 817, 818, 819, 820, 870 and 880.

13 Where a Contractor’s proposed alternative is permitted, no such material that may result in a deleterious reaction with other pavement layers or subgrade, or may be unacceptable to the environment due to potential leachates, shall be used.

14 Where a Contractor’s proposed alternatives are permitted for unbound granular materials, no such materials shall have a plastic index greater than 6% when tested according to BS1377: Part 2 on material passing the 425 micron sieve unless the fraction of such material is less than 10% of the whole.

15 The materials shall be laid to the compacted design thicknesses in Appendix 7/1 plus the associated tolerances given in the Contract Documents, except that additional thickness or increased material quality may be provided where the Contractor finds it to be necessary for the short-term construction condition, in order to comply with the performance requirements specified in Clauses 891 and 892, e.g. when using the foundation as a haul road.

16 Materials to Clauses 614, 615 and 643 shall comply with those clauses, except with respect to compaction method, for which this performance Clause 894 applies.

17 For Class 6S granular filter layer material the Contractor shall so organise work that only the traffic directly engaged in depositing, spreading and compacting the filter material shall be permitted access to the surface of this layer. The Contractor shall not permit the leading edge of the filter layer to extend more than 100 metres beyond the leading edge of the succeeding layer.

18 For Class 6F3 material Optimum Moisture Content shall be determined according to BS1377: Part 4 Method 3.7 (vibrating hammer test). Measurements of moisture content both for control purposes and for Optimum Moisture Content determination

shall be according to BS1377: Part 2 Method 3 (oven dry method) but using an oven on a reduced temperature setting of 45-50°C.

Placement and Compaction

19 Unless stated otherwise in Appendix 7/1, and with the exception of the following 'Placement and Compaction' sub-Clauses, no restriction is placed on the method of compaction of unbound materials so long as the dry density requirements given in Clause 894 are satisfied.

20 Where utilised, Class 6F1, 6F2, 6F3, 6F4, 6F5, 6S, 9A, 9B, 9C, 9D, 9E or 9F materials, as defined in Series 600 of this Specification, shall be formed of one or more layers, each of compacted thickness complying with Clause 612. Class 9D or 9E stabilised materials shall not be placed or constructed above Class 6F granular material or Class 6S granular filter layer material.

21 The absolute minimum compacted layer thickness shall be the greater of the following: 2.5 times the maximum particle size or 150mm for bound layers, or 80mm for unbound layers.

22 If compacted layer thicknesses above 250mm (permitted for layers other than the uppermost foundation layer) or above 225mm (for the uppermost foundation layer) are proposed, then the Contractor shall also propose for acceptance by the Overseeing Organisation the method by which the density requirements of Clause 894 are to be achieved and demonstrated throughout the full layer thickness.

23 For cement and other hydraulically bound mixtures to Clauses 821, 822, 823, 830, 831, 832, 834 and 840, the compaction plant specified in Clause 814 must be used. In the case of materials to Clauses 614, 615 or 643, the plant specified in those clauses must be used .

Subgrade Protection

24 The Contractor shall limit the extent of any unprotected area of subgrade, which is to receive an overlying foundation layer, to that appropriate for the output of the plant in use and the rate of deposition of the overlying material so that trimmed subgrade is covered the same day.

25 No subgrade, which is to receive an overlying foundation layer, shall remain exposed to rain or other adverse weather that may cause degradation.

891 Demonstration Area for Performance Specified Foundations

General

1 This clause forms part of the Performance Related Specification for Foundations (Clause 890), and details a requirement for concentrated testing within a Demonstration Area, prior to regular testing within the Permanent Works (Clause 892). Testing includes CBR Strength Measurement (Clause 893), Density Measurement (Clause 894), Surface Stiffness Modulus Measurement (Clause 895), and Wheelpath Deformation Measurement (Clause 896).

2 Before commencing the construction of each 'stage' of the Permanent Works, the Contractor shall demonstrate the methods, equipment, materials and thicknesses proposed to be used for that stage within a Demonstration Area. One Demonstration

Area is required for each Foundation Area (Ref. Clause 890) where the Works is greater than 2000 m^2 unless, for Foundation Classes 1 and 2 only, the Overseeing Organisation permits its exclusion. Each Demonstration Area shall be not less than 400m^2 and not less than 60m in length.

3 After completion of each ‘stage’ of the Demonstration Area, the Contractor shall carry out the performance tests detailed in this Clause, and provide the Overseeing Organisation with records of the tests and, where required, substantiate compliance with the stipulated criteria in Appendix 7/1.

4 Records of the performance test results for each construction stage, including a record of the age of any stabilised materials and the weather conditions at the time of testing, shall be presented to the Overseeing Organisation in an electronic spreadsheet format, prior to construction of the same ‘stage’ of the Main Works, or the next ‘stage’ of the Demonstration Area.

5 The materials placed in the Demonstration Area may form part of the Permanent Works, provided that they meet the requirements of the Permanent Works.

6 Foundation layers bound with Portland cement (i.e. Class 9A, 9B, 9C, 9D, 9E or 9F materials) should normally be tested (and trafficked, where required) after a minimum curing period of 7 days; a shorter or longer period of time may be appropriate for other hydraulic bound mixtures (HBM). Any restrictions and/or requirements relating to the timing of tests must be provided in Appendix 7/1.

7 Where the Demonstration Area includes any hydraulically bound mixture (HBM), then 5 laboratory specimens shall be manufactured from locations uniformly distributed across each Demonstration Area and tested for compliance in accordance with the relevant ‘standard’ material specification clauses, or with the approved specification relating to the Contractor’s alternative HBM.

8 The methods, materials and thicknesses used in the accepted Demonstration Area shall not be changed during the course of the Main Works construction without prior construction of a further Demonstration Area, where such Demonstration Areas are required.

Trafficking Trial

9 The Contractor must undertake controlled trafficking at one or more ‘stages’ of construction within the Demonstration Area, unless the Overseeing Organisation permits its exclusion. For moisture susceptible foundations, a trafficking trial should preferably be carried out both at the natural in-situ moisture content and then in a wetted condition simulative of inclement weather conditions.

10 Trafficking should be performed using a heavy goods vehicle with axle configuration typical of those to be used on the site and loaded to the maximum weight envisaged. The number of passes should reflect the expected total amount of traffic in standard axles to be carried by that level of the foundation. Otherwise, a default number of passes is that equivalent to 1000 standard axles, as given in Clause 802. The deformation shall be measured in accordance with, and shall not exceed the limits stated in, Clause 896.

11 Foundation stiffness modulus tests at the top of the foundation, in the Demonstration Area only, must be carried out, for bound materials, both in advance of, and after, a trafficking trial. It is required that each individual short-term stiffness modulus

measurements and their running mean of 6 consecutive measurements of the later series of tests shall exceed the appropriate targets in Clause 891 Sub-clause 22. Comparison of the later tests with the earlier tests provides guidance on the likely damage to bound foundation layers by construction traffic.

Top of Subgrade Stage
Performance Assessment

12 The tests at Top of Subgrade (or fill) detailed in this Clause are to be performed even if the Demonstration Area is not to form part of the Permanent Works.

13 The short-term construction subgrade soil strength within the Demonstration Area (Demo CBR) shall be determined in accordance with Clause 893 at not less than 5 locations, distributed uniformly over the Demonstration Area. The locations are to be identified to an accuracy of 0.5m.

14 The Top of Subgrade (or compacted fill) within the Demonstration Area shall be proved by not less than 5 in situ density measurements in accordance with the requirements of Clause 894, coinciding with the CBR test locations.

15 If Class 9A, 9B, 9D, 9E or 9F in situ stabilisation of existing soil material is to be used as the layer immediately overlying the subgrade, then CBR shall be checked at the appropriate depth, e.g. most practically by means of a Dynamic Cone Penetrometer, following the requirements of Clause 893.

16 Demo CBR test results less than the Design CBR, considered as weak areas, shall either be improved, or another Demonstration Area selected, or the Design CBR reset and an appropriate alternative foundation designed, constructed and proved.

Top of Intermediate Foundation Layer(s)
Performance Assessment

17 An intermediate foundation layer includes all layers between the subgrade and the top of the foundation, at which compaction is carried out.

18 Measurements of the short-term surface stiffness modulus must be carried out as detailed in Clause 895. A minimum of 25 stiffness tests are then to be performed, distributed uniformly over the Demonstration Area, except that five of these tests should be located above the Top of Subgrade CBR strength and density tests.

19 The Top of Intermediate Foundation Layer(s) within the Demonstration Area shall be proved by not less than 5 in-situ density measurements, in accordance with the requirements of Clause 894. These 5 tests should be located above the five Top of Subgrade CBR strength and density test locations.

20 Where a Trafficking Trial is to be performed on top of an intermediate foundation layer, the required surface stiffness modulus testing, on bound materials only, must be carried out both in advance of and following the Trafficking Trial. Details of the Trafficking Trial are provided earlier in this Clause. A stiffness reduction might indicate that significant traffic-induced damage might occur in the main works when subjected to an equivalent amount of site traffic.

Top of Foundation Stage
Performance Assessment

21 The surface stiffness modulus and density test location requirements at Top of Intermediate Foundation Layer(s) also apply to this Top of Foundation 'stage'. Additional requirements at Top of Foundation, for each Demonstration Area, are detailed in the remaining sub-Clauses of this Clause.

22 The short-term surface stiffness modulus performance requirements (E and E_{Min}) for the Demonstration Area must be identified in Appendix 7/1, adjusted in accordance with the procedure in the draft HD25(February 2006) to the median value of the five subgrade Demo CBR values from the Demonstration Area.

23 In order to comply with the surface stiffness modulus performance requirements of the Permanent Works:

- Each individual Demonstration Area short-term stiffness modulus value must be greater than or equal to E_{Min} adjusted as Paragraph 22; and,
- The running mean of six consecutive values must be greater than or equal to E adjusted as Paragraph 22.

24 Failure to comply with the surface stiffness modulus performance requirements would necessitate adjustment to the foundation design (i.e. increased layer thickness and/or increased material quality).

892 Permanent Works for Performance Specified Foundations

General

1 This clause forms part of the Performance Related Specification for Foundations (Clause 890), and follows concentrated testing within a Demonstration Area (Clause 891), where required. Testing includes CBR Strength Measurement (Clause 893), Density Measurement (Clause 894), Surface Stiffness Modulus Measurement (Clause 895), and Wheelpath Deformation Measurement (Clause 896).

2 Records of performance test results for each construction stage, including a record of the age of any stabilised materials and the weather conditions at the time of testing, shall be presented to the Overseeing Organisation in an electronic spreadsheet format, prior to construction of the next 'stage' of the Permanent Works.

3 Foundation layers bound with Portland cement (i.e. Class 9A, 9B, 9C, 9D, 9E or 9F materials) should normally be tested (and trafficked, where necessary) after a minimum curing period of 7 days; a shorter or longer period of time may be appropriate for other hydraulic bound mixtures (HBM). Any restrictions and/or requirements relating to the timing of tests must be provided in Appendix 7/1.

Top of Subgrade Stage
Performance Assessment

4 The short-term subgrade soil strength shall be determined in accordance with Clause 893. These tests shall be carried out at 60m intervals along each length of 'construction', except that at least 10 tests shall be carried out for each characteristic subgrade. 'Construction' might be single or multiple lane width. The locations are to be identified to an accuracy of 0.5m.

5 Additional CBR tests shall be carried out as required by the Overseeing Organisation in any specific areas where either potential concern exists, or where evidence of poor subgrade condition, or soil weaker than expected, is observed.

6 Areas where subgrade CBR test results are less than the Design CBR, are to be considered as weak areas, and shall either be improved, or the Design CBR reset and an appropriate alternative foundation designed, constructed and proved prior to construction of the next ‘stage’.

Top of Intermediate Foundation Layer(s)
Performance Assessment

7 An intermediate foundation layer includes all layers between the subgrade and the top of the foundation, at which compaction is carried out.

8 It is advised only, at Top of Intermediate Foundation Layer(s), that surface stiffness modulus tests be performed in accordance with Clause 895 prior to construction of overlying pavement layers, at 20 metre intervals along each lane (including locations which coincide with the subgrade CBR and density tests), with tests in adjacent lanes being staggered by 10m.

9 Density tests, as detailed in Clause 894 are to be performed at a spacing of every 200 metres along each lane of the road when Clause 802 (the method specification for laying and compacting unbound materials) has been followed; otherwise the spacing of these tests shall be every 60m, coinciding with surface stiffness modulus tests where such tests are performed. Tests performed in adjacent lanes must be staggered by 30m. The results shall comply with the requirements of Clause 894.

10 Unless otherwise stated in Appendix 7/1, the surface of each intermediate ‘stage’ of foundation construction shall have the same longitudinal gradient and crossfall as that specified at top of foundation.

Top of Foundation Stage
Performance Assessment

11 The Top of Foundation surface stiffness modulus (E_{PW}) shall be tested in accordance with Clause 894 immediately prior to construction of overlying pavement layers (otherwise at an earlier time provided that subsequent deterioration due to trafficking and/or environmental effects does not occur), at 20 metre intervals along each lane (including locations which coincide with the subgrade CBR and density tests), with tests in adjacent lanes being staggered by 10m.

12 The short-term surface stiffness modulus performance requirements (E_{Min} and E) for the Permanent Works must be identified in Appendix 7/1 based on the subgrade Design CBR strength.

13 In order to comply with the surface stiffness modulus performance requirements of the Permanent Works:

- Each individual Permanent Works short-term stiffness modulus value must be greater than or equal to E_{Min}; and,
- The running mean of six consecutive values must be greater than or equal to E.

14 A foundation that fails to comply with the performance requirements of this Clause when the recorded moisture content is in excess of that in the Demonstration Area, may be re-tested for compliance when the foundation moisture content has reduced.

15 Density tests, as detailed in Clause 894 are to be performed at a spacing of every 200 metres along each lane of the road when Clause 802 (the method specification for laying and compacting unbound materials) has been followed; otherwise the spacing of these tests shall be every 60m, coinciding with surface stiffness modulus tests. Tests performed in adjacent lanes must be staggered by 30m. The results shall comply with the requirements of Clause 894.

893 CBR Strength Measurement

General

1 CBR strength measurements should normally take the form of in-situ tests carried out in the upper 50-300mm of subgrade in accordance with BS1377: Part 9. However, static plate loading, cone penetrometer or shear vane tests are all possible alternatives, where accepted correlations with CBR exist for the materials present.

Dynamic Cone Penetrometer (DCP)

2 Where permitted (i.e. where accepted correlations with CBR strength exist for the materials present), Dynamic Cone Penetrometer testing of subgrade (or fill) materials shall be carried out using a device incorporating an 8kg steel drop weight falling vertically through 575mm and making contact with a relatively light steel anvil. This anvil shall be rigidly attached, via steel rods (less than 20mm diameter), to a 20mm diameter 60^{o} steel cone, which is thus driven vertically into the ground.

3 Exceptionally, other dynamic cone equipment may be permitted providing it has been calibrated against equipment meeting the requirements of this Clause, on the type of materials present.

4 Soil strength expressed as mm/blow shall be converted to a CBR value using the following relationship:

$$\text{Log}_{10}\text{ (CBR)} = 2.48 - 1.057 * \text{Log}_{10}\text{ (mm/blow)}$$

where CBR is given as a percentage value and the penetration rate of the cone is given in units of mm/blow.

5 The result for each test shall be expressed as a 50^{th} percentile penetration rate in millimetres per blow between 50mm and 300mm of penetration from top of subgrade level. However, if the penetration rate falls to less than 2mm per blow, then the test should be aborted with one further test attempted nearby.

894 Density Measurement

1 Each ‘stage’ of the foundation construction shall be tested for in situ density by a nuclear density gauge, calibrated for the material being tested, in accordance with BS1377: Part 9 for unbound materials or Clause 870 for cement and other hydraulically bound mixtures, or by such other in situ density test as may be approved by the Overseeing Organisation. The results shall comply with the requirements of this Clause.

2 The unbound material used in each compacted foundation layer shall achieve a minimum in-situ dry density, when tested in accordance with BS1377: Part 9, or such other test as the Overseeing Organisation may permit, of 95% of the maximum dry density, as determined from the method in BS EN 13286-4. Cement and other hydraulically bound mixtures shall attain a minimum in-situ wet density, when tested in accordance with Clause 870, of 95% of the average wet density of at least five cubes manufactured to BS EN 13286-51.

3 Maximum dry density (for unbound materials) or maximum wet density (for cement and other hydraulically bound mixtures) shall be determined for every 1000 tonnes of material unless otherwise stated in Appendix 7/1 or agreed by the Overseeing Organisation.

895 Stiffness Modulus Measurement

1 Stiffness modulus testing shall be carried out using a Dynamic Plate Test device, which has been properly calibrated to the manufacturer's specification. The equipment shall be capable of delivering a load pulse of peak magnitude 4-15kN, of total duration 15-60 msecs, to a rigid circular plate of 300mm diameter. Both the applied load and the transient deflection, measured directly on the tested surface, shall be measured. The deflection measurement transducer shall be capable of measuring deflections in the range 10-2000 microns.

2 The peak stress applied during each test shall be selected to produce as high a deflection as possible within the measurement range of the deflection sensor.

3 At each test point, 1-3 initial ‘seating’ drops shall be carried out to bed the plate into the surface. Three further drops shall then be carried out. The results from the last set of three drops shall be averaged to give the stiffness modulus applicable to that test point.

4 The stiffness modulus shall be computed at each point tested, using the following formula:

$$E = \frac{k \times (1-\nu^2) \times R \times P}{D}$$

where :

E	=	Foundation Surface Stiffness Modulus (in MN/m^2 or MPa)
k	=	Plate Rigidity Factor = 2
ν	=	Poisson’s Ratio (ν, by default, = 0.35)
R	=	Load Plate Radius (R, by default, = 150mm)
P	=	Contact Pressure (in kPa)
D	=	Deflection under the centre of the plate (in microns)

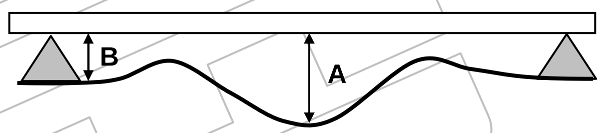
896 Wheelpath Deformation Measurement

1 The Contractor shall ensure that any ruts that develop under construction traffic, measured in accordance with this Clause, nowhere exceed the following limits unless he can demonstrate to the Overseeing Organisation that the long-term performance of the pavement will not be impaired:

- All stabilised/bound surfaces – 10mm
- < 250mm granular – 30mm
- > 250mm granular – 40mm

2 The cumulative rut, summing the deformations from each trafficked foundation layer prior to any re-profiling at any given location, shall nowhere exceed 50mm.

3 Wheelpath Deformation measurement shall be carried out using a straight edge with a length of at least 2m. The straight edge shall be placed transverse to the rut and raised clear from the rut by two identical blocks. The blocks shall be placed on undisturbed material outside of the wheel path. The amount of deformation shall be the difference between the deepest vertical measurement from the straight edge to the surface of the foundation (A) and the height of the blocks (B).



Deformation = A – B.

Section 6. Draft Notes for Guidance

NG 890 Performance Related Specification for Foundations

General

1 This performance specification is supported by laboratory (predominantly strength and durability) testing, as detailed in the specification clauses appropriate to the particular foundation material type(s) to be used.

2 Due to the natural variability of subgrades, the final choice of characteristic foundation types may have to be refined during construction, even though the Designer will have provided estimated lengths of such areas on the Contract-specific Drawings. The Overseeing Organisation retains the authority to request additional sub-division and/or Demonstration Areas if it believes that the Contractor's choice is too restrictive.

3 The foundation structure may include those material types known as capping and/or subbase (or layers performing the same function of providing a platform on which to build the pavement).

4 The short-term, i.e. during construction, subgrade CBR strength would typically be expected to differ from the long-term, i.e. under the completed pavement, equilibrium strength. Similarly, measurements of foundation stiffness during pavement construction are likely to differ from the long-term surface stiffness modulus assumed for design. Values of **E** and $\mathbf{E_{Min}}$, will increase with an increase in the subgrade strength, and vice-versa. Values of **E** and $\mathbf{E_{Min}}$, adjusted in accordance with the procedure in draft HD25 (February 2006) for the likely range of short-term CBR values (applicable to the Demonstration Area, and not the Permanent Works performance tests) are to be detailed in Appendix 7/1.

5. Weak areas are locations where the short-term subgrade strength is so low that these areas are unlikely to strengthen to the Design CBR upon which the foundation design is based. The area will either need improvement or the value of the Design CBR redefined.

6 The measurement of foundation surface stiffness modulus (following testing, where required, at the earlier 'stages'; that is subgrade CBR strength measurement, to determine weak areas; Layer thickness; Material properties including density and, when bound, strength) serves several processes:

- To identify subgrade weak areas not found during the earlier subgrade CBR strength testing, or caused by the Contractor's bad practice (e.g. by not adequately protecting the site from excess water, or draining the site of excess water).
- To identify inadequate upper foundation layers.
- To limit degradation of the foundation by construction traffic. Potential degradation must be quantified in a Trafficking Trial to Clause 891(unless a 'Departure from Standard' is granted by the Overseeing Organisation) by measurement of foundation surface stiffness modulus both before and after trafficking, prior to construction of the next 'stage' of the Permanent Works.

7 This performance specification provides a process of ensuring (as far is reasonably practical to do so in the short-term, i.e. during construction) the adequacy of the foundation to perform the role for which it has been designed during its in-service life.

It also provides a framework within which the Contractor may use skill and judgement to refine a particular Foundation Class Design based on experience of the available materials.

Materials

8 The restriction on foundation materials which may result in a deleterious reaction includes unburnt colliery spoil. However, it may also apply to certain industrial by-products, which the Contractor may propose. Expert advice should be included, where appropriate, with the 'Departure from Standard'.

9 Demonstration Areas (Clause 891) afford an opportunity for gaining experience of the materials to be used as well as adjusting construction procedures and/or design thicknesses. They also permit dynamic plate (i.e. surface stiffness modulus) testing to be carried out and the results checked against the expectations only for the Top of Intermediate Foundation layer 'stages'; and the contractual design requirements for the Top of Foundation level) determined from the design guidance in HD25/06 (DMRB 7.2.2.2).

10 For all materials, but specifically for the Contractor's proposed alternative materials, laboratory testing forms an important step in characterising the mechanical properties prior to developing foundation designs. Advice is provided in HD25/06, and the following should be noted:

- The Triaxial test (BS EN 13286-7) provides stiffness modulus and shear strength data for unbound materials, but may not be suitable for materials having large particle size. For cement and other hydraulically bound mixtures, BS EN 13286-43 describes two techniques for stiffness modulus measurement, whereas Parts 40, 41 and 42 describe different strength measurements.
- Alternatively, the 170×170×170mm 'Springbox' which fits inside a NAT loading frame is suggested as a suitable tool for the measurement of mechanical properties of unbound granular and weak hydraulically bound mixtures. With relatively slight modification, the equipment is also suitable for obtaining Static Stiffness slightly stronger (i.e. specimens that do not require confinement) hydraulically bound mixtures. Output is in terms of a stiffness modulus, which can be used directly in pavement design for unbound granular materials and also provides information on the stiffness of hydraulically bound mixtures at various ages and with/without load induced distress. This apparatus also provides a relative measure of permanent deformation resistance (rutting resistance) of unbound/weakly bound mixtures. The Springbox allows the material to be tested in a realistic moisture state; soaking followed by a 24 hour drainage period is generally considered appropriate.
- Characterisation of granular materials can be made using the 300×300×150mm Shear Box (see Transport & Road Research Laboratory Report RR64) where, if the 'peak shear stress ratio (PSSR)' is greater than 2.8, then the material is very likely to be suitable for direct trafficking by road vehicles. If it is between 1.9 and 2.8 there is some risk of rut development, and for PSSR less than 1.9 rutting is likely, although such materials may still be suitable in the long-term so long as they are protected during the construction process.
- A further practical alternative for in situ testing is the Dynamic Cone Penetrometer (DCP), see Clause 893, where experience suggests that materials with a penetration rate of less than 17mm per blow (>15% CBR)

are likely to be suitable for direct trafficking (unless they are unsuited to such testing due to the presence of large particles) and for Class 1 foundations. The uppermost layer of a Class 2 foundation would usually achieve a DCP penetration rate of less than 9mm per blow (>30% CBR).

11 Crushed rock or sand filter layers of 50mm minimum thickness, made using Class 6S granular filter layer material, can be used to prevent the ingress of cohesive particles from the top of the subgrade into an open graded foundation layer. A filter layer is not generally required if Class 6F granular material is used.

12 The introduction of BS EN 13285 requires separate classes for Class 6F granular material from sources other than the excavated parts of the same Site. Class 6F4 is a fine graded unbound mixture complying with BS EN 13285. It is similar to Class 6F1, but derived from the excavated parts of the Site. Class 6F5 is a coarse graded unbound mixture complying with BS EN 13285. It is similar to Class 6F2, but derived from the excavated parts of the Site. BS EN 13285 unbound mixtures are made using aggregates complying with BS EN 13242.

Placement and Compaction

13 Pavement foundation construction, as permitted or required in Appendix 7/1, might typically commence by means of one of the following procedures:

(i) Where the lowermost pavement foundation layer consists of imported material, excavate (in cuttings) or complete the placement of fill (on embankments) or remove any protection layer and trim the surface to form the subgrade. Immediately compact with one pass of a smooth-wheeled roller having a mass per m width of roll not less than 2,100kg or a vibratory roller having a mass per m width of roll not less than 700kg or a vibrating plate compactor having a mass per m² of not less than 1,400kg, except that only smooth wheeled rollers shall be used on Class 3 chalk material. Test short-term subgrade strength at the frequency detailed in Clause 891 (Demonstration Area) and Clause 892 (Permanent Works), and immediately deposit, and where appropriate stabilise, and compact the lowermost pavement foundation layer.

(ii) Where in-situ stabilisation of an existing soil or of an already-constructed embankment is to be used, test short-term subgrade CBR strength at the frequency detailed in Clause 891 (Demonstration Area) and Clause 892 (Permanent Works), and construct the lowermost foundation layer by stabilising the intact material.

NG 891 Demonstration Area for Performance Specified Foundations

1 For slow curing HBMs, an extended curing period may be specified in Appendix 7/1 before testing and augmented by laboratory evidence showing that the expected 360 day performance will be met. A shorter period of time between laying and testing may be appropriate for particularly slow curing HBM to ensure the stability of the mixture in the absence of bond in the short-term and confirm that the material is suitable for construction of the next 'stage'.

Trafficking Trial

4 It should be noted that a Trafficking Trial cannot guarantee deformation resistance in the Permanent Works and it extends the time and resources applied to approving a foundation. A trafficking trial may not be necessary if:

- Evidence is available to show that the proposed foundation (materials, construction procedures and layer thicknesses) has performed well at other sites under the same moisture and trafficking conditions.
- Deformation resistance has already been proven at a lower level within the foundation.
- The type of foundation construction is of a type that is unlikely to be susceptible to deformation, as might typically be expected at the Top of Foundation for a Foundation Class 3 or 4.
- There is no intention to traffic the foundation.
- The Site is too small to justify such a trial.

3 Wetting of the Demonstration Area and re-trafficking is intended to assess likely performance in wet weather. It is suggested that sufficient volume of water to cover the trial area to a depth of 10mm is spread as uniformly as possible and that a period of 1 hour is then allowed prior to re-trafficking.

4 If the measured deformation is in excess of the requirements of Clause 896, then either the foundation should be improved and subsequently proved by another Trafficking Trial, or the planned works should be adjusted to reduce the construction traffic. If the foundation is to be trafficked by special, very heavy vehicles (e.g. to transport bridge segments), additional consideration should be given to proving the performance of the foundation under these vehicle loads. Whether a Trafficking Trial is performed or not, it will still be the responsibility of the Contractor to ensure that the foundation meets the requirements specified for the Permanent Works in Clause 896.

5 The purpose of trafficking a Demonstration Area is to understand the behaviour of the foundation layers under construction traffic and to ensure that the subgrade is not overstressed. Based on a successful trial it may be concluded that the level concerned is able to withstand trafficking without any special precautions. However, often with marginal materials, special precautions in the form of a limit on traffic movements, a protection layer, or restricted movements in wet weather are necessary. The trial may help to make decisions about such restrictions.

6 Particular attention should be paid to Class 6F3 material. This material may sometimes appear satisfactory in the short term but deform significantly later. A static test, for example a 12T axle parked for 24 hours, is likely to reveal if a deformation problem exists.

Top of Subgrade Stage Performance Assessment

7 The finding of soil weaker than that expected in the design process should trigger an investigation, to ensure their localised nature, and that such low CBR values are not generally likely to be encountered within the foundation Area represented by that particular Demonstration Area.

Top of Intermediate Foundation Layer(s)
Performance Assessment

8 It is a requirement that at the top of each intermediate stage in the foundation construction of the Demonstration Area only, surface stiffness modulus testing is carried out in order to give confidence that the performance requirement at Top of Foundation stage is achievable. The expected stiffness modulus should be deduced from the pavement foundation design information given in HD25/06 (DMRB 7.2.2.2). Additional tests should be carried out in any specific areas where evidence of poorer than expected condition is found, in order to determine the extent of the area more exactly. Such areas will not in themselves fail to meet the requirements of the Contract but they present a danger that the Foundation Class surface stiffness modulus requirements at the Top of Foundation will not be met.

9 In some circumstances the Contractor may choose to wet the Demonstration Area so that it reflects the most pessimistic moisture condition anticipated on the site while the foundation is exposed. Measurements obtained on the wetted foundation may provide a warning of potential problems in adverse weather. Results should be reported to the Overseeing Organisation in order to assist in optimising future pavement designs.

Top of Foundation Stage
Performance Assessment

10 When investigating a failure to comply with the surface stiffness modulus performance requirements, the results of surface stiffness tests performed at the Top of Intermediate Foundation layer(s) should also be considered.

11 In some circumstances the Contractor may choose to wet the Demonstration Area so that it reflects the most pessimistic moisture condition anticipated on the site while the foundation is exposed. Measurements obtained on the wetted foundation may provide a warning of potential problems in adverse weather. Results should be reported to the Overseeing Organisation in order to assist in optimising future pavement designs.

NG 892 Permanent Works for Performance Specified Foundations

General

1 For slow curing HBMs, an extended curing period may be specified in Appendix 7/1 before testing and augmented by laboratory evidence showing that the expected 360 day performance will be met. A shorter period of time between laying and testing may be appropriate for particularly slow curing HBM to ensure the stability of the mixture in the absence of bond in the short-term and confirm that the material is suitable for construction of the next ‘stage’.

Top of Subgrade Stage
Performance Assessment

2 It is of the utmost importance that areas weaker than the Design CBR strength are identified and suitably treated. Particularly soft areas may often be identified visually, for example by observing ground movement under plant loading or even under foot. Additional testing can then be carried out to confirm the depth (e.g. using the Dynamic Cone Penetrometer) and lateral extent (e.g. using Dynamic Plate surface stiffness modulus tests) of the weak area. The Contractor is permitted to use

whatever technique(s) is deemed suitable for treatment of weak areas, as long as the minimum subgrade Design CBR strength requirement is met. Additional excavation and replacement with material of adequate quality is likely to be the most cost-effective for relatively small areas, although various compaction techniques or stabilisation are also alternatives. Consideration should always be given to the problems that arise when drainage paths are not provided (e.g. a pocket of permeable material surrounded by impermeable material that could act as a reservoir for water, eventually causing gradual softening of the surrounding material).

3 Remedial measures are also required to any area of subgrade whose CBR strength falls below the Design CBR due to disturbance caused by inappropriate actions on the part of the Contractor, though such areas fall outside the definition of 'soft spots' for potential additional expense contractual payment purposes.

4 For each Foundation Area, the prepared surface of the subgrade should, shortly before placement of overlying construction materials, attain the Design CBR strength. Otherwise, there is an increased risk that the Top of Foundation Stage surface stiffness modulus requirements will not be achieved.

5 In selecting embankment material to form the pavement subgrade, the Contractor has to bear in mind the material's likely in-situ properties after placement, particularly in the short term. In the absence of prior successful use of the same material, it may be possible to test the material to be placed and compacted at source for CBR strength although due attention must be paid to the possibility of softening due to wetting up and/or remoulding during and after placement.

Top of Intermediate Foundation Layer(s)
Performance Assessment

6 Surface stiffness modulus test results should be compared with those values obtained from the Demonstration Area in order to give confidence that the performance requirement at Top of Foundation Stage is achievable.

Top of Foundation Stage
Performance Assessment

7 The minimum age of the bound material at which the foundation stiffness modulus should be measured is typically 7 days for fast curing Portland cement bound materials but older for slower curing HBMs dependent on strength development. Ideally, prior to the specified age, the foundation will not be trafficked.

8 It is useful to plot the running mean of six consecutive surface stiffness modulus results against the site chainage as the trend in foundation stiffness may give notice of a possible future non-compliance.

9 It is only permissible for the Contractor to change material specifications and layer thicknesses in order to increase (and not decrease) the foundation quality, as judged by foundation stiffness, in the Permanent Works relative to that approved in a Demonstration Area.

NG 893 CBR Strength Measurement

General

1 It should be noted that, for coarse-grained materials, there might be an appreciable difference between CBR values obtained in-situ and in the laboratory, with the in-situ values being lower due to the effects of confinement in the laboratory test mould (although this should not be confused with low values resulting from exposure to rainfall or a high water table). This difference should be taken into consideration when specifying in-situ requirements in Appendix 7/1.

2 On sites where access to the subgrade is likely to be restricted, for example on maintenance contracts, consideration should be given to use of a rapid technique such as the Dynamic Cone Penetrometer.

Dynamic Cone Penetrometer (DCP)

3 The type of cone penetrometer specified is that originally adopted by the Transport Research Laboratory. If any alternative is to be used, then it should be carefully calibrated against equipment complying with the Specification for the specific types of material encountered.

4 The calculation of the average penetration rate should not be unduly influenced by the cone striking isolated stones in a generally, fine grained cohesive material.

5 The Dynamic Cone Penetrometer may also be used through many materials, particularly in a composite foundation, to measure both their CBR and layer thicknesses, although this strength measure will not normally be specified in the Contract for materials overlying the subgrade since results are highly dependent on particle size and can therefore, without calibration to specific materials, be misleading. These values can, however, act as a useful additional measure for assessment of Demonstration Areas.

NG 894 Density Measurement

1 The density requirement is intended not only to improve material durability, but also to ensure that no secondary compaction occurs in the long term. For example, some materials may, in good weather, form a stiff platform and be able to carry traffic even though the density is low. However, if moisture content increases, long-term consolidation of the layer can occur.

2 In interpreting density results, due account should be taken of the variation in maximum dry or wet density with composition of the material; the grading envelope for foundation materials can be very wide. Where possible, information on the variation of density with gradation for the materials proposed should be used.

3 For coarse materials it may not be possible to assess density using the nuclear density meter. Alternative standard, but time consuming, methods based on excavating a measured mass of material and determining the volume of the hole created are permitted by the Specification (subject to Overseeing Organisation approval) and may need to be adopted.

NG 895 Stiffness Modulus Measurement

1 When the device applies its maximum stress, for lower class foundations tested at intermediate stages, the deflection of the structure tested can be over 1000 microns; whereas for the highest foundation class, maximum deflection of only about 50 microns will be produced. A peak stress of 100kPa should be targeted, unless the deflection measurement typically falls outside the range 100-1000 microns.

2 Stiffness modulus testing can be affected by a loose and uneven interface between the foundation and the plate of the test device. It is recommended that three seating drops of the falling weight are performed on unbound materials prior to obtaining a measurement of foundation stiffness; seating drops may not be necessary on bound materials and are replaced by a single drop to confirm stability and operation of the device. For unbound materials, no more than 10 drops in total should be applied to any one location to prevent localised additional compaction affecting the results.

3 If any equipment is proposed which does not fully comply with the Specification, it may be permitted at the discretion of the Overseeing Organisation, provided that it is carefully calibrated against equipment complying with the Specification, for the specific types of material and layer thickness encountered on the site. This calibration would normally be carried out as part of the Demonstration Area testing.

NG 896 Wheelpath Deformation Measurement

1 The limit on rutting is primarily intended to ensure that significant ruts (>20mm) at subgrade level are avoided, to prevent accumulation of water and local subgrade softening. If the subgrade is sufficiently permeable, then this problem will not arise. It may also be possible for the Contractor to cut a trench and to prove that, notwithstanding the rut at the surface, no significant subgrade rut is present. In such a case, the Overseeing Organisation should make a judgement, based on damage to the upper foundation layers and the ease of use of the foundation by site traffic as to whether the deformation occurring is acceptable. For example, some sands and gravels may rut excessively during construction. However, following re-profiling and compaction, they may achieve satisfactory properties for placement of the upper layers and, once confined by the pavement, may perform satisfactorily in the long term.

2 The more stringent rut limits applying to stabilised/bound surfaces recognises the fact that, in practice, if visible rutting occurs in such materials, then this rutting will be accompanied by significant loss of stiffness, which is likely to result in non-attainment of the desired Foundation Class.

3 Whilst the presence of shoulders to a rut is indicative of a deformable material, and this may provide valuable information during a trafficking trial, the actual specified measurement of deformation is based on the change in level from an untrafficked datum to the bottom of the rut. This is because this measure is more closely related to deformation taking place in the subgrade.

4 It is the Contractor’s responsibility to ensure that the foundation does not suffer excessive deformation. If a foundation needs to be re-profiled during foundation construction, then the implication is that the foundation has already failed to comply with the Specification. Re-profiling alone may not stop further deformation and may disguise problems for the future such as ponding of water in ruts in the subgrade.