
Second Edition 2004

6 SPECIFICATION GUIDELINES

6.1 General

In writing a specification for the construction of a natural stone pavement the following issues should be considered. Where appropriate, references are given to the relevant section in this guide.

6.2 Stone selection

6.2.1 General

Selection of stone and stone products is primarily covered in Section 3 of this guide and falls into two categories,

- The properties of the stone material
- The properties of the product made from the stone

The following table details the all the characteristics, which should be considered when specifying stone.

EN Requirements	Section 3.2.	
Dimensions	Section 3.2.1.	
Test Methods	Section 3.2.1.	Table 3.1.Figs 3.1,3.2 & 3.3.
Permissible Deviation	Section 3.2.2.	Tables 3.2, 3.3, & 3.4.
Geological and Engineering Properties	Section 3.2.3.	
Test Methods	Section 3.2.3.	Table 3.5.
Aspects	Section 3.2.3.	
Petrography	Section 3.2.3.	
Porosity	Section 3.2.3.	
Strength	Section 3.2.3	
Durability	Section 3.2.3.	
Skid/Slip Resistance	Section 3.2.3.	
Chemical Surface Treatment	Section 3.2.3.	
Permissible Deviation	Section 3.2.4.	Tables 3.6, 3.7 & 3.8
Evaluation of conformity	Section 3.2.5.	
Acceptance Criteria	Section 3.2.6.	Tables 3.9. & 3.10. Fig, 3.4.
Additional Guidance	Section 3.3.	
Specification	Section 3.3.1.	Table 3.11
Product Integrity	Section 3.3.2.	
Surface Texture	Section 3.3.3.	
Skid and Slip Resistance	Section 3.3.4.	Table 3.12
Effects of de-icing salts	Section 3.3.5.	
Colour	Section 3.3.6.	
Petrological Description	Section 3.3.7.	
Other properties and test methods	Section 3.3.8.	Table 3.13
Strength	Section 3.3.8.	
Porosity	Section 3.3.8.	
Durability	Section 3.3.8.	
Resistance to Polishing	Section 3.3.8.	
Sources of information	Section 3.3.9	

The first part of the above list gives the basic specification for the stone and products made from stone, which will then comply with the current European Normalised Standards (EN). The second part of the list relates to the additional guidance given in Section 3 and will ensure that the products will be better able to meet the requirements of BS 7533, the recommendations of this Guide and the specification arrived at for any particular pavement.

6.2.2 Dimensional tolerances

The tolerances required by BS 7533 and this Guide are more stringent than those of the EN Standards for stone products. In particular the dimensional tolerances required to ensure the pavement performs adequately may not be met if products are simply specified to the EN standards. Accordingly the designer has to consider how to meet the tolerances required for the pavement, with reference to Section 4 and Section 7 of this Guide.

There are two options: -

- Firstly, tighter tolerances in the manufacture of the stone product need to be agreed with the supplier before orders are placed. This requirement will increase the cost of the stone product.

- Secondly, the specification may require that individual stones be selected manually in order to ensure that the construction tolerances for joint width can be achieved.

6.2.3 Selection of Stone on Site

An example of selection is given below in Figure 6.1. This is for a nominal 100mm wide sett with a manufacturing tolerance of +/- 20mm. This would allow the width of a stone unit to lie in a range between 80mm to 120mm. In order to meet the construction tolerances of say 10mm on joint width, these units would have to be selected to give bands of width as follows

Figure 6.1 – Example of Bandwidth for Sett Courses

Nominal width of band (mm)	Tolerance on band width (mm)	Range of bandwidth (mm)	Joint width (mm)
85	+/-5	80 - 90	10
95	+/-5	90 – 100	10
105	+/-5	100 – 110	10
115	+/-5	110 - 120	10

Where a pavement is loaded at the upper end of its design capacity, achieving the close control of the tolerances on the joint width becomes critical to its structural performance and design life. Here achieving this selection into bandwidths becomes very important and indeed the bandwidth may need to become tighter and selection of units made more vigorous. In these circumstances it might be necessary to impose a smaller bandwidth of say 5mm i.e. +/- 2.5mm.

Even with this degree of selection, meeting the joint width tolerance depends on the skill of the layer.

Guidance

The basic specification of stone and stone products given in the current European Standards needs to be more precise to ensure the products meet the requirements of good practice.

In particular the dimensional tolerance allowed in current standards means that design and construction tolerances may not be achieved and manual selection of units may be required.

6.3 Compatibility of Structural Response of Materials in Construction of the Pavement

There are a number of materials, which have to be specified for any road construction. Beginning at the bottom is the foundation, (sub grade and capping layer), the next layer is the sub-base, the next is the roadbase, then there is the base course and then the wearing surface.

As discussed earlier the choice of materials for each layer needs to be consistent with the structural response of the pavement, i.e. flexible materials for a flexible construction and rigid (stiff) materials for a rigid construction.

Not only is it also important that the layers are compatible with each other in terms of their stiffness but that the stiffness increases from the bottom to the top.

The various materials for the lower layers are similar for both types of structure. These lower layers are selected using standard road design standards and specifications for the loading category as described below. However the upper layers differ considerably for flexible and rigid forms. In keeping with the rest of this guide the following sections are divided between the two types of construction. Where necessary, notes are repeated under each heading.

Guidance

The various layers of any pavement should be structurally compatible with the structural response of the overall pavement.

6.4 Materials for Flexible Construction

6.4.1 Foundation for Flexible Construction

The foundation of the pavement has two basic elements, which have to be specified:

Strength of sub grade (CBR)	*(Section 4)*
Capping layer	*(Section 4).*

Another important characteristic of these foundations is that they should be permeable or should be laid with a fall to shed water.

6.4.1.1 Capping layer

Where low strength sub-grades are encountered and a capping layer is required to improve the bearing of the formation then it should met the capping specification given in either the Specification for Highway Works or the Series 800 of the Manual of Contract Documents for Highway Works (MCHW).

6.4.2 Sub-base

Sub-base material should be a Granular Sub-base Material Type 1 complying with Clause 803, Specification for Highway Works or with Series 800 of the Manual of Contract Documents for Highway Works (MCHW). Where a site is confined and material placement and compaction cannot comply with Clause 803, a dry bulk mass density or minimum CBR specification should be applied.

BS 7533 Part 7 requires 97% of the dry bulk density to be achieved. A nuclear density gauge should be used to check the level of compaction on site. The dry bulk density has to be measured in the laboratory by testing the actual material to be used, to determine the optimum moisture content and the dry bulk density.

With the CBR specification, the minimum CBR should be 30 percent.

6.4.2.1 Profile Of Bases And Tolerances For Various Layers

Another important characteristic of the foundation layers and sub-base layer is that they should be permeable or should be laid with a fall to shed water. There is also a requirement, that in order to meet the tolerances on the laying course thickness, the base layers are profiled to follow the profile of the finished surface to within 5mm. (Section 7)

Annex B of the BS 7533 Part 7 gives the tolerances for different layers of the support structure in terms of the maximum permissible deviation from the design level, when measured over a 3m grid. The tolerances for each layer are shown in Figure 6.2. Additionally, Annex F of BS 7533 Part 7 provides longitudinal falls and cross falls to be applied to the completed pavement to prevent ponding. Again these are shown in Figure 6.2

Where the layer is within the tolerances of Annex B and where the layer profile follows the profile of the upper layers, which itself adheres to the guidance given in annex F relating to falls, then the lower layers will automatically shed water. These tables are repeated below as Figure 6.2

Therefore the profile of the foundation and base layers should be related to the profile of the finished surface.

6.4.3 Roadbase Layers For Flexible Construction

Type of Roadbase	*(Section 4, Section 7)*
Strength of Roadbase	*(Section 4, Section 7)*

BS7533 Part 10 limits Flexible Constructions to areas of lighter loading. It is unlikely that a road base will be required to give the pavement the necessary structural capacity under lighter loads. If a roadbase layer were required then it would typically comprise a bitumen macadam material complying with either the Specification for Highway Works or the MCHW and associated standards. There are however many materials and combinations of materials which might satisfy the structural design criteria and be suitable for use. Indeed in some combinations of load and strength of foundation, the road base layer may comprise unbound type 1 material i.e. the same material typically used in the sub base layer.

What is important in flexible constructions is that any road base is flexible. Therefore the materials should attain a minimum measured dynamic stiffness modulus of 2000MPa, when tested in compliance with BS DD 213: 1993. The material should be compacted to a minimum of 97 percent refusal density as measured on site using a calibrated nuclear density gauge. To achieve this low stiffness requires a more viscous material typically with a penetration around 200.

In all cases the road base should be permeable if possible, or be laid to shed water at the tolerances given in Figure 6.2.

Tolerance for Layers

Layer of Pavement	Flexible construction	Rigid Construction
	mm	Mm
Sub base	+20 -15	+15 -15
Roadbase	0 -12	± 5
Surface course	± 6	± 6

Falls for surface drainage.

Type of drainage	Recommended	Extreme limits
Crossfall rough elements recessed points	3.00%	1.5% to 7%
smooth	2.50%	
Longitudinal rough	Minimum 2.5%	Maximum 8%
smooth	Minimum 1.25%	Maximum 8%

Note 1 Some materials can be laid on slopes steeper than these gradients, but as most paved areas are shared with pedestrians they would be considered to be un-walkable, 8% is considered to a comfortable maximum.
Note 2 To ensure positive drainage, the finish level of the paving to the top surface of drainage inlets and channel should be minimum of 5 mm. This is important to avoid ponding around drainage inlets or channels.
Note 3 In large paving areas, it is important to consider the resultant fall from the combination of cross fall and longitudinal fall. Large areas need to be divided into panels, which can be drained particularly where levels are constrained by edges of buildings etc

Figure 6.2 Tolerances for Layers and Falls for Surfaces

6.4.4 Basecourse for Flexible Construction

Again because BS7533 Part 10 limits Flexible Constructions to areas of lighter loading, a basecourse may not be required. If a basecourse layer were required then it would typically comprise a bitumen macadam material complying with either the Specification for Highway Works or the MCHW and associated standards. There are however many materials and combinations of materials which might satisfy the structural design criteria and be suitable for use.

Again what is important in flexible constructions is that any basecourse is flexible. Therefore the materials should attain a minimum measured dynamic stiffness modulus of 2000MPa, when tested in compliance with BS DD 213: 1993. The material should be compacted to a minimum of 97 percent refusal and again be more viscous, typically with a penetration around 200.

In all cases the basecourse should be permeable if possible, or be laid to shed water at the tolerances given in Figure 6.2 above.

6.4.5 Laying Course Materials for Flexible Construction

Grading	(Section 7.)
Type	(Section 7.)

BS 7533 Part 7 defines specific types of sand and crushed rock to be used as laying course material. It defines the grading for such materials depending on whether the stone unit is sawn or cropped. These materials and their grading are given in Figure 6.3

6.4.6 Joint Materials for Flexible Construction

Grading	(Section 7.)
Type	(Section 7.)

The same specifications apply to the jointing materials for flexible construction. It is strongly recommended that the materials for jointing should be the same as those used in the laying course.

Grading requirement for bedding layer and jointing materials for sawn setts

Sieve size	Percentage passing each sieve	
Mm	Bedding Naturally occurring	Jointing
5	90 – 100	100.00
2.36	75 – 100	100.00
1.18	55 – 90	95 - 100
0.6	35 – 65	50 - 100
0.3	10 – 45	15 - 60
0.15	0 –10	0 - 15
0.075	0 - 1.5	0- 3

Grading requirement for bedding layer and jointing materials for cropped setts

Crushed rock		Sands	
Sieve size	% passing by mass	Sieve size	% passing by mass
10.0mm	100	5.0mm	100
5.0mm	70 to 100	2.36mm	100
2.36mm	25 to 100	1.18mm	80 to 100
1.18mm	15 to 45	0.6 mm	70 to 100
0.6 mm	5 to 25	0.3mm	50 to 100
0.3mm	3 to 20	0.15mm	50 to 60
0.15mm	0 to 15		

Figure 6.3

6.4.7 End Performance Tests for Flexible Surfaces- Insitu and Laboratory Tests for Laying course and Jointing

The critical component of the surface layer is the lock up achieved in the bedding and joint matrices.

The specification for the compaction of the bedding should be based on the degree of compaction achievable with the fine aggregate used. This should be ascertained in advance of construction from the supplier's information or by laboratory tests.

These tests should also establish the moisture content at which the fullest compaction of the material will be achieved – this is referred to as the Optimum Moisture content for compaction. Maintaining the material at or near to the derived optimum moisture content is critical to the compaction process and ultimately to the performance of the pavement.

A test protocol for an assessment of the compactibility of aggregate has been developed at Heriot-Watt University. Material is compacted in a 150mm diameter rigid mould using a 120mm-diameter centrally located plate. Details of the equipment are in an unpublished report, "Granite Sett Performance- Behaviour of Bedding Material", by MacRae (1999), Heriot-Watt University. Where depth of the bedding varies across the surface then a series of tests is required to be carried out to achieve the range of expected fully compacted bedding depths. This test determines the optimal moisture content of that specific aggregate.

During installation it is critical that the moisture content of the fine aggregate should be +/-2 percent of optimum during the stage of compaction to refusal. The surface layer should be compacted to refusal as described in Section 7.

After it is compacted the surface should be tested. A suitable end performance test is a plate-bearing test, using a 350mm plate to exert a bearing pressure of 600kPa. The settlement measured in the surface after the plate is applied should not exceed 2mm. With trench reinstatements a smaller plate is required. Here a 200mm plate should be used, at a bearing pressure of 800kPa. The settlement measured should not exceed 1mm.

At present, no end performance tests are available to assess the degree of lock-up in the joints and between individual elements resulting from the process of layer compaction. As previously described the degree of lock-up is time based after the surface is open to traffic. No data is yet available on the lock-up process under trafficking.

It is recommended that trial panels are constructed on site to check that the laying course materials can be kept and used at near optimum moisture content and to allow initial insitu tests to be undertaken before the main works start. Thus, if the intended performance is not achieved on the trial panels, then any necessary adjustments to materials composition and/ or site practices can be made.

Guidance

Materials for capping, sub bases and road bases for flexible construction are specified in accordance with current Road Standards.

Materials for laying course and joints are specified in accordance with BS 7533 Part 7.

It is crucial that these materials are laid close to their optimum moisture content, which should be determined prior to construction.

End performance testing should be specified to check that the pavement as constructed meets the design intention.

It is recommended that a trial panel be constructed to allow verification tests to be undertaken before the main works start.

6.5 Materials for Rigid Construction

6.5.1 Foundation for Rigid Construction

The foundation of the pavement has two basic elements, which have to be specified:

Strength of sub grade(CBR)	*(Section 4)*
Capping layer	*(Section 4).*

Another important characteristic of these foundations is that they should be permeable or should be laid with a fall to shed water.

6.5.1.1 Capping layer

Where low strength sub-grades are encountered and a capping layer is required to improve the bearing of the formation then it should meet the capping specification given in either the Specification for Highway Works or the Series 800 of the Manual of Contract Documents for Highway Works (MCHW).

6.5.2 Sub-base

Sub-base material should be a Granular Sub-base Material Type 1 complying with Clause 803, Specification for Highway Works or with Series 800 of the Manual of Contract Documents for Highway Works (MCHW).

Where a site is confined and material placement and compaction cannot comply with Clause 803, a dry bulk mass density or minimum CBR specification should be applied.

BS 7533 Part 7 requires 97% of the dry bulk density to be achieved. A nuclear density gauge should be used to check level of compaction on site. The dry bulk density has to be measured in the laboratory by testing the actual material to be used, to determine the optimum moisture content and the dry bulk density).

With the CBR specification, the minimum CBR should be 30 percent.

6.5.2.1 Profile Of Bases And Tolerances For Various Layers

Another important characteristic of the foundation layers and sub-base layer is that they should be permeable or should be laid with a fall to shed water. There is also a requirement, that in order to meet the tolerances on the laying course thickness, the base layers are profiled to follow the profile of the finished surface to within 5mm. (Section 7)

Annex B of the BS 7533 Part 7 gives the tolerances for different layers of the support structure in terms of the maximum permissible deviation from the design level, when measured over a 3m grid. The tolerances for each layer are shown in Figure 6.2. Additionally, Annex F of BS 7533 Part 7 provides longitudinal falls and cross falls to be applied to the completed pavement to prevent ponding. Again these are shown in Figure 6.2

Where the layer is within the tolerances of Annex B and where the layer profile follows the profile of the upper layers, which itself adheres to the guidance given in annex F relating to falls, then the lower layers will automatically shed water. These tables are repeated below as Figure 6.4

Therefore the profile of the foundation and base layers should be related to the profile of the finished surface.

6.5.3 Roadbase Layers for Rigid Construction

Type of Roadbase	*(Section 4, Section 7)*
Strength	*(Section 4, Section 7)*

A roadbase may be required for rigid constructions, particularly in areas of heavy loading.

If the design requires a roadbase layer then it would be typically

- Heavy duty bitumen macadam materials complying with either the Specification for Highway Works or the MCHW and associated standards with a penetration of about 100. There are however many materials and combinations of materials which might satisfy the structural design criteria and be suitable for use.
- Cement bound materials.

The choice here will depend on the choice of basecourse. If a further bitumen macadam layer is use for the basecourse then a similar roadbase would be more appropriate. If a concrete slab is used for the basecourse them CBM roadbase is preferred.

What is important is that whatever materials are specified they act in a rigid manner under load.

Additionally roadbases should be designed to be permeable, if possible, or be laid to shed water at the tolerances given in Figure 6.4.

Tolerance for Layers

Layer of Pavement	Flexible construction	Rigid Construction
	mm	Mm
Sub base	+20 -15	+15 -15
Roadbase	0 -12	± 5
Surface course	± 6	± 6

Falls for surface drainage.

Type of drainage	Recommended	Extreme limits
Crossfall rough elements recessed points smooth	 3.00% 2.50%	 1.5% to 7%
Longitudinal rough smooth	 Minimum 2.5% Minimum 1.25%	 Maximum 8% Maximum 8%

Note 1 Some materials can be laid on slopes steeper than these gradients, but as most paved areas are shared with pedestrians they would be considered to be un-walkable, 8% is considered to a comfortable maximum.
Note 2 To ensure positive drainage, the finish level of the paving to the top surface of drainage inlets and channel should be minimum of 5 mm. This is important to avoid ponding around drainage inlets or channels.
Note 3 In large paving areas, it is important to consider the resultant fall from the combination of cross fall and longitudinal fall. Large areas need to be divided into panels, which can be drained particularly where levels are constrained by edges of buildings etc

Figure 6.4 Tolerances for Layers and Falls for Surfaces

6.5.3.1 Heavy Duty Macadam Roadbase

A Heavy Duty Macadam roadbase should be designed to attain a minimum measured dynamic stiffness modulus of 5000MPa, when tested in compliance with BS DD 213: 1993. The material should be compacted to a minimum of 97 percent refusal density and site density should be measured using a calibrated nuclear density gauge.

6.5.3.2 Cement Bound Macadam Roadbase

Cement Bound Material Category 3 and 4 should comply with the requirements of Series 1000 Specification for Highway Works. Again the layer should attain a stiffness of 5000Mpa. The material should be compacted to a minimum of 97 percent refusal density and site density should be measured using a calibrated nuclear density gauge.

6.5.4 Basecourse Layers for Rigid Construction

A basecourse layer is normally required in all but the lightest loading categories where rigid constructions are used. It would be typically: -

- Heavy Duty Bitumen Macadam Material complying with either the Specification for Highway Works or the MCHW and associated standards with a penetration of about 100. (There are however many materials and combinations of materials which might satisfy the structural design criteria and be suitable for use).

- Cement Bound Material most probably in the form of a concrete slab

In all cases the basecourse should be permeable if possible, or be laid to shed water at the tolerances given in Figure 6.4 above.

Again what is important is that whatever material is specified the basecourse acts in a rigid manner.

6.5.4.1 Heavy Duty Macadam Basecourse

A Heavy Duty Macadam Basecourse should be designed to attain a minimum measured dynamic stiffness modulus of 5000MPa, when tested in compliance with BS DD 213: 1993. The material should be compacted to a minimum of 97 percent refusal density and site density will be measured using a calibrated nuclear density gauge.

6.5.4.2 Concrete Slab Basecourse

Concrete Slab Basecourse should comply with the requirements of the appropriate series of the Specification for Highway Works or the MCHW. Again the layer should attain a stiffness of 5000Mpa. The concrete should be designed, detailed and installed in accordance with current standards.

Guidance

Sub bases, roadbases and basecourses for rigid construction should be specified to comply with current specifications for the design and construction of roads together with associated material standards.

A variety of materials and combinations of these materials are appropriate but it is vital that the layer acts in a rigid manner.

The layer should be profiled to follow the finished surface to ensure that the subsequent layers can be laid to met tolerances and that water is shed from the surface of the layer

6.5.5 Laying Course and Joint materials for Rigid Construction

6.5.5.1 Specification Of Fine Concrete For Laying Course And Joint

a) **Fine concrete for laying course**

Minimum compressive strength	15N/mm^2	(depending on traffic load category)
Minimum adhesive strength	0.8N/mm^2	
Maximum Young's modulus	15000	

This fine concrete for laying course must be frost resistant and allow the passage of water through it after it has cured.

b) **Fine concrete for Jointing Material**

Minimum compressive strength	15-40N/mm^2	(depending on traffic load category)
Minimum flexural strength	6N/mm^2	
Minimum adhesive strength	1.2N/mm^2	
Maximum Young's modulus	20000	
Minimum density	2.0	

This jointing material must be frost resistant and resistant to de-icing salts
Fine Concrete for joints must achieve a balance between strength, durability, low shrinkage and workability.

The primary characteristics of fine concrete for both the laying course material and the jointing material which have to addressed when designing the concrete are: -

- **Strength** is not just compressive but also shear and flexural. Fine concrete made from small sized graded aggregate and cement with compressive strength values of between 10-15N/mm^2 have achieved measured composite shear strength values greater than 1N/mm^2, and flexural strength values greater than 1.5N/mm^2. When designed for high durability in environments where salt is used for de-icing, and which are shrinkage compensated, they have achieved shear strength values and flexural strength values in excess of 2.5N/mm^2 and 3N/mm^2 respectively. Whilst in-situ joint strength can be assessed using a Schmidt Hammer it is recommended that small diameter cores are taken from the surface and taken to the laboratory to test if the strengths properties are being achieved.

- **Durability** is achieved when the cement paste fully fills the voids within a fine aggregate structure; the fine aggregate structure should be fully packed within a joint.

- **Interface shear strength** is maximised when the face of a stone element is in full contact with the joint material; the face of a stone element should fully 'wet-out'. Wetting the surface of a stone element prior to filling ensures ease of joint filling and effective hydration of the cement at the stone surface. Full wetting-out of the face of a stone element is achieved when the volume of cement paste just exceeds that of the voids within the sand fine aggregate structure.

- The **Fluidity and Cohesiveness** of a concrete is controlled by the grading of the fine aggregate, water content and use of additives. The mix should use a grading of fine aggregates to enable full packing with little or no compaction energy i.e**. self-compacting concrete**. A further issue to be considered is the need for different workability for the laying course and the joints. The laying course concrete may have to be slightly stiffer that the concrete used in joints. The workability may also have to be altered if the laying course concrete has to be permeable as required by BS7533 in situations where the layer cannot otherwise shed water. Appropriate construction methods are discussed in Section 7.

- **Removal of surplus material** from the exposed surface of stone is controlled by the grading of the fine aggregate. Gradings with a minimum of fine factions are better. Appropriate construction methods are discussed in Section 7.

- The **shrinkage of concrete** is a function of the water to cement ratio used, and of the water absorbency of the fine aggregate. Shrinkage is more of a problem with higher strength concrete and additives can be introduced to compensate for shrinkage.

- The **Curing Time** of the concrete determines when the pavement can be subjected to traffic loading. The concrete used may have to achieve its design strength quickly to allow the pavement to be brought into use as soon as possible. Normally 28 days are allowed to let the concrete gain the specified characteristic strength. A standard concrete will achieve 2/3rds of its characteristic strength after 14 days, e.g. a 60N/mm2 concrete will achieve 40 N/mm2 at 14 days. Therefore if quicker curing is required then a higher strength concrete might be used in order that the "Design strength" is achieved within the 28-day period. Alternatively accelerating additives can be included in the concrete mix, although it is important that no secondary effects occur.

It is for the designer to agree with the supplier how to achieve these characteristics in the design of fine concrete for the laying and joint material for rigid pavements. Fine concrete should be mixed by volume. The volume of cement and water can be defined so that the volume of hydrated cement paste fully fills the void space created within the fine aggregate. Such fine concrete will achieve a high compressive strength.

Referring to the design tables in Section 4, the requirements for joint concrete are that it may have to be in the range of between 15 and 40 N/mm^2 compressive strength. To ensure compactibility it is recommended that the water to cement ratio should not exceed 0.7. As the strength increases and, in particular, for category 4 loading, compensatory additives should be introduced.

Concrete Design

Where a **simple concrete** is being used without additives or accelerated curing, the **designer** may be competent to decide on the mix to be used. This method design approach requires good quality control on site to ensure mix proportions are strictly adhered to, particularly the water to cement ratio. It is strongly recommended that all component materials are pre – bagged to ensure consistency of the mix. Where a more **complicated** concrete mix is required consideration should be given to using a performance specification with material being designed, manufactured and transported by the **supplier**. There are a number of “ high performance” **proprietary concrete mixes** available, many with particular properties. The performance characteristics of these materials can be assessed from data sheets, but it is recommended that the **manufacturer’s** advice be sought on the most appropriate use of their products in any given situation.

Guidance

The characteristic performance parameters for fine concrete are listed above and in BS7533 part 7: - Strength, Durability, Interface Shear Strength, Fluidity and Cohesiveness, Removal of Surplus Material, Shrinkage of Concrete, Curing Time

The fine concrete should be designed in conjunction with the supplier to take account of the primary characteristics of the concrete to ensure it can be used to meet the design intentions.

Where uncomplicated fine concrete can be used to meet the design intention, the designer may fell competent to specify the mix. Pre bagged materials should be specified to ensure consistency of workmanship. It is crucial to control the water content of site-batched concrete.

Where more complicated concrete is required it is recommended that the concrete is designed, manufactured and transported by the supplier.

If high performance proprietary materials are to be used the manufacturer should be involved at the design and specification stage.

6.5.6 End Performance Tests for Rigid Surfaces- Insitu and Laboratory tests for Laying Course and Jointing

6.5.6.1 Workability of Fine Concrete

A meter, which measures the workability of any concrete, has been developed at Heriot-watt University. This meter can be used to check the workability of fine concrete on site. The meter gives a “flow rate” value, which corresponds to the workability of the concrete. The measured value ought to be within a predetermined range for the concrete. This predetermined value should be obtained from tests carried out prior to works on site, at the stage of mixture design.

6.5.6.2 Depth of Joint Filling

The depth of joint filling should be checked on site by taking 18mm cores through joints at appropriate intervals, such as one core per $20m^2$ carrying Category 4 loading.

6.5.6.3 Strength of Fine Concrete

During laying, test cubes of fine concrete should be taken at the rate of one cube per $100m^2$ of surface. The cubes should be covered by damp hessian and stored adjacent to panels until time of testing. Cubes should be tested at 7,14 and 28 days to check that the fine concrete has achieved the specified strength and to check the curing rate. (This testing should be carried out in accordance with the standards for structural concrete).

6.5.6.4 Development of Strength during Curing Time

Progressive testing of the cubes helps define the rate at which joint mortar attains its design strength. Where this period (Curing Time) is critical, such as when the pavement has to be opened to traffic earlier than the recommended 28days, it is vital to ensure the test cubes cure under the same conditions as the fine concrete in the pavement. In this case cubes should be stored in a heated water bath with the temperature of the water controlled by a temperature probe set into a joint in the pavement. Consideration should be given to collecting such data from trial panels built prior to the actual pavement.

6.5.6.5 Shear Strength in Joints

As discussed in Section 4 the shear capacity between the joint concrete and the wall of the units is of prime importance in terms of structural capacity of the pavement. The shear capacity of the joint mortar is calculated by dividing the load in kn. by the total joint mortar area measured in m^2. This is easy to calculate but is difficult to measure in practice in a built surface. There is however a direct relationship between compressive strength and shear capacity as shown in Figure 6.5. This will require laboratory test, prior to construction, on trial mixes to check that the selected concrete achieves this relationship.

Figure 6.5 Relationship between Compressive Strength and Shear Capacity

Cube strength (N/mm^2)	*Minimum shear capacity (N/mm^2)*
8-12	1
13-17	1.4
18-22	1.8
23-27	2.2
28-32	2.6
33-37	3
38-	3.4

However this varies with types of stone and types of fine aggregates. To determine the relationship between shear strength and compressive strength requires a number of test samples taken from a trial panel constructed using the actual stone elements and fine concrete that have been specified.

Cubes compacted to the same degree as the concrete within the joints should be formed. The cubes should be covered by damp hessian and stored adjacent to panels until time of testing. Cubes strengths should be measured at the same time as the joint concrete is being subject to a pullout test. Pullout tests should be performed on individual elements within the trial panel. A minimum of three pullout tests should be performed with any single combination of stone element and mortar specification. The pullout load should be recorded. The depth of joint mortar should be measured in the hole left behind (or from 18mm cores). The shear capacity of the joint can then be calculated by dividing the load in kn. by the total joint mortar area measured in m^2. The relationship between compressive strength and shear capacity should lie within the data shown in Figure 6.5 above and should confirm the results of previous test undertaken at the design stage.

Once it has been established that the relationship between shear strength and compressive strength is correct, then subsequent successful testing of fine concrete for compressive strength will give confidence that the shear strength is also being achieved.

6.5.6.6 Proof Loading

Proof loading tests should be undertaken at an initial rate of one test per $50m^2$ of the surface area, increasing to one test per $200m^2$ of surface once data confirms the consistency and adequacy of construction.

With sett construction 100mm diameter cores should be taken from a surface. The cores should extend through the roadbase. Half of the cores should be trimmed to provide a cylinder including the stone element and attached bedding layer. The bedding layer should be at least 40mm thick. Trimmed cores can be used to measure the shear strength of the bond at the interfaces between the laying course and the stone unit.

Cores, which also have the basecourse material attached can be used to measure the shear strength of the bond at the interfaces between the basecourse and laying course.

Two laboratory compression tests should be undertaken to prove

- The strength of the overall construction
- The bearing strength of the laying course

In each case the proof load should be 70 percent of design failure load.

6.5.6.7 Scale of tests

The range of tests recommended here is extensive and may be impractical for small schemes although it may be that there is prior experience of the proposed materials and that proof loading tests have already established characteristic performance of the pavement construction to be used.

It is strongly recommended that at a minimum, 18mm cores are taken to check joint filling and that all cube testing of fine concrete describe above be undertaken.

Guidance

End performance testing should be specified to check that the pavement as constructed meets the design intention in terms of, Workability of Fine Concrete, Depth of Joint Filling, Strength of Fine Concrete, Development of Strength during Curing Time and Shear Strength in Joints

It is recommended that a trial panel is constructed to allow verification tests to be undertaken before the main works start.

6.6 Sample Specification

6.6.1 Typical materials

Table 6.3 is an example of a list of typical materials showing the reference for the material specification and for any sources of guidance on their use.

Figure 6.6 - Typical Materials Specification

Materials	*Specification*	*Guidance*
Sub-base, Type 1 CBM 3 & 4	MCHW Vol 1, Series 800 MCHW Vol 1, Series 1000, Clauses 1035 & 1038	MCHW Vol 2 “ “
20mm open graded bitumen macadam basecourse 20mm dense bitumen macadam basecourse Dense Bitumen Macadam roadbase Heavy Duty Macadam roadbase	BS 4987 : Part 1 : 1993 Clause 6 with loading category 1 BS 4987 : Part 1 : 1993 Clause 6.5 MCHW Vol. 1, Series 900, Clause 903 with a binder penetration of 100 pen max. MCHW Vol. 1, Series 900, Clause 930	BS 4987 : Part 2 : 1993 BS 4987 : Part 2 : 1993 MCHW Vol 2/ BS 4987 :Part 2 MCHW Vol. 2/ BS 4987 :Part 2
Bedding materials	BS 7533	Sections 4, 6 & 7
Jointing materials	BS 7533	Sections 4, 6 & 7
Natural stone material Natural stone product	En 1341, BS 7533 En 1341, BS 7533	Section 3 and MATHESON G D (1999). The Characterisation and Specification of Natural Stone Setts for Streetscape Work. *Report P/1013/2/IB/SKM, Matlock Consulting Ltd*.
Natural stone slabs	EN 1341 :1993	

This listing is not intended to be prescriptive but to indicate materials, which are readily available and meet the practical guidance of this document. There are alternatives to these materials, which can be selected by an experienced designer, which if used correctly, will provide the same level of performance in the final pavement.