Advice Note 2

Materials and Specifications

Design Manual for Urban Roads and Streets

Rialtas na hÉireann
Government of Ireland

Design Manual for Urban Roads and Streets (DMURS)

Advice Note 2 - Materials & Specifications, expands on the concepts of quality, function and durability identified in section 4.2.6 Materials and Finishes of the Design Manual for Urban Roads and Streets (DMURS) document and provides guidance in relation to pavement classification, function, pavement types, specification, slip & skid resistance and material selection.

It is viewed as an aid to designers and specifiers to support assured and informed decision making at specification stage to ensure sustained longevity of pavements in service and an assurance against costly repercussions. Prepared in collaboration with State Agencies, Local Authorities and the private sector, this guidance document supports the aims and objectives of the primary DMURS document and particularly in the context of increased expenditure and enhancement of our public realm over the last number of decades.

It is particularly important now with a current focus on Urban Regeneration and housing investment following the advent of Project Ireland 2040, Rebuilding Ireland and the National Planning Framework.

This guidance is based within the framework of European Testing Standards and BS 7533 Pavements Constructed with Clay, Natural Stone or Concrete Pavers and has now been updated to provide more in-depth guidance relating to the selection of natural stone and paving material based on geological and material properties.

It details and expands on principle material properties such as Strength, Water Absorption, Durability and Resistance to Abrasion. All of which have significant implications in terms of material performance in use. This expanded guidance will further underpin and provide additional confidence at specification stage, ensuring compliance with the contract works requirements and sustainable use of material and financial resources.

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An Roinn Tithíochta, Rialtais Áitiúil agus Oidhreachta
Department of Housing, Local Government and Heritage

An Roinn Comhshaoil, Aeráide agus Cumarsáide
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CCMA
Cumann Lucht Bainistíochta Contae agus Cathrach
County and City Management Association

ipb insurance

Asna Square, Clonakilty

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INTRODUCTION

This addendum sets out to expand on the concepts of quality, function and durability identified in section **4.2.6 Materials and Finishes** of this manual and to provide guidance in terms of construction design, material selection and specification.

A considered scheme is essential in order to ensure a sustainable outcome having regard to the significant stresses imposed on our streets, roads and shared areas by increased traffic growth. This is compounded with the technical advancement in motor design allowing for higher vehicle weights and vehicle configurations.

In response to the requirement for surfacing to withstand significant loadings balanced with an aspiration that our cities, towns and villages might restore and maintain its sense of place, the British Standards Institution **(BSI) created BS 7533, Pavements constructed with Clay, Natural Stone or Concrete Pavers.**

BS 7533 encompasses technical standards for the design and construction of both 'rigid' and flexibly constructed paved areas and can be used for paved areas subject to pedestrian and vehicular loadings with axle loads up to 11000kg and a cumulative design traffic of up to 30 million standard axles (msa).

Most significantly, the British Standard ensures sustained longevity and assurance against costly repercussions whereas a non-compliant system cannot offer any minimum life expectancy.

Using a non-compliant system may in some cases have a lower initial outlay, but the ongoing life cost of such constructions is generally significantly higher owing to the additional ongoing maintenance, increased public liability claims and reworked streets.

To avoid costly pavement failures, it is critical that any design is underpinned by a robust and sustainable construction response to function following a thorough structural design methodology of which there are three (3) options:

a) BS7533, Part 10 - design life method for pavements of deep stone units.

b) BS7533, Part 8 - design life method for shallow stone units e.g. slabs and flags.

c) Full analytical method using theoretic principles.

Guidance in this document relates to options a) & b) only.

Well considered schemes enhance place, prioritise sustainable movement, calm traffic and provide longer term durability (Main Street, Castlebar).

PAVEMENT FUNCTION

While on the one hand our streets have a role to serve as transport corridors facilitating the movement of vehicles, cyclists and pedestrians, a less quantifiable but significantly more important concept is that our built fabric is the foundation of our national collective memory and civic expression at a social, cultural and historical level. When the hierarchical balance is overextended to that of transport this can appreciably diminish a streets value as a place.

The focus of the DMURS manual is on a balanced approach to the reduction of traffic speeds through self-regulating design coupled with improving the comfort of pedestrians and cyclists whilst creating an enhanced sense of place in a manner that does not rely on intrusive regulatory controls.

Some of these measures include the narrowing of unnecessarily wide roads, wider pedestrian thoroughfares, tree-planting, street furniture, the creation of traffic tables, squares and shared surfaces. By stripping away regulatory controls and softening vehicular infrastructure in this manner, this serves to reopen vistas thus restoring a sense of historical setting and spatial character.

Examples of Pavement Failure.

Self-regulating junction using contrasting surface materials (Main Street, Castlebar).

Traffic Loading

It is important that the uses and functions of a street are first assessed in order to reasonably predict the magnitude and type of loadings expected. Stone surfacing (if incorrectly designed) can fail under a single pass of a heavy load. Thus, the frequency of passes is not necessarily as important as it may be for other surfaces such as flexible asphaltic concrete.

BS7533, Part 10 details site categories of traffic loading for natural stone pavements. This sets out the type of vehicles expected (heavy, light), the frequency of passes (per-day) and the site category.

Site Category	Heavy Vehicles per day	Typical Applications
IA	<100	Adopted highways and commercial developments used regularly by heavy vehicles.
IB	<30	
IIA	<10	Adopted highways and other roads e.g. cul-de-sac, petrol station forecourts, pedestrian projects subject to regular heavy traffic.
IIB	<5	Car parks receiving occasional heavy traffic. Footways regularly overridden by vehicular traffic.
IIIA	<1	Pedestrian projects receiving only occasional heavy traffic. Footways overridden by occasional vehicular traffic.
IIIB	Nil	Car parks receiving no heavy traffic. Footways likely to be overridden by no more that occasional vehicular traffic.
IV	Nil	Private drives, paths, patios, hard landscaping. Areas receiving pedestrian traffic only e.g. school playgrounds.

Layout and Geometry

The geometry of the paving layout (e.g. gradients, junctions etc.) has a significant bearing on the magnitude and type of loading experienced by stone paving. This secondary loading is both horizontal and tensile and is normally beyond standard construction mortars to cope with.

BS7533, Part 10 also recognises the additional effect site conditions can generate in terms of high horizontal loading. A weight factor, as per the list below, should be applied to expected daily traffic figures.

A Standard carriageway width, level and traffic movement linear.
Weighting = 1.0

B Radius of curvature <100m and / or gradient >10%. Vehicles turning.
Weighting = 2.0

C Substandard carriageway width.
Weighting = 3.0

D As per C above but with a radius of curvature <100m and / or gradient >10%
Weighting = 4.0.

SELECTION OF NATURAL STONE

Slabs, Setts and Kerbs are the principle natural stone paving elements employed in a public realm scheme.

Regardless of the particular stone chosen, its selection must be based on an informed assessment of its durability and expected lifespan having regard to its inherent geological and engineering properties. Principle aspects affecting its longevity in use include its resistance to freeze thaw action, its design use (see below) and its abrasion resistance. This guidance sets outs performance recommendations for compressive strengths, bending / flexural strength, abrasion resistance, porosity, water absorption, durability, surface finishes and slip / skid resistance.

The SCOTS Guide States,

> *"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 be durable enough to maintain this fitness for purpose over the design life of the streetscape".*

Those specifying natural stone in streetscapes must understand the characteristics of the manufactured product (the stone paving element) and the natural material and that its selection is compatible with its intended use. It is critical that the requisite descriptions, test results etc. are obtained from the producer / supplier in order to ensure compatibility with expected performance values.

Material Selection and context:

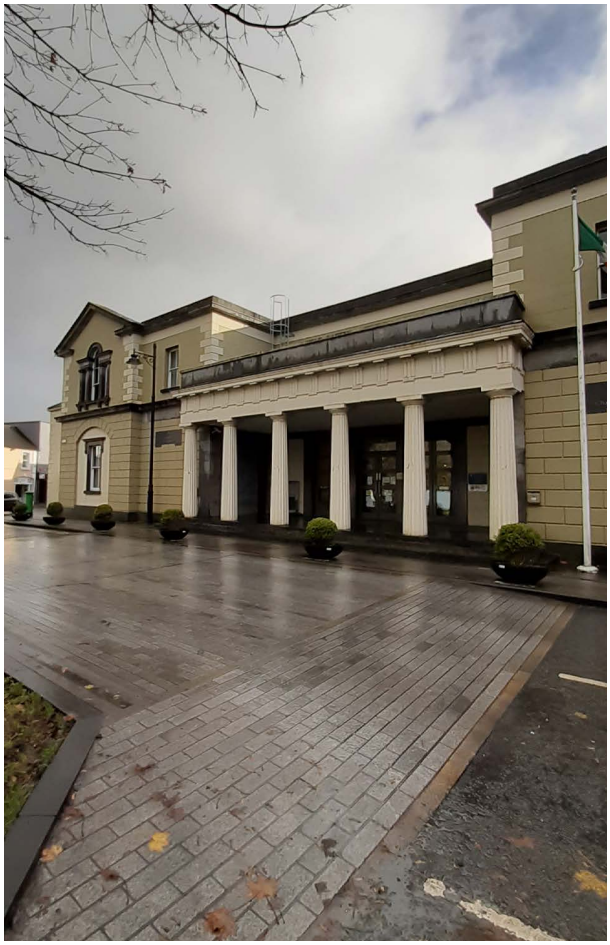
A less scientific aspect of material selection is context and the urban landscape. The street surface underscores the character of place and appreciation of our built heritage. It is for this reason that new and contemporary public realm design solutions must acknowledge its setting, and should not preclude considerations relating to colour, tone, texture, type, geometry, detailing, style and pattern. This approach may be informed by historic buildings, walls, gate surrounds, street vistas or indeed, extant paving such as cobbles, flags and kerbs.

It should be noted that some historic materials may not meet modern requirements for skid resistance and material performance.

However, retention is always favoured in the interest of historical posterity and the preservation of character. Indeed, the protection status of any original features should be confirmed as they may form part of or be within the 'curtilage' of a protected structure.

In relation to the restoration and conservation of historical paving, reference should be made to *'Paving - the Conservation of Historic Ground Surfaces'* as published by the Departments of Arts, heritage & the Gaeltacht.

For additional guidance refer to the standards stated in this document and *Natural Stone Surfacing - Good Practice Guide'* (SCOTS Guide).



The Mall, Castlebar

Natural Stone: The Design Stage

When choosing a stone type for incorporation into building works an understanding of the material and its 'fitness for purpose' in use is critical. Selection on the basis of texture and colour and without due regard to physical and chemical properties could have significant consequences. Therefore, the choice of a particular stone should not be primarily influenced by aesthetic considerations, but should take into account the intended architectural and structural function, exposure to the elements, and expected performance over the anticipated design life.

'Fitness for purpose' in use requires a considered understanding of a particular stones, geology, quarry dimensional constraints and properties such as strength, durability, porosity, water absorption and abrasion resistance. These aspects affect suitability selection in terms of cladding, paving, detailed working application and weathering. Environmental analysis plays a part. Is the site sheltered or exposed? Is their a likelihood of salt contamination, erosion or chemical attack? Can the pavement be readily maintained?

The stone must also be capable of being worked, sawn, dressed and tooled in the required manner. An understanding of these criteria will better inform design and selection decisions.

As a building material, **Dimensioned Stone** is a product and as such is therefore subject to the **Construction Products Regulations.** Under the Construction Products Regulation (CPR) CE marking has become mandatory. CE marking is the only way to demonstrate that a product, or system, complies with the CPR. It is a manufacturer's declaration that their product meets the minimum requirements of a harmonised technical specification, enabling them and their agents to place their product on the construction market. The manufacturer is required to produce declarations of performance to confirm compliance with the Construction Product Regulations. European standards for the testing and placement of natural stone include:

- **I.S. EN 1926:2006 Natural stone test methods. Determination of uniaxial compressive strength.**
- **I.S. EN 1936 Natural stone test methods. Determination of real density and apparent density, and of total and open porosity.**
- **I.S. EN 12371 Natural stone test methods. Determination of frost resistance.**
- **I.S. EN 12372 Natural stone test methods. Determination of flexural strength under concentrated load.**
- **I.S. EN 12407, Natural stone test methods - Petrographic examination**
- **I.S. EN 12440, Natural stone - Denomination criteria**
- **I.S. EN 13373 Natural stone test methods - Determination of geometric characteristics on units.**
- **I.S. EN 13755 Natural stone test methods. Determination of water absorption at atmospheric pressure.**
- **I.S. EN 1926 Natural stone test methods. Determination of uniaxial compressive strength.**
- **I.S. EN 14157 Natural stone test methods. Determination of the abrasion resistance.**
- **I.S. EN 14146:2004. Natural stone test methods. Determination of the dynamic elastic modulus of elasticity**
- **I.S. EN 14231 Natural stone test methods. Determination of the slip resistance by means of the pendulum test.**
- **I.S. EN 1341 Slabs of natural stone for external paving. Requirements and test methods.**
- **I.S. EN 1342 Setts of natural stone for external paving. Requirements and test methods.**
- **I.S. EN 1343 Kerbs of Natural Stone for External Paving - Requirements and Test Methods.**

European Standards I.S. EN 1341, I.S. EN 1342 and I.S. EN 1343 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 to determine these properties. The list of properties comprises dimensions, flatness of surface, freeze/thaw resistance, flexural or compressive strength, abrasion resistance, slip resistance, aspects, water absorption, petrographic description and surface treatment.

Geological properties of stone paving units (slabs, setts and kerbs) and the methods used for testing are defined in the I.S. EN Standards and are usually determined on samples taken from the stone element.

CE Marking and Labelling:

The manufacturer is responsible for affixing the CE mark. The CE marking symbol shall be displayed in accordance with Directive 93/68/EEC. The following information must accompany the CE marking symbol:

a) name or identifying mark of the manufacturer and registered address of the manufacturer

b) last two digits of the year in which the marking was affixed

c) reference to the relevant European Standard and the year of its publication (e.g. I.S. EN 1341:2012)

d) description of the product and its intended use:

- 1) generic name (e.g. natural stone slabs).
- 2) traditional name, petrological family, typical colour and place of origin;
- 3) intended use: "for external pedestrian and/or vehicular circulation areas.
- 4) surface treatment of the stone (if any).

e) performance on the essential characteristics which are to be declared for the relevant intended use, as classes or values, including "Pass" for pass/fail requirements (where necessary), or as "No performance determined" (i.e. NPD) for characteristic(s), where this is relevant, namely:

- 1) release of dangerous substances: where relevant.
- 2) breaking strength, dealt with by: flexural strength.
- 3) slipperiness, dealt with by: slip resistance (pedestrian circulation areas only).
- 4) skid resistance, where required (vehicular circulation areas only).
- 5) durability of breaking strength, of slipperiness and of skid resistance, dealt with by
  - i) freeze/thaw resistance, measured as the mean flexural strength (in MPa) after 56 freeze/thaw cycles.
  - ii) freeze/thaw resistance with de-icing salts;
  - iii) polished slip or skid resistance declared in accordance with national provision.

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.

CE

AnyCo Ltd.

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EN 1341:2012

Natural stone slabs

for external pedestrian and/or vehicular circulation areas

RELEASE OF DANGEROUS SUBSTANCES	NPD
BREAKING STRENGTH, as:	
- flexural strength (EN 12372), as: (lower expected value)	12,2 MPa
SLIPPERINESS, as:	
slip resistance wet (EN 14231):	45
SKID RESISTANCE, as:	
- skid resistance according to MS method xx	35
DURABILITY;	
- of flexural strength against: freeze/thaw	(12,2/10,0) MPa
Freeze-thaw with de-icing salts	(9.4)
- of slip resistance	42
- of skid resistance	32

Selection of Natural Stone & Material Performance

There are four principle properties that must be considered when selecting a building stone. They are:

1. **Strength (flexural and compressive).**
2. **Water Absorption (porosity and stain resistance).**
3. **Durability (resistance to freeze / thaw, hardness, abrasion resistance, chemical composition).**
4. **Resistance to abrasion (slip resistance).**

Specifiers should refer also to BS7533, Part 12 - Guide to the structural design of trafficked pavements constructed on a bound base using concrete paving slabs and natural stone slabs. Specifically Annex C, Physical Properties of Surface Course Materials.

Asna Square, Clonakilty *(2013)*
Varied stone finishes reflect diverse urban space functions

1 - Strength

Compressive strength - Most dimension stones usually perform well under compression. Compression is measured in terms of Mpa - Megapascal (1 megapascal equals 1,000,000 pascals, SI unit for pressure). **The compressive strength shall be determined using the test method in I.S. EN 1926 and the lower expected value (EL) shall be declared.**

Typical values are:

Stone Type	Typical Compressive Strength (MPa)
Granite	300 - 100
Marble	150 - 80
Quartz-based	120 -10
Limestone	150 - 4
Slate	200 - 25

There are no European acceptance limits for compressive strength. International best practice (ASTM) advises a minimum compressive strength standard requirement for the following building stone:

- **Granite used as a building stone should be 130Mpa**
- **limestone 55Mpa (high density)**
- **Limestone 23Mpa (Medium density)**
- **Limestone 12Mpa (Low Density)**
- **Marble 52Mpa**

Flexural Strength - is a key property that underpins the adequate performance of a dimension stone in use and particularly where a pavement is traversed by or is likely to be traversed by vehicular traffic. The magnitude of predicted loading on the principle design elements, should they be subject to vehicular traffic, must be predetermined. For example, in the case of traffic tables, public squares or shared surfaces. The dimension stone must have a sufficient strength to cope with expected stresses. Certified technical data documenting the quality, type and performance of the paving unit is crucial in order to determine its likely failure limits in use.

Typical examples of natural stone supplied to the Irish market include:

- Irish Bioclastic Limstone - bending / flexural strength = 10 to 13Mpa
- Commercial granites - bending / flexural strength = 14 to 19Mpa

The flexural strength shall be determined using the test method in I.S. EN 12372 and the lower expected value (EL) shall be declared.
BS 7533 Part 12 recommends the following:

Property	Igneous		Sedimentary	
	Class 1	Class 2	Class 1	Class 2
Flexural Strength (tested to I.S. EN12372)	12Mpa	15Mpa	08Mpa	12Mpa

Annex A of I.S. EN 1341 and I.S. EN 12372 should be used to calculate the break-loads of stone elements. The required thickness of a slab, for example, can be determined by using the following formula:

$$t = \text{the } \sqrt{\text{ of } \frac{1500 \times P \times L \times Fs}{W.Rf}}$$

t = required slab thickness (in mm)
P = is the breaking load (in kN), for the expected use of the paving
L = length of the slab
W = width of the slab
Rf = certified flexural strength / Flexural Resistance (Mpa)
Fs = safety factor

Safety factor for bound construction

1.2 when L is ≤ 600mm or 1.8 when L is > 600mm

Safety factor for unbound construction

1.8 when L is ≤ 600mm or 2.4 when L is > 600mm

In addition to the certified stone **flexural strength**, the relationship of a given paving units dimensions (length, width and thickness) is also critical i.e. the shape of the paving element has a direct bearing as to how it will perform under load. Therefore, certain shapes having a certain modular ratio (such as setts and cubes) are more suited to particular forms of trafficked construction in terms of structural response.

Class	Minimum Breaking Load kN	
0	No requirement	Decoration
1	0.75	Slabs bedded in mortar, pedestrian area only.
2	3.5	Pedestrian & Cycle areas.
3	6.0	Occasional car, light vehicle and motor cycle access. Garage Entrance.
4	9.0	Walking areas, market places occasionally used by delivery vehicles and emergency vehicles.
5	14	Pedestrian areas often used by heavy lorries.
6	25	Roads, streets and petrol stations.

Table A.2, I.S. EN 1341

Formula 'P' was previously used and offers designers an insight into the likely paving unit dimensions that will cope with expected stresses.

$$P = \frac{Rtf \times W \times t2}{1500 \times L \times 1.6}$$

1.6 = safety factor (up to max plan dimension of 900mm)

The calculated ***break load*** (kN) of the paving unit should at least match or preferably exceed the expected traffic loads as per table A.2 of I.S. EN 1341 which offers suggested breaking loads for different classes of use. Refer to the DMURS Advice note 02 for further detail.

BS 7533 Part 10 classifies setts / cubes by dimensions.

Size Category	Cubes / Setts	Setts I			Setts II			Design Joint Width (mm)
	Min. Nominal size dimension (mm)	Nominal size dimension (mm)			Nominal size dimension (mm)			
		Depth	Width	Length	Depth	Width	Length	
Size 1	40 / 60	-	-	-	-	-	-	6 - 10
Size 2A Size SB	70 / 90, 90/100	- 100	- 100	- 200	- -	- -	- -	8 - 12
Size 3	150 / 170	150	100	200	180	150	200	10 -15

2 - Water absorption:

I.S. EN 13755 specifies a method for determining the water absorption of natural stone (at atmospheric pressure). It is expressed as a percentage (%) by ratio of the mass of the saturated sample to the mass of the dry sample. Porosity is a measure of the likelihood that a given stone material will reach a degree of saturation high enough to cause damage under natural conditions. Surface staining and the ability of a material to absorb liquids, oils and other contaminants is directly related to its porosity. A higher water absorption capacity allows for a higher 'stain holding' capacity.

The empty space between grains in stone is referred to as porosity and can vary greatly with type from less that 1% in granites to more than 20% in the case of some sandstones. The porosity and pore structure are important factors as they influence the durability and degradation of the stone. These qualities determine how the material and moisture will interact, what degrees of saturation will occur and how likely it is that water will freeze.

The porosity of a material has a direct bearing on its ability to resist **frost damage**. Frost damage is caused by moisture freezing inside the material. This can cause the stone to swell, crack and splinter. When water freezes, the volume of **water** increases and damage occurs when this volume increase cannot be absorbed by sufficient empty pores thus causing an increase in the internal pressure. If this pressure exceeds the **tensile strength** of the material, then micro-cracks occur. Visible frost damage develops after an accumulation of micro-cracks as a result of several **freeze-thaw** cycles. Internal damage manifesting as micro-cracks and loss of cohesion can result in loss of dynamic modulus of elasticity i.e. a reduction in flexural and compressive strength. The presence of salt (such as in ground water) can compound this effect.

The table below shows the typical absorption capacity for a range of dimension **Stone Types.**	**Water Absorption Typical Range (weight %)**
Granite	0.8 - 0.01
Marble	0.8 - 0.04
Quartz -based	12 - 0.3
Limestone	26 - 0.08
Slate	6 - 0.3

In relation to Water Absorption, Annex C (C.1) of BS7533, Part 12 recommends the following using I.S. EN 13755 Natural stone test methods (Determination of water absorption at atmospheric pressure):

Property	**Igneous**		**Sedimentary**	
	Class 1	**Class 2**	**Class 1**	**Class 2**
Water absorption (tested to I.S. EN 13755)	**0.4%**	**0.25%**	**3.5%**	**2.5%**

Notes:
Calcareous stones are susceptible to etching from acidic substances such as wine, soft drinks and urine. The use of polished limestone and marble in any location where acidic spills may occur can lead to conspicuous, etched spots, which can only be removed by mechanical polishing. It is important to note that impregnating sealers will not prevent this etching from occurring. These sealers are designed to restrict the absorption of stains and therefore will not prevent surface etching.

In construction and detailing, every effort must also be made to avoid a situation where the critical value of the degree of saturation is exceeded. This might happen in practice during very wet conditions such as when a stone constantly absorbs ground water or when a stone is exposed to a leaking drain pipe.

3 - Durability

Durability
The durability of natural stone used as a building material decreases over time due to weathering phenomena such as frost action, insolation, salt crystallization, plant root action or chemical decomposition such as dissolution of carbonates and sulfates, leaching from silicates and sulfides etc. In addition, durability depends heavily on both its strength and porosity as discussed in the preceding sections. Dimension stone is considered a durable material provided it is congruent with its intended environment, application and use. Decay is normally due to one or all of the following mechanisms:

- **Salt Attack**
- **Freeze / Thaw Cycling**
- **Dimensional Instability.**

Durability is a complex criteria determined by inherent strength, water absorption and pore space. A higher strength can mitigate the forces applied on the stone by the crystallisation of salts or the expansion of ice crystals. A lower water absorption generally correlates to a greater durability, as it restricts the passage of deleterious solutions, but a larger pore size can assist with durability by reducing the pressure applied by salt or ice crystallization on the walls of the pores. Flexural strength of dimensioned stone can be reduced in the case of saturation.

Testing
- **Freeze/thaw resistance is determined using the test method in I.S. EN 12371 and the results expressed and declared as the mean flexural strength after 56 cycles of freeze/ thaw.**
- **Determination of resistance to salt crystallisation is prescribed by I.S. EN 12370:2020, Natural Stone Test Methods.**
- **I.S. EN 13755 Natural stone test methods. Determination of water absorption at atmospheric pressure.**

I.S. EN test methods are clearly defined for freeze / thaw resistance, salt crystallization resistance and water absorption. However, there are no tests specifically developed for the purpose of determining the durability of stone elements other than those defined in the European Standards listed above.

I.S. EN 12371 and I.S. EN12370 are tests to measure the durability of rock in an aggressive environment and provides an indication of the likely resistance to weathering processes and may emulate the effect of de-icing salts. Resistance to salt attack involves cycles of soaking specimens in a salt solution followed by oven drying. On completion of cycling, the material that is lost from each specimen is weighed and recorded as a proportion of the original weight** of the specimen.

Various soluble salts are often found as efflorescence or crystals on stone surfaces. Salt originates from ground water rising through the stone from the soil, air-borne salts from sea spray, air pollution or dissolved minerals from the stone itself or from products of chemical reactions. There are no published minimum European recommendations relating to performance of stone due to salt attack but international guidance suggests the following:

Weight loss (%)	Environment suitability
<0.1	Aggressive environments, constant wetting and drying and exposure to salt attack.
0.1 - 1	Exposed to continual wetting and drying or moderate salt attack.
1 - 5	Exposed to intermittent wetting and drying or moderate level salt attack.
6 - 10	Exposed to infrequent wetting and drying or low level salt attack.
>10	Suitable only for sheltered locations free from exposure to salt attack.

***Note: The difference between the two weight measurements in grams is the volume in cubic centimetres (one cubic centimetre of water has a mass of 1 gram).*

Hardness
Shore Hardness is a measure of the hardness of a given material or how resistant it will be to permanent indentation. It is measured by the depth of indentation that is created on the material with a specified force. There are different Shore Hardness scales for measuring the solidity of different materials with varying properties and presented as having values between 0 and 100. Higher values indicate higher hardness and vice versa. Hardness / brittleness value of rocks reflect its workability characteristics as well as impact resistance.

Temperature
A stone surface exposed to the blazing sun can reach a fairly high temperature. This causes a temperature gradient between the surface and the inner parts of the stone.

As a result of the coefficient of thermal expansion, a thin outer shell expands and tends to pull away from the cooler layer within. Under perfectly dry conditions, the stresses that develop are insufficient to fracture fresh massive stone, but in the presence of water, repeated alterations of heating and could possibly lead to rupture'.

Chemical composition
The **Typical chemical composition of Indigenous Bioclastic Limestone is 98%** Calcium, 0.7% Quartz, 0.7% Dolomite, 0.2% organic Carbon, less than 0.1% Iron Sulfate. Because of its extremely low Iron composites content, the material is suitable to be used under the environmental pressure of a city or industrial environment without risk of discoloration or staining. Material with a Dolomite content of over 3% should be rejected.

4 - Resistance to Abrasion

Abrasion of natural stone is defined as damage of its top layer due to friction and or impact from an element interacting with the stone layer. This friction causes particles to separate resulting in loss of mass, volume and stone thickness. Wear is unlikely to be graded evenly across a surface course / pavement. There will be greater wear at turning points; at places where the movement of pedestrians is constrained and at commonly used pathways.

Good abrasion resistance is important to maintain the intended surface finish of paving materials. A low resistance to abrasion can result in a significant change in the slip / skid characteristics of the surface by grinding caused by grit and other surface contaminants. The abrasion resistance of the stone needs to be assessed to determine the effect the anticipated traffic may have on the slip rating. That is to say, a given stone paving unit may have a satisfactory slip / skid resistance rating **(USRV - Unpolished slip resistance value)** when first incorporated into the works. However, its abrasion resistance characteristics will determine how readily it will wear and polish in use as a surface course material.

Abrasion testing is conducted in accordance with the Requirements of I.S. EN 14157 and determines the abrasion volume loss of samples and the higher expected value (EH) shall be declared. In relation to Abrasion Resistance, Annex C (C.1) of BS7533, Part 12 recommends the following:

Property	Igneous		Sedimentary	
	Class 1	Class 2	Class 1	Class 2
Abrasion Resistance (tested to I.S. EN 14157)	18mm	12mm	28mm	22mm

It is important to ensure that the in-service slip/ skid resistance is maintained above appropriate levels. It may not be sufficient to select a material type with an appropriate PTV (Pendulum Test Value) and assume this will provide adequate resistance to polishing such that the slip / skid resistance will not fall to unacceptable levels.

It is essential that the paving elements be tested to ensure that they have adequate initial slip & skid resistance and are re-tested at appropriate time intervals.

SLIP & SKID RESISTANCE

Slip/Skid resistance is an indication of the frictional properties of the manufactured surface of a stone or concrete paving unit and its ability to resist pedestrian slipping and vehicular skidding.

Surface Treatment
Natural stone paving units are usually specified with coarse textured surfaces which are assumed to give satisfactory slip / skid resistance. Examples include flamed, peon or bush hammered surface treatment. The slip / skid resistance of fine textured surfaces of slabs and setts (the surface course) is defined by the **Unpolished Slip Resistance Value (USRV**) determined using the **Pendulum Friction Test procedure (PTV) for wet conditions in I.S. EN 14231** Natural stone test methods - Determination of the slip resistance by means of the pendulum tester. I.S. EN 1338: 2003 & I.S. EN 1339: 2003 refers to concrete flags & bricks and both rely on pendulum test results. there is no requirement in the standards for kerbs, it is recommended that the requirements for setts & slabs be applied.

I.S. EN 1341 (4.5) and I.S. EN 1342 (4.6) state that a USRV measurement, made using a wide slider/ full swing on a pendulum, that is greater than 35 in wet conditions, can usually be considered acceptable for surfaces that are horizontal or sloping at less than 6 %.

Annex C (C.1) of BS7533, Part 12 recommends Pendulum Test Values (PTV) of 40 (low risk) for pedestrian areas and up to 45 for vehicular trafficked surfacing (when tested in accordance with BS 7932:2003.

In service guidance - The SCOTS Guide recommends a minimum **in-service Skid Resistance Value (SRV)** of 40 for level sites with pedestrian or low speed trafficked uses. For sites where there is a gradient of > 10% a minimum in-service SRV of 45 is recommended. Resistance to polishing can be estimated using the PSV test in BS 812-114:1989 Method for the Determination of the Polished Stone Value.

Notwithstanding the recommendation in I.S. EN 1341, EN 1342 and BS7533 Part 12, this guidance document recommends that all surface course paving material should achieve a 'low risk rating' when tested in wet conditions and at least an unpolished slip resistance value (USRV) of 55 or higher.

In order to ensure that the in-service slip / skid resistance (SRV) is maintained above appropriate levels, this increased acceptance limit offers an additional factor of safety by allowing for the wear and polishing of the surface course material that may occur over time.

The abrasion resistance of the surface of natural stone, concrete paving block or concrete flag should be determined to ensure the durability and performance of the surface in-service. Resistance to polishing action is determined principally by abrasion resistance quality of the stone. In terms of a suggested acceptance limit a PSV of 55 is recommended.

The SCOTS Guide states - *"The skid/slip resistance of natural stone elements is a subject of considerable concern and debate" among architects and engineers. It is not sufficient to select a material type with an appropriate* **PSV** *and assume this will provide adequate resistance to polishing such that 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 ".*

It is recommended that slip resistance testing should be carried out on full size-controlled samples before and after grouting of the sample. Similarly, slip resistance testing should be undertaken on project completion and 12 months after completion. If the values remain relatively unchanged and are not indicative of an issue, then the testing frequency could be extended to bi-annual testing. Records of testing should also be retained.

Explanatory notes:

PTV - Pendulum Test Value. *PTV is measured by means of a slider mounted at the end of a pendulum arm which imitates the action of slipping and determines the dynamic friction of the surface. The results are measured on a scale under a "Pendulum Test Value" (PTV). Standards that use the Pendulum Test include BS 7976, used for pedestrian surfaces, I.S. EN 14231, used for natural stone modular tiles, I.S. EN 1338 & 1339 for concrete products. The standards vary slightly both in their procedures and in the type of rubber slider used. There are two types of rubber used, slider 96 (formally known as Four-S) rubber which simulates a standard shoe sole and slider 55 (formally known as TRRL).*

USRV - Unpolished Slip Resistance Value. *The USRV is the mean pendulum value obtained on 6 pendulum test specimens.*

SRV - Skid Resistance Value *is an in-service surface course test using a Pendulum Tester and is equivalent to PTV.*

PSV - Polished Stone Value. *The Polished Stone Value (PSV) gives a measure of resistance to the polishing action resulting from vehicle and pedestrian traffic. The action of road vehicle tyres on road surfaces results in polishing of the top, exposed aggregate surface, and its state of polish is one of the main factors affecting the resistance to skidding. Resistance to this polishing action is determined principally by the inherent qualities of the stone itself (Abrasion Resistance) Resistance to polishing can be estimated using the PSV test in BS 812-114:1989 Method for the Determination of the Polished Stone Value.*

PPV - The resistance to polishing of clay pavers is expressed as a ***polished paver value (PPV).*** *As a first approximation PPV is equivalent to polished stone value (PSV) for aggregates. A minimum polished paver value (PPV) of 45 should be specified for general use - TII - Footway Design.*

Table NA.7 Slip/skid resistance of I.S. EN 1338:2003 Concrete Paving Blocks - Requirements and test methods.

If the manufacturer declares a slip/skid resistance value, the following slip resistance table gives an indication of the value against the potential for slip.
Note: The information in this table is taken from The measurement of floor slip resistance. Guidelines recommended by the UK Slip Resistance Group, Issue 2, RAPRA, 2000.

Pendulum Test Value	Potential for slip
Below 19	High
20 to 39	Moderate
40 to 74	Low
Above 75	Extremely Low

Other reference standards include:

- BS 7976 Slip Resistance Testing: The Pendulum test
- I.S. EN 13036 Road and Airfield surface characteristics. Test methods - method for measurement of slip / skid resistance of a surface: The pendulum test
- I.S. EN 7932:2003 - Determination of the unpolished and polished pendulum test value of surfacing units.
- I.S. EN 124:2000 - Gully Tops and manhole tops for vehicular and pedestrian areas - gully tops and manhole tops made of steel reinforced concrete.
- BS 9124:2008 - Specification for steel and aluminium access cover systems with over 1 m clear opening.

TYPES OF PAVEMENT CONSTRUCTION

BS 7533 (1 to 12)

The two primary forms of pavement construction, rigid & flexible, differ principally in how they each behave structurally to applied load.

- Rigid surfaces are not intended to deform under load but should remain rigid.
- Flexible surfaces deform in an elastic manner under load and revert to or near to their original profile once the load has passed.

Flexible paving construction

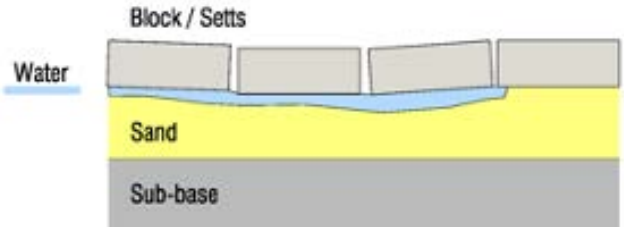
(BS 7533 Parts 2 & 3)

Flexible paving is an unbound construction comprised of a compacted sub-base, sand bedding, modular brick or natural stone and a sand joint. The elements are stabilised by mechanical interlock and friction in the unbound material.

Advantages are:
- Lower capital cost.
- No curing period required allowing early opening to traffic.
- Allows for small movements.
- Can be lifted and re-laid following opening-up for public utilities.

Disadvantages are:
- Limitation in road carrying capacity.
- Surface cleaning operations will result in the loss of the jointing (sand) material.
- Wash out of the jointing material by surface water movement or damaged downpipes / gullies.

Flexible constructions typically fail in a number of ways:
- Water ingress.
- Restraint i.e. the edge restraint condition is insufficient to retain paving in position resulting in brick creep.
- Inadequate compaction.
- Fatigue i.e. the cumulative effect of a number of cycles of load both vertical & horizontal.
- Joint failure i.e. loosening or loss of the constituent jointing material resulting in lifting and movement of the paving elements.



If planned and designed correctly there are a number of ways to extend the operational life of flexible paving in use and they are:
- the sub-base must be thoroughly constructed and compacted having first investigated the site characteristics (ref: california bearing ratio cbr%);
- subject to site conditions, consider using geosynthetic membranes as an integral part of the subbase construction. these systems offer significant benefits such as restricting the intermixing of different soil types, leaching of soil particles, free drainage / passage of ground water and additional strength;
- pay particular attention to the edge condition by using rigid construction in order to provide adequate restraint;
- compartmentalise sections of paved area in order to contain brick creep if it should occur. this technique should ideally be by way of rigid construction and could form part of the landscaping aesthetic;
- materials should be used at optimum moisture content for compaction;
- joint newly-laid paving as soon as is possible. if inclement weather conditions persist, consider using plastic covers to limit detritus washing in to the joints;
- consider using sand stabilisers in order to prevent failure associated with sand washout. these have the added benefits of preventing water ingress, maintaining joint elasticity and are better able to cope with cleaning operations;
- the bedding sand used should be certified for its use such as clean grit sand or sharp sand to BS7533 part 7 and I.S. EN 12620:2002 (2008) (see slabs, flags and tiles).

Inappropriate pavement design leading to differential settlement, movement and uneven surfaces.

Inappropriate road design and specification leading to fatigue and rutted tracks.

The table below, taken from BS7533 Part 2, offers guidance in relation to the subbase structural design of lightly trafficked pavements.

Loading or end use description	**BS 7533-2, loading category**	**Maximum commercial vehicles per-day**	**Minimum compacted sub-base thickness (mm)**				
			Design CBR				
			≤2%	**3%**	**4%**	**5%**	**6%**
Commercially trafficked pavements, roadways, heavily trafficked commercial areas, adopted major roadways and streets, freight depots, container and shipping terminals, rail depots etc.	Category I	For commercially heavy trafficked pavements a more detailed site-specific design will be required to be carried out in accordance with BS7533-Part 1 and with the assistance of Civil Engineer.					
Adopted highways and other roads e.g. cul-de-sac, petrol station forecourts, pedestrian projects subject to regular heavy traffic.	Category II	≤ 5. For commercial vehicle movements more than 10 refer to BS7533-Part 1 and Civil Engineer's design advice.	400	350	250	150	150
Pedestrian projects receiving only occasional heavy traffic. Footways overridden by occasional vehicular traffic.	Category IIIA	<1	350	300	225	150	150
Car parks receiving no heavy traffic. Footways likely to be overridden by no more that occasional vehicular traffic.	Category IIIB	Nil	300	250	175	100	100
Private drives, paths, patios, hard landscaping. Areas receiving pedestrian traffic only e.g. school playgrounds.	Category IIIB	Nil	200	150	125	100	75

Clonakilty Emmet Park with mix of concrete pavers and natural stone

Example of flexible paving using 160 x 160 x 60mm deep proprietary concrete brick.

Slabs, Flagstones & Tiles

Slabs, flagstones and tiles were traditionally laid in the form of flexible unbound construction on flexible (and permeable) bedding and jointing. Traditional bedding materials include thoroughly compacted sharp sand or hydraulic lime mixes. This form of construction should not be specified if regular traffic movement is expected. BS7533 Part 8 Guide for The Structural Design of Lightly Trafficked Pavements of Precast Concrete Flags and Stone Slabs should be referred to where vehicular traffic loading 'may' occur during its service life.

BS 7533 Part 8 relates specifically to relates specifically to flexible construction and precludes the use of cementitious based mortars (rigid construction). Laying courses (bedding) should be no less than 40mm and no more than 50mm. A weak flexible mix of hydraulic lime bedding mortar with 1-part cement to 3 parts lime and 10 parts grit sand / CLASS V and jointed with 1-part hydraulic lime to 2 parts sand can be considered. This mix mitigates wash out and prevents insect boring.

However, for large flag sizes usually specified for commercial and public applications, BS7533 Part 4, Code of Practice for the construction of precast concrete flags or natural stone slabs, allows for slabs and flags to be bedded and jointed with mortars. Slabs, flagstones and tiles can be designed to cater for category III & IV traffic loads where the site category is A, but it is recommended that the design is tested.

With both approaches, the strength of the bond between the various elements (i.e. flag, bed and base) is critical to avoid lateral creep. In the case of adopting BS 7533 Part 8, lateral movement must be mitigated against by providing robust edge restraints. Where the nearest edge restraint may be some distance from the point of lateral loading, as in the case of a large public square, the design may dictate a flag unit of some weight coupled with the use of proprietary primers to aid adhesion between the flag and bed and the bed and base as per BS7533 Part 4.

Sand

The sand used shall be certified for its use. Sand shall be clean grit sand or sharp sand to BS 7533 Part 7 and I.S EN 12620:2002 (2008) with the following characteristics:

- The individual grains should be angular in nature, thereby creating an interlock between adjacent grains;
- a higher proportion of bigger grains reduces the amount of water that can be retained by the sand, making it very free draining;
- a very low silt and clay content, which again makes for a free-draining material;
- best sands are igneous in origin.

Characteristics of suitable sand are:	Unsuitable sands are:
• The individual grains are angular in nature. • High proportion of bigger grains (3mm to 6mm). • Free draining. • Salt free. • Low clay / silt content.	• Crushed limestone dust. • Building sands.

Rigid Paving in the Public Realm
(BS 7533 Parts 1, 7, 8, 10 & 12)

Rigid Paving is constructed using a mortar paving system and its construction is a series of layers beginning with the subgrade.

Rigid Construction pavements are stabilised by the setting action of the fine mortar joint material. Shear and adhesion between the paving units and the joint materials provide the primary resistance to load. The Laying Course provides resistance to punching shear. Consistency of compaction of the fine concrete /mortar in joints and laying course is vital for structural performance. Concrete should be used at optimum moisture content.

Layer 1 - the subgrade:

I.S. EN 1997-2:2007, Geotechnical design. Ground investigation and testing and I.S. EN ISO 22476 series Geotechnical investigation and testing).

At the detailed design stage (& prior to tendering) the supportive value of the subgrade, the California Bearing Ratio (CBR), should be established. The CBR value determines the required depths of roadbase and subgrade design and ensures it is suitable to bear the load of the construction above.

Layer 2 - the subbase:

The subbase (capping layer) is next and should be a consolidated construction of compacted crushed stone (Type A (803) & Type B (804)) material meeting the requirements of I.S. EN 13242:2002+A1:2007, SR21: 2004+A1: 2007 (Revised 2012) and manufactured to I.S. EN 13285: 2010 Unbound Mixtures.

This consolidated layer must be capable of providing a suitable surface on which to construct the roadbase. It is imperative that there is no settlement, contraction, heave or other movement. The depth, build-up and any reinforcement of the sub-base must reflect the type of traffic loading the paving is to receive and will require a build-up design specified to meet traffic requirements. For commercially heavy trafficked pavements a more detailed site-specific design will be required to be carried out in accordance with BS7533-Part 1 (with the assistance of a Civil Engineer). The following tables are extracts from I.S. EN 13285.

Subgrade & subbase preparation for traffic table.

Granular Material Type A (803):

Table 8/5: Granular Material Type A

IS EN 13285 Categories -				
Mix Designation:		**0/31,5**		
Oversize Category:		**OC 80**		
Overall Grading:		**G_B**		
Sieves for Grading / Fines Category	**ISO Sieve Size (mm)**	**Percentage by Mass Passing**		
		Overall Grading Range	**Supplier Declared Value Grading Range**	**Tolerance on the Supplier Declared Value**
2D	63	100	No Requirement	No Requirement
D	31,5	80 - 99		
A	16	55 - 85	63 - 77	±8
B	8	35 - 68	43 - 60	±8
C	4	22 - 60	30 - 52	±8
E	2	16 - 47	23 - 40	±7
F	1	9 - 40	14 - 35	±5
G	0,5	5 - 35	10 - 30	±5
UF_7	0,063	0 - 7	No Requirement	No Requirement
LF_N	NR	NR		
Grading of individual batches – differences in values passing selected sieves				
Retained sieve size, mm	Passing sieve size, mm	Percentage by mass passing		

Granular Material Type B (804):

Table 8/6: Granular Material Type B

IS EN 13285 Categories -				
Mix Designation:		**0/31,5**		
Oversize Category:		**OC 80**		
Overall Grading:		**G_A**		
Sieves for Grading / Fines Category	**ISO Sieve Size (mm)**	**Percentage by Mass Passing**		
		Overall Grading Range	**Supplier Declared Value Grading Range**	**Tolerance on the Supplier Declared Value**
2D	63	100	No Requirement	No Requirement
D	31,5	80 - 99		
A	16	55 - 85	63 - 77	±8
B	8	35 - 65	43 - 57	±8
C	4	22 - 50	30 - 42	±8
E	2	15 - 40	22 - 33	±7
F	1	10 - 35	15 - 30	±5
G	0,5	0 - 20	5 - 15	±5
UF_7	0,063	0 - 7	No Requirement	No Requirement
LF_N	NR	NR		
Grading of individual batches – differences in values passing selected sieves				
Retained sieve size, mm	Passing sieve size, mm	Percentage by mass passing		
		Not less than	Not more than	
8	16	10	25	
4	8	10	25	
2	4	7	20	
1	2	4	15	

NOTE: The particle size shall be determined by the washing and sieving method of IS EN 933-1

Layer 3 - the roadbase:

This third layer is created using a C30 to C40 reinforced concrete slab that should be allowed to cure for a minimum of 28 days before opening to traffic. Where the project programme may dictate, the concrete (and subject to the advice of a civil engineer) may be allowed to reach 7 days before traffic loading is permitted. Dense Bitumen Macadam (DBM) can also considered as a suitable road-base.

Concrete:

Concrete shall conform to the requirements of I.S. EN 13877 Part 1, Parts 2 and I.S. EN 206-1 with cement provided in accordance with I.S. EN 197-1. If GGBS (Ground Granulated Blast Furnace slag) is specified, this should be up to a maximum of 50% and provided in accordance with I.S. EN 15167-1. Concrete quality should have an intended working life of at least 50 years. The design thickness of the concrete road base is subject to the traffic loading category / user class predicted and table 11 of BS75 33 Part 10 should be referred to.

Site category	**Nominal compacted sub-base thickness (mm)**					**Nominal compacted thickness (mm)**		**Sett Size Category**
	Design CBR					**Bituminous or asphaltic**	**Cement bound**	
	2%	**3%**	**4%**	**5%**	**≥6%**			
Category I	450	350	250	150	150	200	200	
Category II	300	275	250	150	150	200	200	
Category IIIA	300	275	250	150	150	200	150	
Category IIIB	300	275	250	150	125	200	100	
Category IV	300	250	200	110	110	40	100	

The example above refers to a ramp and table construction designed to Category I or user class 6 (Table A.2, I.S. EN 1341) and illustrates a concrete road-base / slab of 200mm. This depth should be treated as a minimum with thicker slabs of 200+ allowed for at tender and increased at all points likely to experience high impact loads such as the bottom and top of a ramp for example. The minimum requirement is that the slab must achieve a stiffness of 5000Mpa.

Paving elements at all high impact points should also be bedded with high performance bedding mortars. The thickness of the concrete road-base can be decreased if a less onerous user class is predicated but should be capable of supporting the expected traffic loadings.

Roadbase construction for traffic table.

Movement joints:

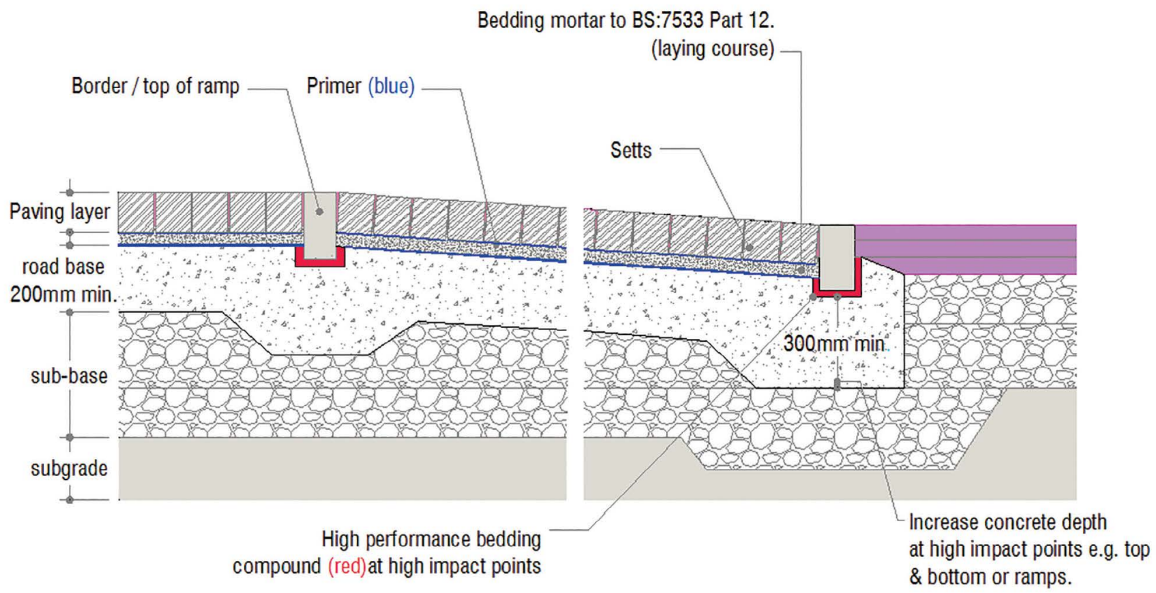
Expansion and contraction of a cement bound road-base needs to be considered and should be designed by a consultant civil engineer if deemed necessary. In terms of rigid construction using deep stone units, the concrete road-base may not experience the same temperature stresses that an exposed slab may be subject to. This aspect may be more applicable to large expanses of paving as opposed to smaller and more localised installations.

Reinforcement:

Reinforcing Steel (Reinforcement shall comply with the following standards):

- Hot Rolled and Cold Worked Carbon Steel Bars - I.S. EN 10080 and BS 4449 (Grade B500B or B500C).
- Steel Wires - I.S. EN 10080 and BS 4482 (Ribbed Grade B500).
- Steel Fabric - I.S. EN 10080 and BS 4483 (Grade B500A, B500B or B500C).

Steel fabric reinforcement should have a minimum nominal bar size of 8mm (for Grade B500A). *(Refer to TII 1000 series for additional detail).*



Road-base detail.

Roadbase construction for traffic table.

Layer 4 - bedding:

A BS 7533 approved proprietary mortar paving system is then used to lay the setts or flags. The bedding course shall be 40mm minimum and shall not be used as a regulating course to achieve falls. The laying course material used for rigid surfacing should conform to the recommendations for fine bedding concrete in BS 7533-7:2002 Annex C.2.1 and BS7533-12: 2006 Table 3. The mortar should have a minimum compressive strength of 30 N/mm2.

Although priming of the road-base is not a specific requirement of the British Standard; it has now become standard practise to use a proprietary primer at this layer. Priming here is more than beneficial because it provides a higher bond between the road-base and the bedding material.

The bedding material should conform to Annex C.2.1 of BS 7533-7 & table 3 of BS 7533-12:

- Minimum compressive strength of 15 N/mm² (Measured in accordance with BS 1015-11)
- Minimum adhesive strength of 0.8 N/mm² (Measured in accordance with BS 1015-12)
- Modulus of elasticity (15000) N/mm² (Measured in accordance with din 18555-6)
- Maximum shrinkage of 0.15% (Measured in accordance with I.S. EN 445).

High performance Bedding Mortars:

Where exceptionally high flexural, adhesive or compressive strength is required a resinous mortar may be an appropriate alternative for the bedding mortar. A resinous mortar is particularly suited to areas of high impact, shallow bed or high flex, such as raised carriageways or recessed manhole covers. The material copes with extremely high compressive forces and tolerates a greater degree of flexural strain. They can achieve a bond strength in excess of 45N/m2 and flexural strength of over 22N/m2.

Rigid paving using granite setts bedded in mortar on concrete roadbase.

Layer 5 - Surface layer:

Once the base layers have been adequately constructed the setts or flags can be laid. One of the most common causes of failure is when the paving element comes away from the bedding mortar. Priming the paving element will prevent this failure and is essential to meet BS 7533. The bond strength will increase from ca1N/mm2 to above 2N/mm2.

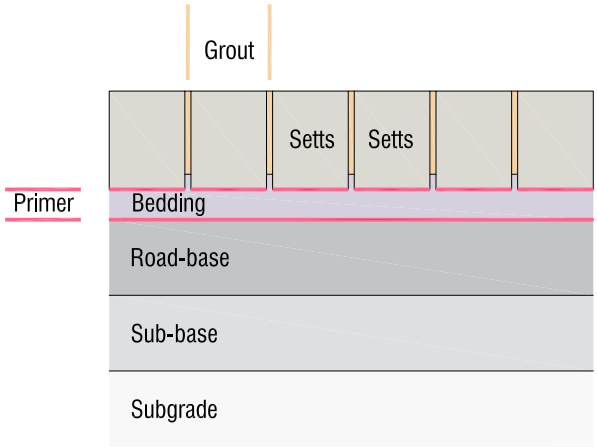


Diagram: Not to scale

A diagram showing the typical build-up of a BS 7533 compliant paving construction.
This diagram refers to the Moist Bed with Full Depth Slurry method.

This method is capable of carrying the highest loading capacity. Here the units are rammed into the moist laying course which should not rise more than 15 to 20mm up the joint. The joints are then filled with fine concrete jointing material which must be self-compacting.

Completion:

To finish the rigid pavement construction to BS 7533 standard, a choice of 2 methods can be used for grouting the joints:

1 - Mortar Gun

The handheld gun injected method offers a more traditional 'struck' joint finish but is considerably more laborious. It must also be considered that there is a greater potential for workmanship errors, such as voids in the joints due to poor application, and generally this method requires a 'lighter touch' for better end results.

2 - Slurry method

The slurry (flowable) method is faster, more cost-effective and robust.

Traffic table / rigid paving ready for jointing.

There are many benefits to using the slurry method including:

- Slurry grouting, due to its application, is inherently fast and efficient meaning large areas can be grouted quickly;
- slurry grout can be applied in less than perfect weather conditions and its fast setting properties means it can be trafficked more quickly than traditional pointing methods;
- voids in joints, which are a major cause of failure, are avoided because the application method ensures the filling of joints from bottom to top;

Material performance:
Jointing material should conform to table 2 of BS 7533-12:

- minimum compressive strength of 40 N/mm² (Measured in accordance with I.S EN 1015-11);
- minimum adhesive strength of 1.2 N/mm² (Measured in accordance with I.S EN 1015-12);
- minimum flexural strength of 6 N/mm² Measured in accordance with I.S EN 1015-11;
- modulus of elasticity (20 000) N/mm² (Measured in accordance with din 18555-6);
- minimum density of 2000kg/m³ (Measured in accordance with I.S EN 1015-11);
- maximum shrinkage of 0.15% (Measured in accordance with I.S EN 445).

Surplus jointing 'wash off'.

Jointing preparation:

Jointing shall be carried out to BS 7533:12. Preparation - joints should be clean of any detritus. Vulnerable surfaces should be protected e.g. street furniture - bollards / lamp-posts etc. Ensure surface is wetted prior to placing slurry and misted during application. Jointing material should be mixed in strict accordance with the manufacturer's instructions. The process should be repeated to ensure that the joints are topped up completely. BS 7533 Part 10 should be referred to when specifying joint widths to ensure consistency of compaction.

Staining of the paving can be a concern and guidance should be sought from the manufacturer as to the appropriate method to clean the surface of excess jointing wash. Proprietary systems are available to seal the surface of the paving unit and this should help to prevent surface staining.

It is also recommended that the vertical face of sawn units (setts) be retextured in order to provide greater frictional characteristics between the unit and jointing material.

Disadvantages of rigid paving are:

- high initial capital cost;
- difficult to access public utilities post construction;
- slurry staining during jointing operations if not properly washed off;
- jointing 'slurry wash' can run into nearby storm drains if not properly controlled;
- works programme and site operations must allow for curing times.

Advantages are:

- High load carrying capacity over a longer life span.
- Lower maintenance and life cycle costs.
- High visual aesthetic.

Granite kerbs being lifted into place.

Rigid construction can fail.

- Rigid construction can fail under a combination of a very heavy single loading event coupled with fatigue. It is important to first consider the pavement design life having regard to future events that may be remote but could happen e.g. use of a heavy lift mobile crane.
- Rigid pavements can be designed to have an indefinite life. However, a design life must be pre-determined if heavy load conditions are expected.

Edge restraint.

BS7533 Part 7 requires that edge restraints be robust enough to withstand override by pedestrian and vehicular traffic, including construction traffic. The edge restraint should present a vertical face to at least below the laying course, to prevent the loss of the laying course materials from beneath the surface course. This is normally provided by deep dished channels, natural stone or concrete kerbs securely bedded & haunched in concrete.

Deep granite channel used as an edge restraint

WORKMANSHIP

(BS7533-7)

Workmanship & quality control

This is probably the single most important aspect of any successful project. The laying of modular paving units requires a high degree of skill and care. Properly trained and experienced personnel is therefore of paramount importance.

Consistent quality is demanded across a number of aspects.

- Setting out and maintaining working lines.
- Sorting & pattern formation.
- Tolerances on joint widths and bedding courses.
- Consolidation and compaction of materials both bound and unbound.
- Trimming & 'cutting in'.
- Material handling.
- Material storage.
- Cleaning.

The works contract

The works contractor must be able to demonstrate that only appropriately trained and experienced personnel will be employed on any given project. Ideally this requirement should be sought at pre-qualification stage and prior to contract award.

It should be a requirement of any works contract that the applicable competency be demonstrated by the construction of full size, controlled samples.

Key issues.

- Consistent compaction of the constituent materials is crucial.
- Paving elements should be sorted to achieve optimum tolerances both in the joint width and laying course.
- The structural support layer must be compacted to optimum moisture content.
- Equally compaction of jointing material (flexible construction) at the optimum moisture content is important.
- Construction joint should be incorporated in concrete road-bases.
- Vertical faces of paving units should be clean & wetted prior to jointing (slurry method).
- Jointing material should fill the joint completely.

Example of workmanship.

STREET FURNITURE

ACCESS COVERS

(Ref: I.S. EN 124:2015 series Gully tops and Manhole tops for vehicular and pedestrian areas).

The consideration of service vaults, manhole lids and other utility furniture needs to be given some thought at the design stage and prior to tendering. Particularly if the possibility exists that traffic may traverse over public utilities. Consideration should include such matters as:

- Capital cost.
- Hierarchy
- Consultation with statutory undertakers & utility companies.
- Specification.

The design of the paving layout needs to take account of utility covers and It is recommended that accurate survey information is first obtained to do so. This will avoid / mitigate on site conflicts ensuring a more seamless appearance and avoiding additional costs. This will also determine the extent of new furniture required.

It is also recommended that statutory undertakers and utility companies should be consulted. Particularly if it is envisaged that discreet lids and covers will form part of the design / streetscape.

Proprietary service vault access covers designed to incorporate inset paving must meet the requirements of Class B125 of I.S. EN 124:2015 where laid in paved areas that may experience occasional service or emergency vehicle use. It is recommended that the advice of a structural / civil Engineer is sought if such lids will occur in frequently / heavily trafficked areas (e.g. Class C250 Group 3).

Generally, inset paving lids should be manufactured from 6mm steel (min.) and galvanised. It must be remembered that utility covers come in a variety of sizes therefore it is important to determine if single or multiple cover units will be required (hence the value of a pre-tender survey). In the case of the latter, inverted 'T' shaped removable cross-pieces will be required.

The Structural Frame

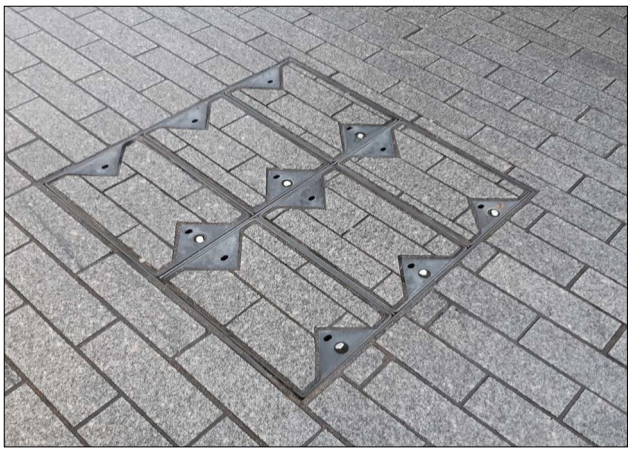
The Structural Frame should be provided with a flange or steel lugs to allow bonding of the frame with the bedding material. Careful detailing and workmanship at the paving and frame interface is required to ensure longevity in service and to avoid localised payment collapse. Pavement failure about utility lids occurs most often with flexible constructions. This occurs due to inadequate compaction of the sublayers around the rigid utility riser leading to slumping and loose paving units. This can be compounded by vehicle overrun.

Individual covers:

The individual covers should be lockable to avoid unauthorised lifting and to secure the covers in place.

The insert paving must be bedded using high performance bedding mortars conforming to the following performance standards:

- compressive strength: After 24 hours (38.00 N/mm²), 7 days (75.00 N/mm²);
- tensile strength: After 24 hours (14.30 N/ mm²), 7 days (15.60 N/mm²);
- flexural strength: After 7 days (22.40 N/mm²);
- density of hardened material: After 24 hours (2050 kg/ m³), 7 days (2070 kg/ m³);
- compressive modulus: After 7 days (11.20 Kn/ mm²);
- Flexural modulus: After 7 days (10.80 GN/ m²)
- bond strength: 45.00 (N/mm²),



Inset paving lids.

Proprietary Surface Water Channels

(I.S. EN 1433:2002/A1 2005) Drainage channels for vehicular and pedestrian areas. Classification, design and testing requirements, marking and evaluation of conformity).

Where required, proprietary surface water channels must be manufactured in accordance with I.S. EN 1433 and in accordance with the design load class / category:

Class A15 - Light pedestrian

Class B125 - Light & Medium Duty

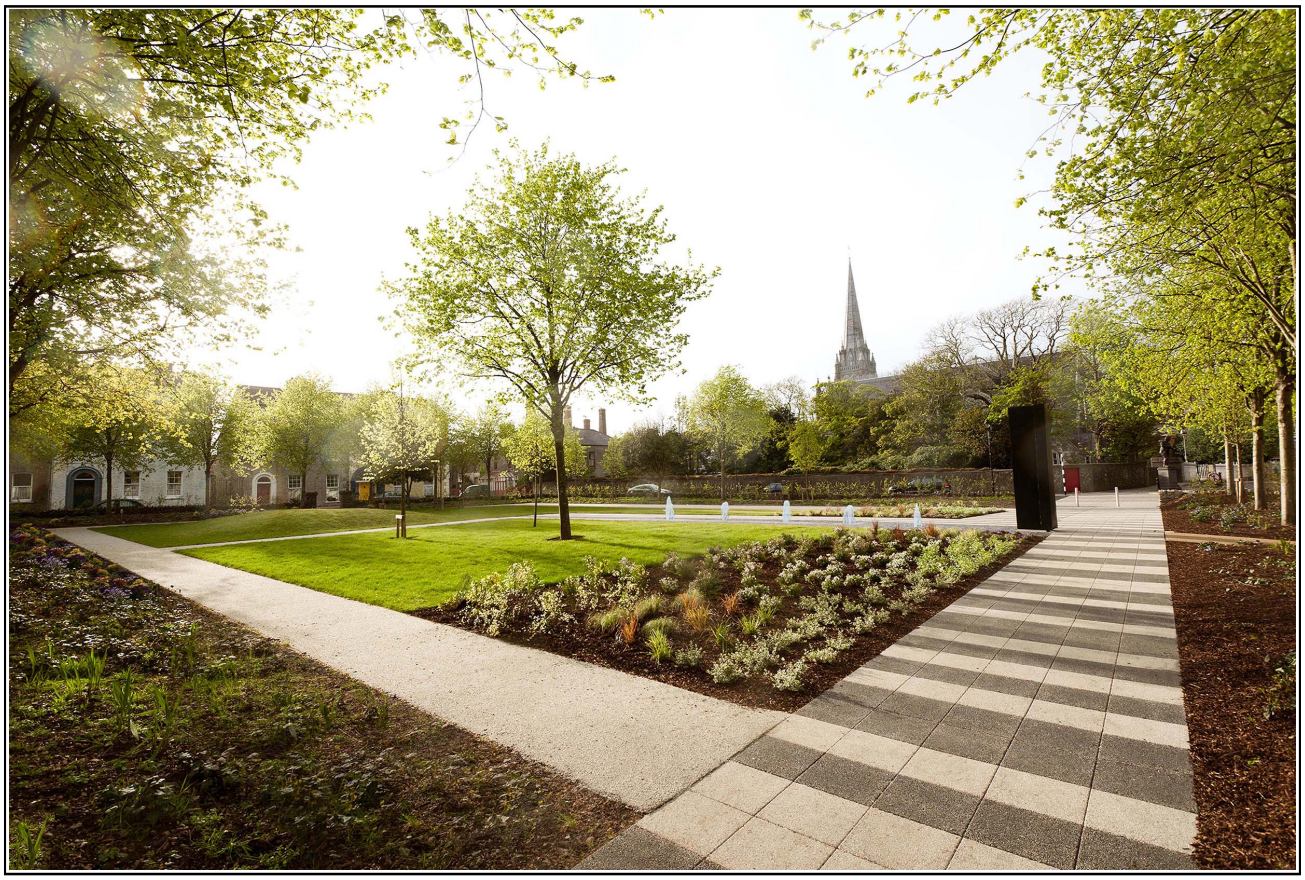
Class C250 - Light & Medium Duty

Class D400 - Main road & Trafficked Areas.

Gratings should incorporate 'Heelguard' characteristics.

Paving Restraint Edging

Generally, the free paving edge (e.g. bordering grassed areas) should be restrained using concrete haunching. However, this can become friable over time or damaged by occasional service traffic. Ideally this haunching should be reinforced with steel reinforcing bars dowelled into the concrete (vertically) and tied to continuous reinforcement bars (horizontal). Alternatively, heavy duty aluminum edging is available on the market. These are 'L' shaped in profile with the flange plate dowelled to a solid base (bitumen or concrete). They also have the added benefit in that they can be used to create curves and other free form shapes in plan.



Clonakilty Emmet Park

REFERENCE STANDARDS

BS 7533-1:2001
Pavements constructed with clay, natural stone or concrete pavers. Guide for the structural design of heavy-duty pavements constructed of clay pavers or precast concrete paving blocks.

BS 7533-2:2001
Pavements constructed with clay, natural stone or concrete pavers. Guide for the structural design of lightly trafficked pavements constructed of clay pavers or precast concrete paving blocks.

BS 7533-3:2005+A1:2009
Pavements constructed with clay, natural stone or concrete pavers. Code of practice for laying precast concrete paving blocks and clay pavers for flexible pavements.

BS 7533-4:2006
Pavements constructed with clay, natural stone or concrete pavers. Code of practice for the construction of pavements of precast concrete flags or natural stone slabs.

BS 7533-6:1999
Pavements constructed with clay, natural stone or concrete pavers. Code of practice for laying natural stone, precast concrete and clay kerb units.

BS 7533-7:2010
Pavements constructed with clay, natural stone or concrete pavers. Code of practice for the construction of pavements of natural stone paving units and cobbles, and rigid construction with concrete block paving.

BS 7533-8:2003
Pavements constructed with clay, natural stone or concrete pavers. Guide for the structural design of lightly trafficked pavements of precast concrete flags and natural stone flags.

BS 7533-9:2010
Pavements constructed with clay, natural stone or concrete pavers. Code of practice for the construction of rigid pavements of clay pavers.

BS 7533-10:2010
Pavements constructed with clay, natural stone or concrete pavers. Guide for the structural design of trafficked pavements constructed of natural stone setts and bound construction with concrete paving blocks.

BS 7533-11:2003
Pavements constructed with clay, natural stone or concrete pavers. Code of practice for the opening, maintenance and reinstatement of pavements of concrete, clay and natural stone.

BS 7533-12:2006
Pavements constructed with clay, natural stone or concrete pavers. Guide to the structural design of trafficked pavements constructed on a bound base using concrete paving flags and natural stone slabs.

BS 7533-13:2009
Pavements constructed with clay, natural stone or concrete pavers. Guide for the design of permeable pavements constructed with concrete paving blocks and flags, natural stone slabs and setts and clay pavers.

Natural Stone Surfacing - Good Practice Guide' (prepared by Society of Chief Officers of Transportation Scotland).

BS 7533-101. Pavements constructed with clay, concrete or natural stone paving units - Part 101. Code of Practice for the structural design of pavements using modular paving units.

BS 7533-101:2021 is a revised standard that consolidates parts 1, 2, 8, 10 and 12 into one code of practice covering structural design. It also partially supersedes parts 6 and 7.

It provides guidance and recommendations of the structural design of pavements surfaced with natural stone slabs, natural stone setts, natural stone kerbs, clay pavers, concrete paving blocks, concrete paving flags and concrete kerb products manufactured in accordance with European Standards (ENs).

BS 7533-101:2021 *specifically excludes design traffic above the specified maximum and areas of higher vehicle loading such as aircraft pavements and those in ports and specialized industrial areas. It also excludes pavements constructed on bridge decks or suspended slabs such as basement roofs. Specialist engineering advice should be sought when considering the use of modular paving in applications not covered by this standard.*

I.S. EN 1341: 2012
Slabs of Natural Stone for External Paving - Requirements and Test Methods.

I.S. EN 1342: 2012
Setts of Natural Stone for External Paving - Requirements and Test Methods.

I.S. EN 12372:2006
Natural stone test methods. Determination of flexural strength under concentrated loads.

I.S. EN 1926:2006
Natural stone test methods. Determination of uniaxial compressive strength.

I.S. EN 1936
Natural stone test methods. Determination of real density and apparent density, and of total and open porosity.

I.S. EN 12371
Natural stone test methods. Determination of frost resistance.

I.S. EN 12407
Natural stone test methods - Petrographic examination.

I.S. EN 12440
Natural stone - Denomination criteria.

I.S. EN 13373
Natural stone test methods - Determination of geometric characteristics on units.

I.S. EN 13755
Natural stone test methods. Determination of water absorption at atmospheric pressure.

I.S. EN 1926
Natural stone test methods. Determination of uniaxial compressive strength.

I.S. EN 14157
Natural stone test methods. Determination of the abrasion resistance.

I.S. EN 14146:2004
Natural stone test methods. Determination of the dynamic elastic modulus of elasticity.

I.S. EN 14231
Natural stone test methods. Determination of the slip resistance by means of the pendulum test.

I.S. EN 1343
Kerbs of Natural Stone for External Paving - Requirements and Test Methods.

I.S. EN 16165:2021
Determination of slip resistance of pedestrian surfaces. Methods of evaluation.

I.S. EN 13036
Method for measurement of slip / skid resistance of a surface: The pendulum test.

BS 7932:2003
Determination of the unpolished and polished pendulum test value of surfacing units.

I.S. EN 1338: 2003
Concrete Paving Blocks - Requirements and test Methods.

I.S. EN 1339:2003
Concrete paving flags. Requirements and test methods

DD CEN/TS 15209:2008
Tactile paving surface indicators produced from concrete, clay and stone.

I.S. EN 1997-2:2007
Geotechnical design. Ground investigation and testing.

I.S. EN ISO 22476
Geotechnical investigation and testing.

I.S. EN 13285: 2010
Unbound mixtures - specification.

I.S. EN 13242:2002+A1:2007
- IS EN 13242:2002+A1:2007 - Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction.
- SR21: 2004+A1: 2007 (Revised 2012).

I.S. EN 124:2015 series, parts 1 to 6.
Gully tops and manhole tops for vehicular and pedestrian areas.

I.S. EN 1433:2002/ A1 2005
Drainage channels for vehicular and pedestrian areas. Classification, design and testing requirements, marking and evaluation of conformity.

I.S. EN 9124:2008
Specification for steel and aluminium access cover systems with over 1 m clear opening.

I.S. EN 1344:2013
Clay pavers - Requirements and test methods.

I.S. EN 2003
Concrete kerb units - Requirements and test methods.

800 Series, Unbound and Cement bound Mixtures, (TII), Transport Infrastructure Ireland.

900 Series, Specification for Road Works (TII) - Bituminous Materials, Transport Infrastructure Ireland.

1000 Series, Concrete Materials (TII), Transport Infrastructure Ireland.

1100 Series, Footways & Paved Areas (TII), Transport Infrastructure Ireland.

'Paving - the Conservation of Historic Ground Surfaces' as published by the Departments of Arts, Heritage and the Gaeltacht.

I.S. EN 12620:2002 (2008)
Aggregates for concrete.

I.S. EN 13877 Part 1
Concrete pavements - materials.

I.S. EN 13877 Part 2
Concrete pavements - functional requirements.

I.S. EN 197-1:2011
Cement. Composition, specifications and conformity criteria for common cements.

I.S. 15167-1:2006
Ground granulated blast furnace slag for use in concrete, mortar and grout. Definitions, specifications and conformity criteria.

I.S. EN 1015-11:2019
Methods of test for mortar for masonry. Determination of flexural and compressive strength of hardened mortar.

Standards can be purchased at
www.standards.ie

Riverwalk, Castlebar

1. Selection of Natural Stone Summary.

2. Table - The Nature of Stone.

3. Selection of Manufactured Paving Units.

4. Sample Data Sheets.

5. References.

APPENDIX 1

Selection of Natural Stone Summary

Summary of recommended performance properties of natural stone and acceptance limits.

Annex C (C.1) of BS7533, Part 12 recommends the following:

Property	Igneous		Sedimentary	
	Class 1	Class 2	Class 1	Class 2
Flexural Strength (tested to I.S. EN 12372) Min.	12mpa	15mpa	08mpa	12mpa
Water absorption (tested to I.S. EN 13755) Max.	0.4%	0.25%	3.5%	2.5%
Abrasion Resistance (tested to I.S. EN 14157)	18mm	12mm	28mm	22mm

This guidance document recommends that all surface course paving material should achieve a 'low risk rating' when tested in wet conditions and at least an unpolished slip resistance value (USRV) of 55 or higher.

The abrasion resistance of the surface of natural stone, concrete paving block or concrete flag should be determined to ensure the durability and performance of the surface in-service.

Resistance to polishing action is determined principally by abrasion resistance quality of the stone. In terms of a suggested acceptance limit a PSV of 55 is recommended.

Other recommended properties and acceptance limits:

Property	Test Method	Acceptance limit
Strength	UCS	UCS >100mpa
	Flexural (after freeze / thaw)	As above.
Hardness / strength	Schmidt Hammer	RBN >50
Durability	Freeze / Thaw	<5% loss
Resistance to polishing	PSV	≥55

Notes:

Annex C (C.1) of BS7533, Part 12 states - guidance on the desired properties of surface course materials. However, where a material has a successful history of use in this application or where it can be demonstrated by testing or calculation that a stone is suitable, then these recommended properties need not be followed.

Lessons can be learnt from the past performance of a stone type in a structure which may have been exposed to the weathering environment over an extended

APPENDIX 2

The Nature Of Stone

Sedimentary	Igneous	Metamorphic
Sandstone Sandstone is a sedimentary rock containing visible mineral grain constituents held together by natural cement. Sandstones vary widely in terms of constituent minerals, cement types, grain size and pore structure, leading to a wide variety of colours and different performances as building stones. Quartzitic sandstone is a dense, strong, stiff material of low porosity and permeability and can be used for paving applications. The main difference between limestone and sandstone is the lack of a microporous network in sandstones. This means less water can be held by the stone thus there is less potential for the build up of internal pressure created by water freezing or salts crystallising and resulting in bursting or other damage. Their property values compare well with those of granite and other strong, durable igneous rocks.	Fine to coarse-grained crystalline rocks originating from the molten state. Basic or intermediate igneous rocks such as basalt or dolerite are generally dark or grey in colour and contain little or no quartz. Pale or strongly coloured varieties such as felsite and porphyry are generally associated with volcanic areas.	Metamorphic rocks are the products of alteration of sedimentary and igneous rocks by temperature and pressure. Metamorphism is often referred to in relation to 'metamorphic grade', where a low grade metamorphic rock is one which has undergone a moderate degree of alteration and where original features such as bedding are still preserved. High-grade metamorphic rocks may undergo complete recrystallisation or even melting producing a hard crystalline rock with complete destruction of its original textures, containing distinct metamorphic banding such as in schist and gneiss.
Limestone Limestone is a calcareous stone principally composed of calcium and/or magnesium carbonate, commonly formed from the accumulation of fragments of marine organisms. It is widely variable in colour and texture and may contain fossils on a microscopic or macroscopic scale. Indigenous Irish Limestone, and that historically used as a building materially, is classified as a Bioclastic Limestone and is typically of an age greater than 320million years. Known as Blue limestone it was laid down in the Crinoid Age.	**Granite** Granite is a coarse-grained crystalline igneous rock composed of visible quartz, feldspar and mica, intergrown to give a uniform hard building stone. Granites can vary widely in colour.	**Slate** Slate is a general term used for any stone capable of being uniformly split to form a natural roofing tile. 'True slate' is the product of metamorphic alteration of very fine grained rocks at such high temperatures and pressures as to completely recrystallise the constituent minerals to form a series of parallel cleavage planes along which the stone will readily split into thin sheets. 'Stone slates' are sedimentary rocks (or metamorphic rocks) which do not possess true slaty cleavage, commonly splitting into thin slabs along bedding or other planes.
		Marble Marble is a limestone that has been recrystallised by metamorphism under conditions of heat and pressure. The presence of different metamorphic minerals in marbles can result in widely different appearances.

Table derived from Building with Scottish Stone (Natural Stone Institute).

Calcareous Stone is made mainly of calcium carbonate, a chemical compound commonly found in natural stone, shells and pearls. It is sensitive to acidic substances and usually requires different cleaning methods than siliceous stone. Examples include marble, travertine, limestone and onyx.

Siliceous Stone is made of silicates like quartz, feldspar and mica. They tend to be very durable, and relatively easy to clean as they are resistant to most acids. Types of siliceous stone include granite, slate, sandstone, quartzite, brownstone and bluestone.

APPENDIX 3

Selection of Manufactured Paving Units
(extract from Construction Standards for Road and Street Works in Dublin City Council).

Concrete Paving flags must comply with I.S. EN 1339:2003 Concrete Paving Slabs. Requirements and test methods.

Paving flags & tactile paving flags - desirable minimum performance characteristics (as per I.S. EN 1339):
DD CEN/TS 15209: 2008 Tactile Paving Surface Indicators produced from concrete, clay & stone.

Concrete tactile paving slabs are to be provided in accordance with I.S. EN 1339 and CEN/TS 15209;2008). Designed to assist visually impaired pedestrians and tactile indication of hazard zones, crossings and safe travel routes, tactile paving slabs are provided with blisters, bars, corduroy and lozenge shapes to a pattern (depending on the application) to the dimensions and spacing specified in accordance with CEN/TS 15209:2008.

Properties	I.S. EN 1339	Class	Testing	Miscellaneous
Dimensional tolerance	5.2.4 Table 1	Class 3	Annex C	L +/- 2mm W +/- 2mm T +/-2mm
Diagonal dimensions	5.2.4 Table 2	Class 1	Annex C	
Flatness and bow	5.2.4 Table 3	≤ 1.5mm	Annex C	
Water absorption	5.2.4 Table 4.1	Class 2 ≤ 6% as an average	Annex E	
Bending strength	5.2.4 Table 5	Class 3	Annex F	5 MPa
Abrasion resistance	5.2.4 Table 6	Class 4 ≤ 20mm	Annex G	
Freeze / thaw	5.2.4 Table 4.2	Class 3	Annex D	≤1Kg/m2
Slip / skid resistance	5.2.4	USVR 45	Annex I	Low risk, when tested in wet conditions
Breaking load	5.2.4 Table 7	Class 110	Annex F	≥ 11Kn

Concrete Paving blocks must comply with I.S. EN 1338:2003 Concrete Paving Blocks. Requirements and test methods.

Paving blocks - desirable minimum performance characteristics (as per I.S. EN 1338):

Properties	I.S. EN 1339	Class	Testing	Miscellaneous
Dimensional tolerance	5.2.4 Table 1		Annex C	
Diagonal dimensions	5.2.4 Table 2	Class 2	Annex C	
Water absorption	5.3.2 Table 4.1	Class 2 ≤ 6% mean	Annex E	
Tensile splitting strength and failure load	No block shall have a tensile strength less than 3.6 Mpa nor a failure load less than 250 MPa.			
Abrasion resistance	5.3.4.2 Table 5	Class 4 ≤ 20mm	Annex G	
Freeze / thaw	5.2.2.2 Table 4.2	Class 3	Annex D	≤1Kg/m2
Slip / skid resistance	5.3.5	USVR 45	Annex I	Low risk, when tested in wet conditions

I.S. EN 1338 describes how the performance characteristics are to be assessed with detailed test methods and procedures such as:

Splitting Strength (MPa) - is a measure of the ability of the concrete block paving to withstand load. It is determined under laboratory conditions applying a tensile splitting test. The concrete block paving is placed between two rigid bearers after immersion in water and a load uniformly until failure is reached.

Weathering Resistance - is a measure of the ability of the concrete paving block to withstand weathering where specific conditions exist such as frequent contact of the surfaces with de-icing salt under frost conditions. It can be assessed under laboratory conditions by measuring the amount of spalled material from a surface under the cycle of freezing/thawing action using a de-icing salt solution. Or, if no de-icing salt is used, then the measurement of the porosity by measuring the water absorption of the sample should be used.

Minimum required thickness(s) of paving blocks and applications:

Thickness (mm)	Application
50mm	Driveways, patios and footways.
60 / 65	Adopted highways and other roads < 0.5 msa Pedestrian areas that may be subject to vehicular traffic
80mm	Heavy duty pavements 0.5 to 12 msa
100mm	Very duty pavements

Thicknesses are dependent upon traffic volumes, in millions of cumulative standard axles (msa):

up to 0.5 msa - BS 7533-2: 2002, Pavements constructed with clay, natural stone or concrete pavers, Part 2: Guide for the structural design of light duty pavements constructed of clay pavers or precast concrete paving blocks.

0.5 to 12 msa - BS 7533-1: 2001, Pavements constructed with clay, natural stone or concrete pavers, Part 1: Guide for the structural design of heavy-duty pavements constructed of clay pavers or precast concrete paving blocks.

exceeding 12 msa - The structural design of heavy-duty pavements (ports, airports etc.)

APPENDIX 4

Sample Data Sheets

General description:

Indigenous Kilkenny Blue Limestone, from the active quarries in Counties Kilkenny and Carlow, Ireland.

Petrographic description:

A crinoidal, bioclastic limestone, fresh and well compacted, hard and robust. Material with a rich fossil content of mainly brachiopods and polyps.
Finely dispersed carbon through the stone mass results in a blue-grey colour.

Typical chemical composition:

98% Calcium, 0.7% Quartz, 0.7% Dolomite, 0.2% organic Carbon, less than 0.1% Iron Sulfate.

- Because of its extremely low Iron composites content, the material is suitable to be used under the environmental pressure of a city or industrial environment without risk of discoloration or staining.
- Material with a Dolomite content of over 3% shall be rejected.

Technical characteristics:

	Typical Value	Range
Apparent Density	2690 kg m^{-3}	2680-2700 kg m^{-3}
Porosity by Volume	0.31%	0.15% - 0.51%
Compressive Strength	110-126 N mm^{-2}	
Flexural Strength	14.7 N m^{-2}	13.3-15.8 N m^{-2}
Modulus of Elasticity	751 kN mm^{-2}	740-760 kN mm^{-2}
Thermal Expansion	0.01 mm m-1K^{-1}	
Thermal Conductivity	2.5-3.1 W m-1K^{-1}	

DECLARATION OF PERFORMANCE

N° ARDUK-01BHc

1. Unique identification code of the product-type: **ARDUK1341 – Kilkenny Limestone**

2. Intended use(s) of the construction product, in accordance with the applicable harmonised technical specification: **Slabs of natural stone for external paving**

3. Name and address of the manufacturer:

4. Authorized representative:

5. System or systems of assessment and verification of constancy of performance: **System 4**

6a. Harmonised standard: **EN 1341:2012**
6b. Notified body: **na**

7. Declared performance(s)

Essential characteristics	Norm	Performance	Unit
Release of dangerous substances		NPD	
Flexural strength	EN 12372	15,2 ± 2,3 (E^{-} = 11,7)	N/mm²
Slip resistance	EN 14231	NPD	
Skid resistance		NPD	
Frost resistance	EN 12371	168 cycles	
Freeze/thaw resistance – de-icing salts		NPD	
Polishing in use		NPD	

8. Appropriate Technical Documentation and/or Specific Technical Documentation: **na**

The performance of the product identified above is in conformity with the set of declared performance(s). This declaration of performance is issued, in accordance with regulation (EU) No 305/2011, under the sole responsibility of the manufacturer identified above.

DECLARATION OF PERFORMANCE
N° ARDUK-01BHd

1. Unique identification code of the product-type: **ARDUK1343 – Kilkenny Limestone**

2. Intended use(s) of the construction product, in accordance with the applicable harmonised technical specification:
Kerbs of natural stone for external paving

3. Name and address of the manufacturer:

4. Authorised representative:

5. System or systems of assessment and verification of constancy of performance: **System 4**

6a. Harmonised standard: **EN 1343:2012**
6b. Notified body: **na**

7. Declared performance(s)

Essential characteristics	Norm	Performance	Unit
Release of dangerous substances		NPD	
Flexural strength	EN 12372	15,2 ± 2,3 (E^{-} = 11,7)	N/mm²
Frost resistance	EN 12371	168 cycles	
Freeze/thaw resistance – de-icing salts		NPD	

8. Appropriate Technical Documentation and/or Specific Technical Documentation: **na**

The performance of the product identified above is in conformity with the set of declared performance(s). This declaration of performance is issued, in accordance with regulation (EU) No 305/2011, under the sole responsibility of the manufacturer identified above.

REFERENCES

I.S. EN 1926:2006 Natural stone test methods. Determination of uniaxial compressive strength.

I.S. EN 1936 Natural stone test methods. Determination of real density and apparent density, and of total and open porosity.

I.S. EN 12371 Natural stone test methods. Determination of frost resistance.

I.S. EN12372 Natural stone test methods. Determination of flexural strength under concentrated load.

I.S. EN 12407, Natural stone test methods - Petrographic examination.

I.S. EN 12440, Natural stone - Denomination criteria.

I.S. EN 13373 Natural stone test methods - Determination of geometric characteristics on units.

I.S. EN 13755 Natural stone test methods. Determination of water absorption at atmospheric pressure.

I.S. EN 1926 Natural stone test methods. Determination of uniaxial compressive strength.

I.S. EN 14157 Natural stone test methods. Determination of the abrasion resistance.

I.S. EN 14146:2004. Natural stone test methods. Determination of the dynamic elastic modulus of elasticity.

I.S. EN 14231 Natural stone test methods. Determination of the slip resistance by means of the pendulum test.

I.S. EN 1341 Slabs of natural stone for external paving. Requirements and test methods.

I.S. EN 1342 Setts of natural stone for external paving. Requirements and test methods.

I.S. EN 1343 Kerbs of Natural Stone for External Paving - Requirements and Test Methods.

I.S. EN 1469 Natural Stone Products - slabs for cladding requirements.

I.S. British standard BS7533 Parts 1 to 13, Pavements constructed of clay, natural stone and concrete.

Construction Standards for Road and Street Works in Dublin City Council.

Design Manual for Urban Roads & Streets.

Natural Stone Surfacing - Good Practice Guide (Society of Chief Officers of Transportation in Scotland).

'Paving - the Conservation of Historic Ground Surfaces' as published by the Departments of Arts, heritage & the Gaeltacht.

A study of salt weathering cycles impact on limestones Procedia Earth and Planetary Science 17 (2017) 316 - 319.

Stone Testing - An excerpt from the Dimension Stone Design Manual, Version VIII (May 2016) (Natural Stone Institute).

Building with Scottish Stone (Natural Stone Institute).

Studies on the frost resistance of Natural Stone (Lund University).

Frost Resistance of Natural Stone. The Importance of Micro and Nano Porosity (Research carried out by University of Dortmund, Icelandic Building Research Institute and Technical Research Institute of Sweden.

Natural Stone, weathering phenomena, conservation strategies and case studies - Geological Society London.

Characterisation of Irish Sandstone use for Building (Research carried out by Trinity College Dublin and University College Dublin).

Porosity and bulk density of sedimentary rock (G. Edward Manger).

Suggested methods for determining hardness and abrasiveness of rock (International Society for Rock Mechanics, 1978).

Kilkenny Limestone.

Transportation Research Laboratory - Note 39.

TII Footway Design - DN-PAV-03026

Application Guide AG26 - Footway and Cycle Route Design, Construction and maintenance guide prepared for Highways Infrastructure Group, Highways Agency.

BRE - Flooring, paving and setts, Requirements for safety in use IP10/00

National Standards Authority of Ireland (NSAI)

European Standardization Body / Comité Européen de Normalisation - CEN

British Standards Institution (BSI)

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