3. SELECTION OF STONE

3.1 Introduction

Stone materials can account for up to half of the cost of a natural stone streetscape contract. Consequently the selection of stone that is fit for the purpose is a critical part of the project process. Desirable properties that need to be considered relate to the aesthetic, dimensional and physical characteristics of the material comprising the sett element and of the sett element itself. Three European Standards specify the performance requirements and the corresponding test methods:-

a. EN 1341:2000 Slabs of natural stone for external paving – Requirements and test methods.
b. EN 1342:2000 Setts of natural stone for external paving – Requirements and test methods
c. EN 1343:2000 Kerbs of natural stone for external paving – Requirements and test methods

Combined, these standards cover most of the common elements of natural stone surfacing used in streetscape contracts. Each has the status of a British Standard, is mandatory, and takes precedence over all other standards and test methods. Formal specification, evaluation and acceptance of manufactured slabs, setts and kerbs must therefore be in terms of these three standards. However, they do not cover the effect of de-icing salts, an issue likely to be of particular significance in streetscapes.

Guidance
European Standards EN1341, EN 1342, and EN1343 specify the performance requirements and the corresponding test methods for slabs, setts and kerbs – the common stone elements in streetscape contracts. In other sections of the present Good Practice Guide, which deal primarily with pavement design, slabs are broadly classified as flagstones and tiles; setts as cubes, setts and blocks; and kerbs as blocks used for kerbing.

The EN Standards specify the requirements and test methods, and provide for product marking and for the evaluation of conformity. They also cover properties that are important to the trade and as such are primarily directed at producers and suppliers who are required to closely define (in test reports) and control the properties of their products. The designer or buyer can then choose which product will meet his design requirements and be assured that he will be supplied with a product which closely conforms to these requirements. The standards do not provide instruction on design requirements.

The present guide deals primarily with the dimensional and physical properties of the stone elements as required by the European Standards listed above, gives additional guidance on stone selection and design requirements, and discusses other criteria and tests method of relevance. It not concerned with the purely aesthetic design issues of either the stone or the stone elements as this has been dealt with elsewhere (Scottish Enterprise, 1997). However, common laying patterns are described in Section 7.3.5.

The additional guidance and discussion concern desirable geological and engineering properties of both material and product, which are considered relevant to the general selection of stone. These include the aesthetic, geological and engineering properties of the naturally occurring material (the in-situ rock), of quarried blocks (the extracted rock) and of the manufactured product (the stone element). Such properties may be different in the natural material and the finished product and an awareness of the issues involved is important in ensuring fitness for purpose. Much of this guidance has been based on independent work for Glasgow City Council (Matheson, 1999; Matheson, 2000) in which desirable material and product properties, and quality systems for source evaluation and manufacture of natural stone setts, were investigated. It must be stressed however that the additional guidance in no way replaces the requirements of the European Standards.

3.2 European Standard (EN) requirements

European Standards EN 1341:2000, EN 1342:2000 and EN 1343:2000 define specific physical properties and methods of testing to be used for natural stone slabs, setts and kerbs respectively and define methods of evaluating conformity and acceptance. Each standard contains a list of properties and describes reference tests that are to be used determine these properties. These reference tests are included in normative annexes to the standards. Limited further guidance is included in informative annexes.

The list of properties is common to all to all three stone elements and comprises dimensions, flatness of surface, freeze/thaw resistance, flexural or compressive strength, abrasion resistance, slip resistance, aspects, water absorption, petrographic description and surface treatment. Selection should be from this list and be consistent with the product type's intended usage.

In the present guide, the above properties have been grouped into two categories: measurement of the dimensional properties of the stone elements themselves, and geological and engineering testing of the material forming the stone elements. These are dealt with separately in the following sections.

Measurements of the dimensional properties are carried out on representative samples of the stone element themselves, but geological and engineering tests are primarily carried out on specimens cut from the stone elements. Only exceptionally, in the case of very small stone elements, are engineering tests carried out on a whole sett element. It is important therefore that samples prepared for testing are truly representative of the sett elements and are tested in a manner that reflects their intended usage.

3.2.1 Methods used to determine dimensional properties.

Stone elements are individually manufactured products, which are repeated many times over in a pavement design, and although the design may call for different sizes, shapes and colours, the individual stone elements tend not to be random but carefully controlled to produce a desired effect. There is therefore usually extensive repetition of only a limited number of basic sizes, in a limited range of shapes and colours. Standard methods and techniques of measurement are therefore appropriate and have been defined separately for slabs, setts and kerbs. The EN dimensional requirements are illustrated in Figures 3.1, 3.2, and 3,3 and are described in the following text.

Guidance
Unless supplied as random sized, the dimensional properties of the common types of stone elements and the methods of measurement are closely controlled in the EN Standards, and are determined by measurement of the stone element itself.

Slabs are defined in EN 1341:2000 according to their length and width, and by the irregularity, flatness and straightness of their upper face. Where edges have been sawn then direct measurements of the overall dimensions of the stone element are made and the rectangularity of the upper face established by measuring the face diagonals. Where slabs have been riven or hewn then the edges are considered too irregular for precise measurement to be made, and the slab is inserted into an adjustable rectangular box and overall measurements taken between opposing internal sides of the box. In the case of textured flags only, thickness is measured at four points near the corners and the mean, maximum and minimum calculated.

The supplier is required to state the work dimensions of each slab that is tested, unless supplied in random sizes. Where supplied in running lengths, only the widths and thickness need be stated.

Setts are defined in EN 1342:2000 according to their overall width and height, face irregularity, chamfer and undercut. Dimensions are established by taking a number of measurements and calculating the mean, maximum and minimum for width, height and irregularity. Chamfer and undercut are defined at each end using a graduated square on the face, held against the vertical side, and direct measurements made.

The supplier is required to state the work dimensions of each sett that is tested, unless supplied in random sizes.

Kerbs are defined in EN 1343:2000 according to their overall length, width and height, face irregularity, face deviation, chamfer, splay and batter, and radius. Overall dimensions are established by taking a number of measurements and calculating the mean, maximum and minimum for width and height. Face irregularity is measured directly using a profile gauge and the maximum and minimum calculated for four imaginary areas. Face deviation is defined by measuring edge straightness parallel and perpendicular to the top face, and perpendicularity and distortion by using a straight edge and feeler gauges. Chamfer, splay and batter are determined at both ends using a calibrated square on the face, held against the vertical side, and direct measurements made. Radius is determined by placing templates of known radii against the top edge of the face in the case of square kerbs and at the bottom of the chamfer in chamfered kerbs.

Kerbs are normally supplied in free running lengths. Curved kerbs are required to be identified by the supplier in terms of the radius of the vertical face and the maximum working length, where the length is the greatest diameter, and the ends are required to be radial. The minimum length of a curved kerb is 500 mm. Where kerbs have square arrises, there may be a chamfer with vertical or horizontal dimensions not exceeding 2mm. The supplier must declare the dimensions of larger chamfers, splays or batters.

The number of measurements and calculations involved in their determination, and the relevant EN Standard, are summarised in Table 3.1. Measurements are carried out with equipment with an accuracy of 0.5mm, overall dimensions and calculations taken to the nearest mm.

Table 3.1 Dimensional measurement and calculation requirements

Stone Element:	**Slab**		**Sett**	**Kerb**
Definition:	Natural stone paving element with width >150mm and >2 times thickness		Natural stone paving element with length and width 50 to 300mm and not > 2 times thickness. Min. thickness 50mm	Natural stone paving Element, length = or >300mm and used as edging.
Type:	Sawn Edge	Riven or Hewn Edge	All	All
Standard:	**EN 1341:2000**		**EN 1342:2000**	**EN 1343:2000**
Normative Annex:	**A**	**A**	**A**	**A**
Measurement:- Plan				
Length	(4)	(1)		
Mean	(1)			
Width	(4)	(1)	(4)	(4)
Mean			(1)	(1)
Maximum			(1)	(1)
Minimum			(1)	(1)
Diagonal	(2)			
Difference	(1)			
Thickness/Height	(4)*	(4)*	(4)	(4)
Mean	(1)*	(1)*	(1)	(1)
Maximum	(1)*	(1)*	(1)	(1)
Minimum	(1)*	(1)*	(1)	(1)
Face				
Irregularity	(8)	(8)	(8)	(8)
Maximum	(4)	(4)	(4)	(4)
Minimum	(4)	(4)	(4)	(4)
Deviation				
Flatness & Straightness	(2)*	(2)*		
Edge Straightness				(8)
Perpendicularity				(4)
Distortion				(2)
Chamfer & undercut			(8)	
Chamfers, splays and batters				(4)
Radius (Template)				(1)
Test Report Required	Yes	Yes	Yes	Yes

(Numbers in brackets indicate the number of individual measurements or calculations required)
*Textured only

3.2.2 Permissible dimensional deviation

Stone elements are classed according to a permissible deviation and receive marking designations based on some of the classification criteria and the deviation permissible. Separate requirements are defined for slabs, setts and kerbs in terms of plan dimensions, thickness, face irregularities and flatness and straightness and marking designations designated accordingly. These are summarised in Tables 3.2, 3.3, and 3.4. Procedures for measurement and calculation are complex and the reader is referred to the appropriate EN Standard for detailed instruction.

Guidance
Permissible deviations in the dimensional properties of stone elements are closely controlled by the EN Standards. Marking designations for slabs, setts and kerbs have been defined in terms of permissible deviation, Two main classes (**1** and **2**) are defined for slabs, setts and kerbs, according to decreasing deviations in the main dimensional properties. An additional class (**0**), in which thickness is undefined, is established for slabs.

Table 3.2. Permissible dimensional deviation and marking designations for slabs.

Stone Element	**Slabs**				
	Size	**Class**			**Comments**
		0	**1**	**2**	
Dimension					
Plan					
Sawn edges	=< 700 mm	n/a	± 4 mm	± 2 mm	Deviation
Sawn edges	>700 mm		± 5 mm	± 3 mm	Deviation
Riven edges	All sizes		± 10 mm	± 10 mm	Deviation
Marking Designation			***P1***	***P2***	
Diagonals	<700 mm	n/a	± 6mm	± 3mm	Difference
	=> 700 mm		± 8mm	± 6mm	Difference
Marking Designation			***D1***	***D2***	
Thickness					
Textured only	=< 30 mm	No requirement	± 3 mm	± 10%	Deviation
	>30 mm and <=60 mm		± 4 mm	± 3 mm	Deviation
	>60 mm		± 5 mm	± 4 mm	Deviation
Marking Designation		***T0***	***T1***	***T2***	
Face Irregularities					
Riven only	All sizes	Max. 20 mm above, 0 (zero) mm below work surface			
Flatness & Straightness					
Arrises		**Longest test straight edge**			
		0,5 m	1 m	1.5m	
Fine textured face		± 2mm	± 3mm	± 4mm	Deviation
Coarse textured face		± 3mm	± 4mm	± 6mm	Deviation
Thickness	>30 mm =< 60 mm	No requirement	± 4mm	± 3mm	Deviation
	>60 mm		± 5mm	± 4mm	Deviation
Faces		**Gauge length**	**Max convex**	**Max concave**	
Fine textured		300 mm	2.0 mm	1.0 mm	Max Deviation
		500 mm	3.0 mm	2.0 mm	Max Deviation
		800 mm	4.0 mm	3.0 mm	Max Deviation
		1000 mm	5.0 mm	4.0 mm	Max Deviation
Coarse textured		300 mm	3.0 mm	2.0 mm	Max Deviation
		500 mm	4.0 mm	3.0 mm	Max Deviation
		800 mm	5.0 mm	4.0 mm	Max Deviation
		1000 mm	8.0 mm	6.0 mm	Max Deviation
Arrises					
Sharp or square	All sizes	=< 2 mm			Of stated dimens.
Chamfered or rounded	All sizes	± 2 mm			Of stated dimens.

Table 3.3 Permissible dimensional deviations and marking designations for setts

Stone Element	Setts			
	Size	Class		Comments
		1	2	
Dimension				
Plan				
Between riven faces	All sizes	± 15mm		Deviation
Between textured faces	All sizes	± 5mm		Deviation
Between riven and textured	All sizes	± 10mm		Deviation
Thickness				
Between riven faces	All sizes	± 30 mm	± 15 mm	Deviation
Between textured faces	All sizes	± 30 mm	± 5 mm	Deviation
Between riven and textured	All sizes	± 30 mm	± 10 mm	Deviation
Marking Designation		***T1***	***T2***	
Undercut of riven sides				
Perpendicularity	All sizes	<= 15mm		Max. Deviation
Face Irregularity				
Riven	All sizes	± 5 mm		Max. Cavity or Protrusion
Textured	All sizes	± 3 mm		
N.B. when setts are to be laid in fan shaped arrangements then a maximum of 10% of setts, The dimensions of which can lie outside the above deviations by up to 10mm, may be included in the delivery.				

Table 3.4 Permissible dimensional deviations and marking designations for kerbs

Stone Element	Kerbs			
	Size	Class		Comments
		1	2	
Dimension				
Overall Width				
Between hewn faces	All sizes	± 10 mm		Deviation as laid
Between textured faces	All sizes	± 3 mm		Deviation as laid
Between textured and hewn	All sizes	± 5 mm		Deviation as laid
Overall Height				
Between hewn faces	All sizes	± 30 mm	± 20 mm	Deviation as laid
Between textured faces	All sizes	± 10 mm	± 10 mm	Deviation as laid
Between textured and hewn	All sizes	± 30 mm	± 20 mm	Deviation as laid
Marking Designation		***H1***	***H2***	
Batter				
Sawn	All sizes	± 5 mm	± 2 mm	Deviation
Hewn	All sizes	± 15 mm	± 15 mm	Deviation
Textured	All sizes	± 5 mm	± 5 mm	Deviation
Marking Designation		***D1***	***D2***	
Faces				
Straight kerbs only		**Hewn**	**Textured**	
Edge straightness (a)	All sizes	± 6 mm	± 3 mm	Parallel top face
(b)	All sizes	± 6 mm	± 3 mm	Perpend. top face
Perpendicularity (a)	All sizes	+10mm–15 mm	+7mm–10 mm	Top face to front
(b)	All sizes	± 5 mm		Top face to end
Distortion	All sizes	± 10 mm	± 5 mm	Top face
Radius				
Curved Kerbs only	All sizes	=< 2%		Max. Deviation
Face Irregularities				
Hewn	All sizes	+ 10 mm, -15 mm		Deviation
Coarse Textured	All sizes	+5 mm, - 10 mm		Deviation
Fine Textured	All sizes	± 3 mm		Deviation

3.2.3 Methods used to define geological and engineering properties.

The minimum requirements for natural stone paving elements is that they should be produced from a material that is fit for the intended purpose and durable enough to maintain this fitness for purpose over the design life of the streetscape. However stone elements are expected to be reused (recycled) and their life must therefore be considerably greater than that of a streetscape. Consequently, it would be reasonable to expect that the design life of a natural stone element should be in excess of 100yrs. This requires that the durability be beyond reproach.

There is an extremely wide range of geological and engineering properties that could be used to define the required properties of stone elements. The problem lies in deciding which of the many properties are desirable and relevant to the situation in which the material is being used and their measurement. In the EN Standards, appropriate properties and test methods are defined separately for slabs, setts and kerbs. These are summarised in Table 3.5 and described in the following text.

All three EN Standards relating to stone elements also include an informative annex on the measurement of **Longitudinal Fundamental Resonance Frequency**. The relevance and intended usage is uncertain as neither the method nor the annex is referred to in any text in the EN Standards.

> **Guidance**
> The Geological and Engineering properties of the common types of stone elements and the methods used for testing are defined in the EN Standards and are usually determined on samples taken from the stone element.

Table 3.5 Methods used to determine geological and engineering properties.

Stone Element:	**Slabs**	**Setts**	**Kerbs**
Standard:	**EN1341:2000**	**EN1342:2000**	**EN1343:2000**
Property:-			
Geological.			
Aspects	Reference Sample	Reference Sample	Reference Sample
	(Annex F)	**(Annex F)**	**(Annex D)**
Petrography	Petrographic descript.	Petrographic descript.	Petrographic descript.
	(Annex H)	**(Annex H)**	**(Annex F)**
Engineering.			
Porosity	Water Absorption	Water Absorption	Water Absorption
	(Annex G)	**(Annex G)**	**(Annex E)**
Strength	Flexural Strength	Compressive Strength	Flexural Strength
	(Annex C)	**(Annex C)**	**(Annex C)**
Durability	Freeze/thaw resistance	Freeze/thaw resistance	Freeze/thaw resistance
	(Annex B)	**(Annex B)**	**(Annex B)**
	Abrasion resistance	Abrasion resistance	none
	(Annex D)	**(Annex D)**	
Slip/Skid Resistance	Slip resistance	Slip resistance	none
	(Annex E)	**(Annex E)**	
Chemical Surface Treatment	Statement of any treatment carried out		

Aspects are the geological properties of the natural material related to its visual appearance, texture or colour. They are characterised by providing a reference sample, or samples, comprising a number of pieces of the natural stone of sufficient size to indicate the appearance of the final product; the required dimensions are between 0.01 m^2 and 0.25 m^2 in face area. The use of the reference sample avoids the need for what could be complex and detailed text defining the visual properties of the natural stone and considerably simplifies a comparison between the intended stone and that actually supplied to the contract. However, comparisons between the reference sample and test specimens are carried out by viewing them at a distance of two metres and recording any visible differences. This means that only macroscopic features can be referenced in this manner. Smaller scale features are dealt with in the petrographic description of the rock. Guidance on the selection of aspects for a streetscape design is contained in Scottish Enterprise (1997).

Petrography relates to the determination of the macroscopic properties of the rock by visual evaluation of hand specimens and the microscopic properties by thin section evaluation using a petrographic microscope. The resultant petrographic description characterises the colour, fabric, mineralogy, grain size, cracks, cavities and evidence of weathering and alteration in both hand specimens and thin sections. An objective, quantitative microscopic assessment is obtained by using a point counter. The sample and thin section coverage must be large enough to be representative of the petrographic characteristics of the stone being examined and may involve large or multiple thin sections (each typically 3 cm x 2 cm) if the rock has a directional fabric. The objectives of the evaluations are to enable petrographic classification of the material, and to highlight undesirable chemical, physical and mechanical features that might influence behaviour in both the short and long term.

Porosity is an indication of the free intergranular or interstitial pore space in the material and can be estimated by carrying out water absorption testing. At least five specimens are required to be tested. In general, materials high in water absorption tend to be the least strong and durable.

Strength takes many forms but in the present context has been defined as the Flexural Strength for slabs and kerbs and the Compressive Strength for setts. **Flexural Strength** of slabs and kerbs is measured by determining the minimum breaking load when a specimen is placed on two rollers and the load applied in the middle. At least six specimens are required. **Compressive Strength** of setts is measured by testing at least six specimens in the form of cubes or cylinders prepared to defined dimensions related to the expected strength and grain size in the rock. In all stone elements, the appropriate strength must be high enough to resist the vertical loading expected on the site.

Durability is an indication of the ability of the material to resist change, In particular, its ability to resist the effects of climatic change is defined by its Freeze/thaw resistance and its ability to resist the abrasive action of traffic (vehicular and pedestrian) by its Abrasion resistance. **Freeze/thaw resistance** is determined by a test comprising cycles of freezing in air and thawing in water. At least six specimens are required each in the form of a rectangular prism, tested with the long axis parallel to the bedding plane or other anisotropic feature. **Abrasion resistance** is determined using a test which abrades the upper face of the stone element with an abrasive material applied to a rotating abrasion wheel under controlled conditions. The result is a function of the size of the groove produced in the specimen. At least six specimens have to be tested and must incorporate the upper face of the element. There is no requirement to carry out abrasion resistance testing of **kerbs.** In all stone elements, the durability must be high enough for the material to retain its fitness for purpose over the design life.

Slip/Skid resistance is an indication of the frictional properties of the surface of the stone element and its ability to resist pedestrian slipping and vehicular skidding. Coarse textured surfaces cannot be reliably tested and are assumed to give satisfactory slip resistance. The slip resistance of fine textured surfaces of **slabs and setts** is defined by the **Unpolished Slip Resistance Value** determined using the Pendulum Friction Tester. At least six specimens are required with testing being carried out using the 76mm wide or 31.8mm slider depending on specimen size. It should be noted that the Unpolished Slip Resistance Value relates to the stone elements as manufactured and helps to ensure adequate slip/skid resistance on installation. There is no requirement to carry out the slip resistance testing of **kerbs**.

Chemical surface treatment could effect other geological or engineering properties in time and any such treatment must be declared and described by the producer/supplier.

3.2.4 Permissible geological and engineering deviation

The supplier is required to state the geological and engineering properties in terms of the required geological properties and the defined test methods. The stone elements are classed according to the permissible deviation and receive marking designations based on some of the classification criteria and the deviation permissible (usually a maximum or minimum of an expected value). Separate requirements are defined for slabs, setts and kerbs. These are summarised in Tables 3.6, 3.7 and 3.8. Procedures for sampling and testing are complex and the reader is referred to the appropriate EN Standard for detailed instruction.

Guidance

Permissible deviation in the geological and engineering properties of a stone element are closely controlled in the EN Standards according to previously defined classes and the expected values. However, marking designations are only set for frost resistance.

Table 3.6 Permissible geological and engineering deviations in slabs

Stone Element	Slab		
	Class		Comments
	0	1	
Property			
Geological			
Aspects	As Reference Sample		Also shows surface finish
Petrography	According to Petrographic Report		
Engineering			
General			
Water Absorption	Maximum value expected		% by mass
Strength			
Flexural	Minimum value expected		MPa
Durability			
Freeze/thaw Resistance	No requirement	Resistant	No. cycles before failure
Marking Designation	***F0***	***F1***	
Abrasion Resistance	Maximum value expected		mm
Surface Texture			
Slip Resistance	Minimum value expected		USRV

Table 3.7 Permissible geological and engineering deviations in setts

Stone Element	Sett		
	Class		Comments
	0	1	
Property			
Geological			
Aspects	As Reference Sample		Also shows surface finish
Petrography	According to Petrographic Report		
Engineering			
General			
Water Absorption	Maximum value expected		% by mass
Strength			
Compressive	Minimum value expected		MPa
Durability			
Freeze/thaw Resistance	No requirement	Resistant	No. cycles before failure
Marking Designation	***F0***	***F1***	
Surface Texture			
Slip Resistance	Minimum value expected		USRV

Table 3.8 Permissible geological and engineering deviations in kerbs

Stone Element	Kerb		
	Class		Comments
	0	1	
Property			
Geological			
Aspects	As Reference Sample		Also shows surface finish
Petrography	According to Petrographic Report		
Engineering			
General			
Water Absorption	Maximum value expected		% by mass
Strength			
Flexural	Minimum value expected		MPa
Durability			
Freeze/thaw Resistance	No requirement	Resistant	No.of Cycles for 1% loss
Marking Designation	***F0***	***F1***	
Abrasion Resistance	Maximum value expected		mm

3.2.5 Evaluation of conformity

The producer or supplier is required to demonstrate compliance of his product, either new or existing, with the requirements of the relevant standards and with the declared values or classes for the current properties, by carrying out initial testing and factory production control. The values declared must be representative of current production, for example the lowest expected value or the minimum test value in normal production.

> **Guidance**
> The producer or supplier is required to demonstrate the compliance of his product with EN Standards.

Conformity must be accomplished by initial type testing (using tests from the defined properties list) and factory production control, the last mention including incoming raw materials, production processes, finished product testing and stock control. Details of quality systems that could be used are described in Matheson (2000).

3.2.6 Acceptance criteria

Acceptance involves the sampling and testing of the stone elements supplied. Samples from batches delivered by the manufacturer or supplier are obtained using methods consistent with the physical form of the consignment in question. Whenever possible random sampling is used, in which every unit of the consignment has an equal chance of being selected for the sample. When random sampling is impractical or not convenient, a representative sampling procedure can be used. Tests are then carried out on the samples to establish conformity.

> **Guidance**
> Acceptance of stone elements involves sampling and testing after delivery, using random sampling methods whenever possible and comparing each result with that expected.

Acceptance is on the basis of the stone elements satisfying the conformity criteria and falling within the limits defined previously for permissible deviations according to property, class and test method (see Tables 3.6, 3.7 and 3.8). The situation regarding criteria for acceptance, based on the relevant EN Standards, is summarised in Table 3.9

Table 3.9 Acceptance criteria

Standard:		**EN1341:2000**	**EN1342:2000**	**EN1343:2000**	**Comments**
Stone Element:		**Slabs**	**Setts**	**Kerbs**	
		Acceptance Values			
Property	**Basis**				
Dimensions					
All	EN limits	Table 3.1	Table 3.2	Table 3.3	EN (normative)
Geological					
Aspect	Ref. Sample	As expected			
Petrography	Test Report	As expected			
Engineering					
Water Absorption	Maximum value	As expected			
Strength					
Compressive	Minimum value	n/a	As expected	n/a	
Flexural	Minimum value	As expected	n/a	As expected	
Breaking Load	Minimum value	Table 3.10	n/a	Table 3.10	EN (informative)
		(Annex K)		**(Annex J)**	
Durability					
Freeze/Thaw Resistance	Resistant/ not resistant	As expected	As expected	As expected	
Abrasion Resistance	Maximum value	As expected	As expected	n/a	
Surface Texture					
Slip Resistance	Minimum USRV	>35	>35	n/a	EN (informative)
		(Annex L)	**(Annex K)**		

(Note. The "As expected" values are those defined by the manufacturer or supplier for the product.)

The criteria for dimensional acceptance are closely defined but for the geological and engineering requirements they are mostly inferred or on the basis of an *expected* minimum or maximum value. Very little guidance is given to the designer or specifier on what these expected values should be. Informative guidance is however contained in the EN Standards regarding minimum strength (in terms of breaking load) and minimum slip resistance, and is included in Table 3.9.

Guidance

All stone elements must satisfy EN acceptance criteria for dimensional properties and permissible deviations. However, for geological and engineering properties, EN Standards only give informative advice on acceptability limits for breaking load and slip resistance.

The **minimum strength** of slabs and kerbs is defined in terms of **breaking loads** for different classes of use. Six new classes (not comparable to those previously defined) are recognised. The breaking load is calculated using the equation:-

$$P = (R_{tf} \times W \times T^2) / (1500 \times L \times 1.6)$$

where

- P is the minimum breaking load (kN)
- Rtf is the flexural strength (MPa)
- W is the width (mm)
- T is the thickness (mm)
- L is the length (mm)
- 1.6 is a safety factor

This equation is valid for all work dimensions up to 900 mm

Requirements and typical use are summarised in Table 3.10. Note that the class and typical use are different from the loading and site categories used for pavement design in the present guide.

Table 3.10 Suggested breaking loads of slabs and kerbs for different classes of use

Class	Min. Breaking Load kN	Typical Use
0	No requirement	Decoration
1	0.75	Slabs bedded in mortar, pedestrian areas only
2	3.5	Pedestrian and cycle areas. Gardens, balconies
3	6.0	Occasional car, light vehicle and motorcycle access. Garage entrances
4	9.0	Walking areas, market places occasionally used by delivery vehicles and emergency vehicles
5	14.0	Pedestrian areas often used by heavy vehicles
6	25.0	Roads and streets, petrol stations

The equation also allows the flexural strength or the thickness for any given class to be calculated when the breaking load and other dimensions are known. The relationship is illustrated in Fig 3.4.

The **minimum slip resistance** for slabs and setts is indicated in the EN Standards in terms of Safety in Use, where it is stated that "experience has indicated that an **USRV** of greater than 35 can usually be considered safe".

Guidance
Informative guidance on minimum strengths of slabs and kerbs is given in the EN standards in terms of class of use and breaking load. Informative guidance on minimum slip resistance of slabs and setts is given in the EN standards in terms of USRV, values greater than 35 usually being considered safe.

3.2.7. Discussion

In the EN Standards, dimensional requirements, methods of measurement, permissible deviation, conformity and acceptance criteria for the commonest natural stone elements are closely defined and measurement is carried out on the stone elements themselves. There is therefore little cause for ambiguity and a clear idea of the requirements is given. Implementation of these EN Standards will therefore ensure that slabs, setts and kerbs within the required dimensional tolerances can be specified, manufactured, delivered, and that acceptance checks can be carried out on site.

Geological and engineering requirements are less clearly defined and although test methods are described, acceptance limits are left for the designer or buyer to set. EN guidance is only given for minimum breaking load and minimum slip resistance (see Table 3.9.) In addition, testing is normally carried out on samples from a stone element and results may relate more to the material forming the stone element than to the stone element itself. Testing for the likely effects of de-icing salts is also not covered. Further guidance on these issues, and on other aspects considered important in stone and stone element selection, is therefore considered necessary and included in the following sections.

3.3. Additional guidance

The EN Standards are concerned with the permissible dimensional deviations allowed on stone elements of a particular size and shape, and how these are measured; they do not define the basic size and shape. Similarly they are concerned with the test methods to be used to define geological and engineering properties and how conformity with product test reports are to be assessed; they do not define basic geological and engineering requirements. The designer or buyer must set these.

3.3.1. Specification

The designer and buyer must have an understanding of the design implications to both the product (the stone element) and the material (the rock), and be able to specify these in terms of the relevant EN Standard. Such specification would normally be prepared by the designer and written into the specification for the streetscape works and/or the contract for the supply of the stone elements. Although much of this can be based on basic product sizes, descriptions and test results from the producer or supplier, there is still the need to ensure that the stone elements on offer are compatible with for the intended use. This means that the “expected values” in Table 3.9 need to be defined in terms of the streetscape works.

Design requirements for dimensions and shape can be specified by defining the nominal size and shape of the stone elements. For geological properties, an evaluation of the reference sample and the petrological report needs to be made in terms of suitability for the intended use – preferably by an engineering geologist (see Section 3.3.7). For engineering properties, appropriate minimum or maximum test values for each parameter need to be set as acceptance limits. Suggestions for these, based mainly on experience, are given in Table 3.11. Only the dimensional deviations are as defined, and guidance on breaking load and slip resistance as given, in the appropriate EN Standard,

Although there is no requirement in the EN for the slip resistance and abrasion resistance testing of kerbs it is recommended that the same requirements for slabs and setts be applied.

Table 3.11 Specification parameters and possible acceptance limits.

* No EN requirement

Standard:		**EN1341:2000**	**EN1342:2000**	**EN1343:2000**	
Stone Element:		**Slabs**	**Setts**	**Kerbs**	**Comments**
	Specification parameters				
Property	**Basis**	**Possible Limits**			
Dimensions					
All	Size, shape	Permissible Deviation as defined in EN			EN (normative)
Geological					
Aspect	Ref. Sample	No significant difference			Suggested
Petrography	Test Report	No significant difference			Suggested
Engineering					
Water Absorption	Maximum value	2%			Suggested
Strength					
Compressive	Minimum value	n/a	100 MPa	n/a	Suggested
Flexural	Minimum value	See Table 3.10	n/a	See Table 3.10	EN (informative)
Breaking Load	Minimum value		n/a		
Durability					
Freeze/Thaw Resistance	Resistant/ not resistant	Min 28 cycles	Min 28 cycles	Min 28 cycles	Suggested
Abrasion Resistan	Maximum value	23 mm	23 mm	23 mm*	Suggested
Surface Texture					
Slip Resistance	USRV	>35	>35	>35*	EN (informative)
Chemical Surface Treatment	No adverse effect on geological or engineering properties				Suggested

All informative and suggested limits are intended for guidance only and must be set with the intended usage in mind. This is particularly true in the case of EN engineering test methods, on which UK experience is extremely limited.

3.3.2. Product integrity

Integrity in a stone element is regarded as freedom from flaws or weaknesses that could affect its performance and durability. It should be noted that characteristics visible in the reference sample, such as glass seams, spots holes for travertine, worm holes for marble crystalline veins and rusty spots are not considered by the EN Standards as being flaws. However planar weaknesses (generally termed “discontinuities”) can also be present and can significantly alter the strength and durability. Such discontinuities can be either natural (e.g. joints, fractures, bedding or banding planes, foliation, schistosity, cleavage) or induced by the method of excavation (i.e. blast or stress-induced fractures), the last mentioned caused by inappropriate methods of extraction or production. These discontinuities may not be visible in a reference sample when viewed at the distance of two metres as instructed in the EN Standards.

In addition, specimens prepared for geological or engineering testing according to the EN Standards may not contain the discontinuities present at a larger scale. Test results may therefore accurately reflect the properties of the intact (unfractured) material but may not reflect those of the whole stone element. Integrity of each stone element is consequently important and must be in terms of the whole element. It is therefore recommended that a close visual assessment of each stone element is carried out to estimate whether it is suitable for its installation and is free of natural or induced fractures that could adversely affect durability. Ideally this should be part of the factory control system. Stone elements that contain significant weaknesses and have been delivered to site, should be rejected.

Guidance
Stone elements containing visible fractures likely to affect strength or durability should be rejected. Fractures are often best seen by wetting the stone and letting it dry. Any fractures are then often more obvious as they do not dry as rapidly as the exposed surface.

3.3.3. Surface texture

Surface texture is an important characteristic for all faces on a stone element. The texture and finish on the upper surface will influence the skid resistance, evenness and aesthetics of the final pavement surface. The surface texture of the hidden element faces will influence the friction and adhesive characteristics with the adjacent mortar or bedding

The categorization adopted in the EN Standards for slabs, setts and kerbs divides surface texture into fine (<0.5mm), medium (0.5mm to 2.0mm) and coarse (>2mm). Surface texture is strongly dependent of the method used to cut the blocks. Fine grinding, polishing or cutting using a diamond blade produces smooth (i.e. no texture) to fine textured surfaces. Coarse grinding, flame texturing, bush hammering or shot blasting produce fine to medium textured surfaces. Cropping and hand chiselling produces coarse textured surfaces. It should be noted that smooth surfaces are regarded in this guide as having no (zero) surface texture.

Guidance
Smooth surfaces are not recommended on the upper surface or side walls of stone elements. Fine and medium texture is more important for achieving bond and skid resistance than coarse texture. Coarse texture on the upper surface can be beneficial in improving tyre contact under wet conditions. For heavily trafficked sites, element side walls should be sawn and then fine textured by fine picking or sand/shot blasting

3.3.4. Skid and slip resistance

The skid and slip resistance of natural stone elements is a subject of considerable concern and debate. This is largely because there is little guidance available.

Skid and slip resistance of natural stone slabs and setts can be determined according to EN Standards using the USRV test (see Section 3.2.3). This is accomplished by testing a number of specimens cut from the stone element. Resistance to polishing can be estimated using the PSV test (see Sections 3.3.4 and 3.3.8).

In-service skid and slip resistance has been traditionally been estimated directly using a Pendulum Skid Resistance Tester in terms of SRV (skid resistance value). There are no British or European Standards covering the *in-situ* use of this apparatus but procedures are very similar to those used in the PSV test (see Section 3.3.8) and as described in EN Standards (see section 3.2.3).

It is important to ensure that the in-service skid and slip resistance is maintained above appropriate threshold levels. It is not sufficient to select a material type with an appropriate PSV and assume this will provide adequate resistance to polishing such that the skid resistance will not fall to unacceptable levels. It is essential that the stone elements be tested to ensure that they have adequate initial skid and slip resistance and are re-tested at regular time intervals.

Guidance on the level of skid resistance for trafficked roads is given in Table 1 of TRL (Transport Research Laboratory) Road Note 39. This indicates a minimum value of 45 for low risk sites at speeds of 50kph. Guidance on the measurement of slip resistance for floors is given by the UK Slip Resistance Group and Rapra Technology (Rapra, 1996). This indicates a satisfactory level of 40 (wet and dry) and above for rough concrete and coarse pavers. Similar levels can be expected for natural stone elements.

Minimum in-service SRV values of 40 for level sites with pedestrian or low speed trafficked uses are recommended. For sites where there is a gradient of > 10% a minimum in-service SRV of 45 is recommended. The corresponding minimum SRV values for new stone for such sites would therefore be 45 and 50. The rate at which these values would fall to or below the in-service threshold will vary depending on the polishing resistance of the stone elements, the local environment and the use of the pavement. The onus is on the maintaining authority to establish the relevant rate of degradation of SRV for their pavements through in-service measurement regimes. When in-service SRV falls to unacceptable levels retexturing action is required (see Section 8).

Guidance on appropriate measuring frequencies for in-service SRV to determine degradation rates for different categories of site is given in Table 3.12.

Table 3.12 Guidance on in-service skid resistance measurement frequency

Traffic Category	In-service skid resistance measurement frequency
1	2 years
2	18 months
3	12 months
4	6 months

The in-service SRV measurements need to be made on representative areas of the natural stone elements used in the pavement. Because of the variability of these natural materials this will require a minimum of 10 measurement areas from each type of pavement surfacing. As far as is possible subsequent measurements must be taken in similar conditions to the original measurements so that like is being compared with like in determining the degradation rates. Once a degradation profile has been determined the frequency of future measurements and a programme of retexturing can be established.

It is tempting to compare the results of USRV, and PSV testing with those obtained by direct or in-situ testing (SRV) of natural stone elements. Such results are not directly comparable in view of the specially prepared and presented specimens (curved mounts in the case of the PSV test) used in the USRV and PSV tests.

Guidance

Skid and slip resistance are important for all natural stone pavements even when there is no traffic. In-service skid and slip resistance should be evaluated by making in-situ SRV measurements at intervals that are appropriate to the use of the pavement.

3.3.5. Effects of de-icing salts

There are no established tests that specifically relate to the effect of de-icing salts on the durability of stone materials or elements. Although de-icing salts can be expected to lower the temperature at which freezing starts, the presence of salts may increase the aggressiveness of the solutions present before freezing occurs and the freeze/thaw action once freezing commences. The overall effect is however likely to be dependent on the ability of the solutions to penetrate the stone material and crystallise. An indication of the overall effect might therefore be obtained by using attrition type soundness tests (such as the Magnesium Sulphate Soundness test - see section 3.3.8).

Guidance
Although de-icing salts are likely to decrease the temperature at which freezing occurs, they are also likely to increase the aggressiveness of the environment surrounding a stone element and may adversely affect durability. An indication of the effect might be obtained by using the Magnesium Sulphate Soundness Test.

3.3.6. Colour

Colour is of major importance in establishing the required aesthetic properties in the streetscape works, but is extremely difficult to define objectively. Although objective systems for describing rock colour are available (Matheson, 1999), they are not in common use. Colour is also likely to be described differently by the designer, the producer and the supplier and will inevitably be subjective and open to interpretation. The situation is further complicated by the fact that observed colour on an unpolished surface will change depending on whether it is wet or dry, the most brilliant colours been observer when the sample is wet. Observed colour will also differ if the sample is viewed in natural (daylight) or under artificial (street) lighting. It is essential therefore that colour (and colour variation) and the conditions of viewing are described as objectively and accurately as possible, and vital that reference samples (as required in the EN Standards) are kept in order to check conformity and the acceptability of supplied material.

Guidance
Colour is dependent on the conditions under which a stone material is viewed. Descriptions should be as objective as possible and reference samples kept to check conformity and acceptability.

3.3.7. Petrological Description

A **petrological description** is essentially a statement as to the characteristics of the stone type from which an element is made. It is important for the purposes of petrological classification of the rock and to highlight features influencing the likely chemical, physical and mechanical behaviour of the material forming the element. However, it is equally important that these characteristics are evaluated in terms of fitness for purpose of the stone element for the intended use. This is best carried out by an engineering geologist conversant with the intended use, who can assess likely influences on the engineering characteristics.

Petrological reports should be kept short, factual, relevant and quantitative. A graphical, illustrated style of presentation will allow easy assimilation of the relevant facts is recommended; lengthy text descriptions should be avoided. A possible format for such a report is suggested by Matheson (1999).

The necessity to characterise the natural material in terms of its mineralogical components, fabric, structure and any other features is stressed in the EN standards. Both macroscopic (visible in a hand specimen) and microscopic (visible under a microscope) properties are therefore involved. However, the scale of the fabric, structure and other features relative to the stone element is also of importance (see Section 3.3.2 on product integrity) and it is vital to the designer and buyer that these properties are evaluated in terms of the size of the stone element. It is the effect of such features on the strength and durability of the element that is important. Again, this is best evaluated by an engineering geologist experienced in the material and its intended use.

Guidance
The petrological report characterises the material in terms of its macroscopic and microscopic features. Such characteristics need to be related to the size of the stone element. They must also be evaluated in terms of the likely effect on strength and durability, and hence fitness for purpose of the element. This is best carried out by an engineering geologist experienced in the material and its intended use.

3.3.8. Other properties and test methods

Indications of the suitability of a natural stone material for the production of stone elements can be obtained by considering other desirable properties or the results obtained from test methods not having EN accreditation. These have been widely used for testing natural materials and are summarised in Table 3.11 along with possible acceptance criteria. A more comprehensive evaluation is given in Matheson (1999). It must however be stressed again that these must be considered as a means of additional guidance for stone selection and cannot replace the requirements and test methods of the EN Standards described in previous sections. Results obtained from seemingly similar tests may also not be directly comparable with results from the EN test methods and should be used with caution. They are however useful in indicating the potential of materials or products on which EN testing has not yet been carried out.

Table 3.11 Other desirable properties, test methods and possible acceptance limits.

Strength

Property	Test Method	Sample type	Acceptance limit	Comment
Strength	UCS	Core	UCS >100MPa	Lab. test
	Point Load	Core, rock sample	Is(50) >5MPa	Field or Lab. test
Hardness/strength	Schmidt Hammer	Element or Sample	RBN > 50	Field or Lab test
Porosity	Water Absorption	Aggregate	WA <2%	Lab test
Durability	MSS	Aggregate	MSS > 90%	Lab test
	Freeze/Thaw	Aggregate	< 5% loss	Lab test
Resistance to polishing	PSV	Aggregate	PSV >50	Lab test

The uniaxial compressive strength (**UCS**) test (ASTM – D2938 and BS 1881, 1983) is a common means of defining the compressive strength of rock. Another test that can be used to obtain an indication of the compressive strength of the rock is the **Point Load Test** (ISRM, 1985). This last mentioned test is rapid and can be carried out on a range of sample types and shapes. The results of the test can be converted to an $I_{S(50)}$ value that in turn can be correlated to an UCS value. The **Schmidt Hammer Test** (ISRM, 1973, BS 1881:Pt 202, 1986) has also been used to indicate strength. The test is carried out on the surface of the rock or the stone element, to determinate its toughness, elasticity and state of freshness. However, problems in the interpretation of the results in terms of strength and desirable properties of a stone element can be encountered.

Porosity

The porosity of a rock is an indication of the free intergranular or interstitial pore space and can be estimated by carrying out a **Water Absorption Test** (BS812:1975). This test is very similar to that contained in EN1341, EN1342 and EN1343; results should therefore be comparable. Materials with high water absorption tend to be the least strong and durable.

Durability

There are no tests specifically developed for the purpose of determining the durability of stone elements other than that defined in the European Standards described in section 3.2.3. Most tests have been developed for use with aggregates and measure the breakdown of a sample in an aggressive environment. They are however relevant as they can be used to measure the durability of fragments (samples) of the material making up the stone element. The two durability tests that could be considered of relevance in the present context are the **Magnesium Sulphate** Soundness (MSS, BS 812:Pt. 121) and the **Effect of Cycling Freezing and Thawing** (ASTM D5312: 1992). The **MSS** test relies on the test solution penetrating the rock fragments and breaking the bond between grains (or crystals) either through solution or crystallisation-induced stress. As such it is a measure of the durability of the rock in a very aggressive environment and provides an indication of the likely resistance to weathering processes and may emulate the effect of de-icing salts. The **Effect of Cyclic Freezing and Thawing** test is designed for concrete aggregates but could also be used to indicate of the ability of fragments of the rock to withstand freezing and thawing.

Many other durability tests are available but they are considered to have less relevance in the present context.

Resistance to polishing
Resistance to polishing is generally used as an indicator of the skid resistance durability of a rock material for use as aggregate in road surfacings and is traditionally determined using the **Polished Stone Value** (PSV-BS812:1989) test. Knowledge of the PSV of the rock may therefore be used as an indicator of the ability of the stone element to retain its skid and slip resistance after installation. However work carried out in Devon (Grant, 2000) in response to pedestrian slip claims has shown that stone elements polish more rapidly than expected from laboratory determined PSV tests.

A new test, the **Polished Paver Test**, is being developed to test the resistance to polishing of flat paver surfaces and gives the polished paver value (PPV). If the new test gains acceptance then it could be applicable to natural stone elements.

Guidance
Results from non-EN test methods may be useful in indicating the potential of stone material or products on which EN testing has not yet been carried out. Results from seemingly similar testing may however not be directly comparable

3.3.9. Sources of information on stone supplies in Britain

There are wide varieties of rock types available in the UK that may be suitable for use as stone elements for natural stone paving. The most comprehensive source of information and knowledge on these resources is the British Geological Survey (BGS). The BGS principal offices are:-

1. British Geological Survey, Murchison House, West Mains Road, Edinburgh, EH9 3LA, Tel: 0131 667 1000

2. British Geological Survey, Keyworth, Nottingham, NG12 5GG, Tel: 0115 936 3241

The following sources of information are available from the BGS:-

a) The "Directory of Mines and Quarries" includes data on all active quarries, the geological material that they work and the end uses of their output materials. There is also a CD-ROM database of this information that includes active and disused quarries. This is particularly useful as many of the traditional sources of stone element materials are currently disused.

b) The Minerals GIS On-Line Information System (MINGOL) is a geographic information system that provides baseline mineral data including planning constraints, minerals workings, topography, geology, minerals exploration, mineral occurrences, mineral production and infrastructure.

c) The Minerals Portfolio Series of reports catalogue some of the physical properties of the rock materials produced by both active and disused quarries in Scotland.

In addition, the BGS also have databases of rock properties, including many of those required for determining suitability for use as stone elements. These databases include testing results, petrographic descriptions, thin section libraries and sample libraries. It is therefore possible to obtain a preliminary geological assessment of the suitability of a particular resource as a source for stone elements for natural stone paving through a simple desk study exercise. Such desk studies are however mainly applicable to evaluating the material properties of the rock type and will give little indication of the geotechnical issues involved. If there have been any significant changes to the resource since the BGS data were compiled or there are any gaps in the data, then additional evaluation and testing will be required. It will still be necessary to carry out appropriate EN testing on the product as outlined in Section 3 of this guide.

Guidance
Before embarking on an expensive rock characterisation programme check the sources of existing data at BGS. Product testing will still be required.

Editors Note

This section was prepared by George Matheson of Matrock Consulting Limited and draws on the report for Glasgow City Council and Scottish Enterprise Glasgow into the characterisation and specification of natural stone for streetscapes. The use of the material in the report and its extension to reflect the more recent European Standards EN 1341:2000, EN 1342:2000 and EN 1343:2000 are gratefully acknowledged