BS 7533-12:2006

BRITISH STANDARD

Pavements constructed with clay, natural stone or concrete pavers –

Part 12: Guide to the structural design of trafficked pavements constructed on a bound base using concrete paving flags and natural stone slabs

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Contents

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 16, an inside back cover and a back cover.

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Foreword

Publishing information

This part of BS 7533 was published by BSI and came into effect on 30 November 2006. It was prepared by Technical Committee B/507, *Paving units, kerbs, screeds and in-situ floorings*. A list of organizations represented on this committee can be obtained on request to its secretary.

Relationship with other publications

BS 7533 consists of the following parts:

- *Part 1: Guide for the structural design of heavy duty pavements constructed of clay pavers or precast concrete paving blocks;*
- *Part 2: Guide for the structural design of lightly trafficked pavements constructed of clay pavers or precast concrete paving blocks;*
- *Part 3: Code of practice for laying precast concrete paving blocks and clay pavers for flexible pavements;*
- *Part 4: Code of practice for the construction of pavements of precast concrete flags or natural stone slabs;*
- *Part 5: Guide for the design of pavements (other than structural aspects);*
- *Part 6: Code of practice for laying natural stone, precast concrete and clay kerb units;*
- *Part 7: Code of practice for the construction of pavements of natural stone setts and cobbles;*
- *Part 8: Guide for the structural design of lightly trafficked pavements of precast concrete flags and natural stone slabs;*
- *Part 9: Code of practice for the construction of rigid pavements of clay pavers;*
- *Part 10: Guide for the structural design of trafficked pavements constructed of natural stone setts;*
- *Part 11: Code of practice for the opening, maintenance and reinstatement of pavements of concrete, clay and natural stone;*
- *Part 12: Guide to the structural design of trafficked pavements constructed on a bound base using concrete paving flags and natural stone slabs.*

Use of this document

As a code of practice, this part of BS 7533 takes the form of guidance and recommendations. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading.

Any user claiming compliance with this part of BS 7533 is expected to be able to justify any course of action that deviates from its recommendations.

It has been assumed in the preparation of this British Standard that the execution of its provisions will be entrusted to appropriately qualified and experienced people, for whose use it has been produced.

Presentational conventions

The provisions in this standard are presented in roman (i.e. upright) type. Its recommendations are expressed in sentences in which the principal auxiliary verb is "should".

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

The word "should" is used to express recommendations of this standard. The word "may" is used in the text to express permissibility, e.g. as an alternative to the primary recommendation of the clause. The word "can" is used to express possibility, e.g. a consequence of an action or an event.

Notes and commentaries are provided throughout the text of this standard. Notes give references and additional information that are important but do not form part of the recommendations. Commentaries give background information.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

1 Scope

This part of BS 7533 provides guidance on the design of bound pavements surfaced with concrete paving flags manufactured in accordance with BS EN 1339 and natural stone slabs manufactured in accordance with BS EN 1341, both laid in accordance with BS 7533-4. It applies to all pavements including those subjected to commercial vehicular traffic travelling at speeds less than 50 kph with a design life of 40 years.

NOTE Guidance on reinstatement is given in BS 7533-11.

2 Normative references

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

BS 6100-2, *Glossary of building and civil engineering terms – Part 2: Civil engineering*

BS 7533-1:2001, *Pavements constructed with clay, natural stone or concrete pavers – Part1: Guide for the structural design of heavy duty pavements constructed of clay pavers or precast concrete paving blocks*

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

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

BS EN 1339:2003, *Concrete paving flags – Requirements and test methods*

BS EN 1341:2001, *Slabs of natural stone for external paving – Requirements and test methods*

BS EN 1015-12, *Determination of adhesive strength of hardened rendering and plastering mortars on substrates*

3 Terms and definitions

For the purposes of this part of BS 7533, the terms and definitions given in BS 6100-2 and the following apply.

3.1 flag
precast concrete unit, used as a surfacing material, with an overall length that does not exceed 1 m and an overall length which when divided by its thickness is greater than four

[BS EN 1339:2003, definition **3.2**]

3.2 slab
unit of natural stone used as a paving material, in which the working width exceeds 150 mm and exceeds two times the thickness

[BS EN 1341:2001, definition **3.1**]

3.3 paving unit
either a concrete paving flag or natural stone slab

3.4 surface course
layer of paving units that acts as a wearing surface and forms part of the structure of the pavement

3.5 bound surface course
surface course where the paving units are laid on a laying course of concrete with maximum aggregate size of 4 mm and the joints are filled with a cement mortar or grout

3.6 laying course
layer of material on which paving units are bedded

[BS 7533-1:2001, definition **3.2**]

3.7 subgrade
upper part of the soil, natural or constructed, that supports the loads transmitted by the overlying pavement

[BS 7533-1:2001, definition **3.3**]

3.8 pavement
any paved area subject to pedestrian and/or vehicular traffic

3.9 sub-base
one or more layers of material placed immediately above the subgrade

[BS 7533-1:2001, definition **3.5**]

3.10 capping layer
layer of granular or stabilized material at the top of the subgrade to provide a working surface and an improved foundation for the pavement

NOTE The capping layer is an optional layer which may form part of the sub-base (see Table B.1 for the relative sub-base and capping layer thicknesses).

3.11 roadbase
one or more layers of material placed above the sub-base that constitute the main structural elements of a pavement

[BS 7533-1:2001, definition **3.6**]

3.12 commercial vehicle
vehicle with an unladen weight exceeding 1.5 t

[BS 7533-1:2001, definition **3.11**]

3.13 bound roadbase
roadbase consisting of granular material bound with hydraulic binder

3.14 channellized traffic
traffic where the vehicle track width and the traffic lane width are virtually the same

[BS 7533-1:2001, definition **3.7**]

NOTE 1 Normal lane widths in a highway do not generally constitute channellized traffic.

NOTE 2 This can occur in narrow entrances such as gates or induced traffic calming measures and sharp bends where the running lane is less than 3 m in width.

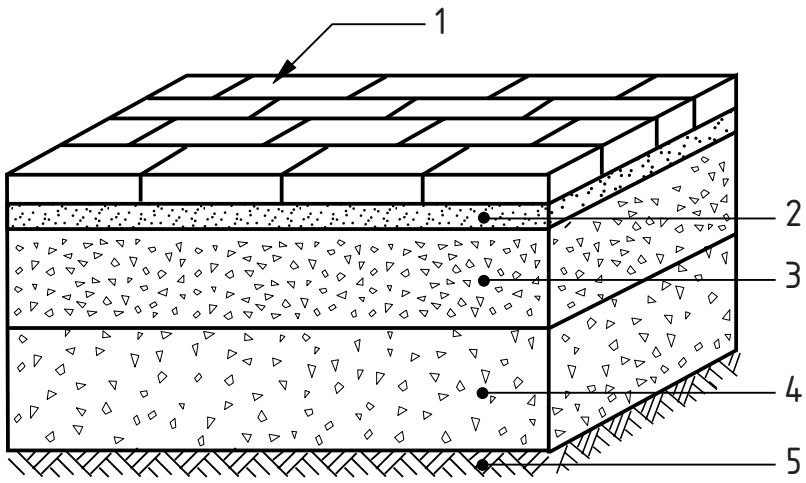
3.15 cumulative traffic
number of standard axles a pavement is designed to carry, measured in standard axles per day

3.16 standard axle
axle carrying a load of 8 200 kg

4 Structure of pavement

A typical cross-section of a pavement is shown in Figure 1.

Figure 1 **Typical cross-section of a pavement**



Key
1 Surface course
2 Laying course
3 Roadbase/sub-base
4 Capping layer
5 Subgrade

5 General design criteria

5.1 Design options

NOTE 1 The only design option provided for a heavy-duty pavement is a bound surface course laid upon a bound roadbase.

NOTE 2 Examples of the use of the design method given in this standard are given in Annex A.

The designer should select the preferred surface course option and then carry out a structural design for the traffic level and subgrade bearing strength of the site (see Clause **6** and Clause **7**). If an acceptable design with the selected surface course is not possible or economic, an alternative surface course option should be selected and the design process repeated.

NOTE 3 The recommended minimum physical properties of surface course material are listed in Table C.1 and Table C.2.

NOTE 4 the structural performance is affected by fatigue and one-off overload, or by repeated loading which can cause:

- *failure in the bedding material;*
- *failure in the bond between the paving unit and the bedding material;*
- *failure in the bond between the bedding material and the roadbase;*
- *failure in the jointing material itself or a failure of the bond between the jointing material and the unit;*
- *failure of the paving unit.*

NOTE 5 Pavements should not be open to full vehicular traffic loading prior to the laying course and the jointing material achieving 60% full design strength.

5.2 Site categories

For the purposes of design, pavements should be categorized according to the commercial vehicular traffic assessment shown in Table 1.

In determining the site category, the use of the surface of the pavement by any construction traffic should be assessed and allowed for.

Table 1 **Site categories for typical vehicle applications**

Site category	Standard axles per day	Typical applications
I	<200	Adopted highways and commercial developments used by a high number of commercial vehicles
II	⩽60	Adopted highways and other roads used by a moderate number of commercial vehicles Petrol station forecourts Pedestrian projects subjected to regular overrun of commercial vehicles
III	⩽5	Adopted highways and other roads used by a low number of commercial vehicles, e.g. cul-de-sac on a housing development Pedestrian projects subjected to occasional overrun of commercial vehicles Car parks receiving occasional commercial vehicular traffic Footways overridden by commercial vehicular traffic
IV	0	Car parks receiving no commercial vehicular traffic Footways subjected to domestic vehicular crossover Private drives, paths, patios, hard landscaping Areas receiving pedestrian traffic only, e.g. school playgrounds

NOTE This table is based on current experience, but does not preclude higher usage by vehicles. The traffic levels (see Table 1) for the use of stone slabs and concrete flags are based upon the materials and construction conforming to BS 7533-4.

5.3 Special cases

High horizontal tensile stresses can be introduced into the pavement where dynamic and/or impact loading occurs, e.g.:

- on traffic calming ramps; or
- where a row of paving units is laid with its surface not flush with the surrounding pavement; or
- for sites subjected to braking or turning; or
- where there are steep hills;

The structural design in terms of vertical loading should remain unchanged but the traffic figures should be multiplied by two before carrying out the design to allow for the higher horizontal tensile stresses.

5.4 Skid resistance and abrasion resistance

It is necessary to ensure the slip/skid resistance of the surface of paving units provide adequate safety against skidding and slipping when new or in service.

NOTE 1 Guidance on the determination of the slip/skid resistance value is given in BS 7932.

NOTE 2 Guidance on minimum slip/skid resistance is given in Annex C.

The abrasion resistance of the surface of natural stone slabs and concrete paving flags should be determined in accordance with BS EN 1341:2001, Annex C and BS EN 1339:2003, Annex G to ensure durability and the performance of the surface.

6 Materials

6.1 General

In bound pavement construction, the successful performance of the sub-base, roadbase, laying course and jointing materials are dependent on the achievement of a specified strength and adhesion as well as workmanship.

Pavements may be constructed over frost-susceptible soils and may require the overall thickness of non-frost-susceptible material to be increased to a value suitable for the locality.

6.2 Roadbase

For bound roadbase the material should conform to BS EN 13877-1:2004, concrete strength class 32/40.

6.3 Surface course

Natural stone slabs should conform to BS EN 1341 and concrete paving flags should conform to BS EN 1339. All paving units should conform to the following size criteria:

- Minimum plan area 50 000 mm^2.
- Maximum length/width ratio = 2:1; any indent in the plan should not exceed half the width of the unit.

At a distance of 50 mm from any edge, any cross-section does not show a horizontal dimension less than 200 mm.

NOTE 1 Experience has shown that paving units conforming to the dimension requirements of BS EN 1339 and BS EN 1441 and having a nominal width dimension less than 300 mm present an increased risk of failure. For sett and concrete block paving reference should be made to BS 7533-7 and BS 7533-10.

NOTE 2 The thickness of a sub-base should be selected from Table B.1, depending upon the site California Bearing Ratio (CBR) (see Table 4).

NOTE 3 The recommended minimum physical properties of surface course material are listed in Table C.1 and Table C.2.

NOTE 4 For slabs where the length:width ratio exceeds 2:1, guidance is given on the slab thickness in relationship to the length:width ratio in Annex D.

6.4 Jointing materials

The jointing materials for bound surfacing should conform to the minimum design cured values given in Table 2.

Table 2 **Jointing material recommendations**

Minimum compressive strength [A)]	40 N/mm^2
Minimum adhesive strength [B)]	1.5 N/mm^2
Minimum flexural strength [A)]	6 N/mm^2
Modulus of elasticity [C)]	(20 000 ± 4 000) N/mm^2
Minimum density [A)]	2 000 kg/m^3
Maximum shrinkage [D)]	0.15%

[A)] Measured in accordance with BS 1015-11.
[B)] Measured in accordance with BS EN 1015-12.
[C)] Measured in accordance with DIN 18555-6.
[D)] Measured in accordance with BS EN 445.

6.5 Laying course material

The laying course material used in bound construction should conform to the minimum design cured values given in Table 3.

Table 3 **Laying course material recommendations**

Minimum compressive strength [A)]	30 N/mm^2
Minimum adhesive strength [B)]	2.0 N/mm^2
Modulus of elasticity [C)]	(18 000 ± 3 500) N/mm^2
Maximum shrinkage [D)]	0.15%

[A)] Measured in accordance with BS 1015-11.
[B)] Measured in accordance with BS EN 1015-12.
[C)] Measured in accordance with DIN 18555-6.
[D)] Measured in accordance with BS EN 445.

7 Design

7.1 General

The foundation design for a bound surface should be irrespective of paving unit size and type.

7.2 Subgrade assessment

The design should be based on an assessment of the subgrade bearing strength, which is described as the CBR. The weaker the subgrade, the stronger the pavement required.

The design CBR should be obtained by measuring the plasticity index or defining the material description of the subgrade and then consulting Table 4.

*NOTE 1 BS 7533-1:2001, **5.1**, gives further recommendations on the assessment of subgrade bearing strength.*

Table 4 **CBR values for different materials**

Type of soil	**Plasticity index**	**Estimated CBR** %
Heavy clay	70	2
	60	2
	50	2
	40	3
	30	4
Silty clay	20	5
Sandy clay	10	5
Silt	Not applicable	1
Sand poorly graded	Not applicable	20 (7) [A)]
Sand well graded	Not applicable	40 (10) [A)]
Sandy gravel	Not applicable	60 (15) [A)]

[A)] The bracketed figures should be considered if these materials are likely to become saturated in service.

Table 4 is intended for use where the water table is 300 mm or more below formation level. In other conditions, specialist advice should be sought.

Effective subgrade drainage should be considered during the design procedure since this can have a significant effect on long-term CBR values.

NOTE 2 Filter drains set at the appropriate level and discharging to a satisfactory outfall or main drainage system have been found to perform satisfactorily.

On sites where the CBR varies from place to place, the lowest recorded values should be used or appropriate designs should be provided for different parts of the site using the lowest CBR recorded in each part.

Soft spots should be removed, and replaced with material having an appropriate CBR.

Care should be exercised in the interpretation of site investigation data. In the case of subgrade, whose strength is a function of their moisture content, the in-service strength can be much lower than the recorded values. Care should also be exercised in using CBR values measured in summer because artificially high figures can be obtained due to dryness of the soil.

7.3 Evaluation of traffic

The number of commercial vehicles using the area should be determined by either a vehicle count or by an estimation based on the site descriptions given in Table 1. The potential for growth of traffic over the intended design life should be considered.

The design for bound construction should take into account the cumulative traffic the pavement has to carry, measured in terms of the number of standard axles per day.

For estimating vehicle usage and the relationship of standard axles refer to Table 5. As the type of commercial vehicles using the pavement will be mixed, the probable daily amount of each type of vehicle should be determined to estimate the total number of standard axles per day.

The design should also take account of channelized traffic or dynamic/impact loading if applicable. A one-off overload can cause failure and should be taken into account in the design.

Table 5 **Standard axles per commercial vehicle**

Vehicle type	Conversion factor
Buses and coaches	1.30
2 axle rigid	0.34
3 axle rigid	1.70
3 axle articulated	0.65
4 axle rigid	3.00
4 axle articulated	2.60
5 axles or more	3.50

7.4 Sub-base thickness

The thickness of sub-base should be selected from Table B.1 depending upon site CBR (see Table 4).

NOTE The thickness of a sub-base makes no allowance for it to be used as a site access way during construction.

Under adverse weather conditions, or for CBR of 3% or less, the use of a geotextile separating membrane beneath the sub-base is recommended.

For CBR less than 2%, specialist advice should be sought about what would be an appropriate pavement sub-base design.

On frost-susceptible soils the total construction thickness should be the minimum recommended for the site location, in cases of doubt a minimum of 450 mm of non frost-susceptible material should be used.

7.5 Roadbase thickness

The roadbase thickness should be designed in accordance with Table B.2 for the different traffic loadings.

7.6 Surface course design

For a given site category (see Table 1) the appropriate minimum paving unit thickness should be selected from Table B.3.

NOTE Substantial recessed joints formed through abrasion and weathering can reduce the service life of a pavement.

7.7 Movement joints

The location of movement joints in the units should reflect other movement joints through the structure (base). For applications where there are no movement joints in the base, depending on layout, movement joints in the surface should be at the periphery. In straight paved areas, experience has shown that the interval between joints should not exceed 100 m. Where there is a change in direction of the paved area, consideration for an expansion joint should be given to the existing stress point(s).

8 Preparation, construction and tolerances

Preparation of the subgrade and construction of the surfacing should be in accordance with the recommendations in BS 7533-4.

Annex A (informative) Worked examples

A.1 Example A

A.1.1 Background

A new development wishes to place paving elements in a central square, which is accessible to cars and commercial vehicles for delivery to domestic premises only. A site investigation shows that clay soil is present and the testing of samples predicts a foundation CBR value of 4%. The site will not be trafficked during construction.

The slab type to be used is a sedimentary rock (sandstone).

A.1.2 Design process

A.1.2.1 Surface selection

Sandstone class 2 from Table C.1, 50 mm thick.

A.1.2.2 Traffic assessment

Using Table 1, for above conditions site category II has been selected.

A.1.2.3 Bound surface design

From Table B.1;

- capping layer 300 mm thick and sub-base 150 mm thick; or
- sub-base only 250 mm thick.

From Table B.2;

- concrete roadbase thickness, 150 mm thick C40 concrete; or
- 180 mm thick C30 concrete.

Laying course thickness 30 mm.

A.2 Example B

A.2.1 Background

An area of stone paving has been proposed as part of a town centre improvement. It will be widely used by buses and delivery vehicles though cars will be excluded for most of the day.

A site investigation was carried out and the foundation CBR was predicted to be 10%. The product to be used is an igneous material. The site will be used for site vehicles during construction

A.2.2 Design process

A.2.2.1 Surface selection

Igneous rock (granite) Class 1, 60 mm thick

A.2.2.2 Traffic assessment

Table 1, for this application category I

A.2.2.3 Bound surface design

From Table B.1:

- capping layer 180 mm thick and sub-base 150 mm thick; or
- sub-base only 150 mm thick.

From Table B.2;

- concrete roadbase thickness, 150 mm thick C40 concrete; or
- 180 mm thick C30 concrete.

Laying course thickness 30 mm.

A.3 Example C

A.3.1 Background

A new pedestrian area in a town centre will be used occasionally by commercial delivery vehicles. The CBR value of the subgrade is greater than 15%. Vehicles will not use the site during construction.

A.3.2 Design process

A.3.2.1 Surface selection

Concrete paving flag Class 1, 60 mm thick

A.3.2.2 Traffic assessment

Table 1, for this application category III

A.3.2.3 Bound surface design

From Table B.1, sub-base only 150 mm thick.

From Table B.2;

- concrete roadbase thickness, 125 mm thick C40 concrete; or
- 150 mm thick C30 concrete.

Laying course thickness 30 mm.

Annex B (normative) Base thickness design

Table B.1 **Capping – sub-base thickness**

CBR	Combined capping – sub-base [A]		Sub-base only [C]
	Capping [B]	Sub-base [C]	
%	mm	mm	mm
2	450	150	400
2.5	400	150	350
3	350	150	300
4	300	150	350
5	250	150	220
8	200	150	190
10	180	150	175
15	150	150	150
> 15	0	150	150

NOTE 1 Formation to have minimum CBR as stated in Table 4.

NOTE 2 Sub-base may consist of unbound material or hydraulically bound material (HBM).

NOTE 3 Intermediate values may be interpreted.

[A] The combined capping – sub-base option can be replaced by the sub-base only option

[B] Capping to have a minimum laboratory CBR of 15%.

[C] Sub-base to provide a minimum laboratory CBR of 30%.

Table B.2 **Roadbase thickness**
Dimensions in mm

	Site category					
	I and II		III		IV	
Site traffic conditions	Non-trafficked	Used by site access traffic	Non-trafficked	Used by site access traffic	Non-trafficked	Used by site access traffic
C32/40 concrete	150	180	125	150	100	125

Table B.3 **Minimum paving unit thickness**
Dimensions in mm

Site category	Natural stone slabs		Concrete flags	
	Class 1	Class 2	Class 1	Class 2
I	60	50	60	50
II	60	50	60	50
III	50	40	50	50
IV	30	30	50	50

NOTE Where large plan areas of slab are used the thickness should be increased to avoid damage in installation, seek manufacturer's advice.

Annex C (informative) Physical properties of surface course material

NOTE This is an informative annex that provides some guidance on the properties of surface course materials. Where a material has a successful history of use in this application or where it can be demonstrated by testing and calculation that a stone is suitable these recommended properties need not be followed.

Recommended slip/skid resistance

- For pedestrian use only Pendulum value 40
- For vehicle use Pendulum value 45

When tested in accordance with BS 7932:2003.

Table C.1 **Recommended properties of surface course material (rock)**

Property	Igneous		Sedimentary and others	
	Class 1	Class 2	Class 1	Class 2
Minimum flexural strength [A)]	12 MPa	15 MPa	8 MPa	12 MPa
Abrasion resistance [B)]	18 mm	12 mm	28 mm	22 mm
Water absorption [C)]	0.40%	0.25%	3.50%	2.50%

[A)] Tested to BS EN 12372
[B)] Tested to BS EN 14157:2004, Method A
[C)] Tested to BS EN 13755

Table C.2 **Recommended properties of surface course material (concrete)**

Property	Concrete	
	Class 1	Class 2
Characteristic bending strength [A)]	3.6 MPa	5.0 MPa
Abrasion resistance [B)]	20 mm [D)]	20 mm [D)]
Weathering resistance [C)]	Class 3	Class 3

[A)] Tested to BS EN 1339
[B)] Tested to BS EN 14157:2004, Method A
[C)] Tested to BS EN 1339:2003, **5.3.2** (weathering test)
[D)] Tested to BS EN 1339

Annex D (informative) Guidance on slab thickness in relationship to length:width ratio

Thickness of natural stone slabs for minimum flexural strength requirements of non standard length:width ratio are given in Tables D.1 to D.3.

Table D.1 **8 MPa flexural strength**
Dimensions in mm

Site category	Minimum thickness based on length/width ratio	
	3 to 1	4 to 1
I	150	175
II	115	130
III	95	105
IV	75	85

Table D.2 **12 MPa flexural strength**
Dimensions in mm

Site category	Minimum thickness based on length/width ratio	
	3 to 1	4 to 1
I	125	145
II	95	110
III	75	85
IV	65	80

Table D.3 **15 MPa flexural strength**
Dimensions in mm

Site category	Minimum thickness based on length/width ratio	
	3 to 1	4 to 1
I	110	130
II	85	95
III	70	80
IV	60	65

To calculate other thickness of stone slabs with different flexural failing strength, use the equation in BS EN 1341:2001, Annex B.

Bibliography

For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

BS EN 445, *Grout for prestressing tendons – Test methods*

BS EN 1015-11, *Methods of test for mortar for masonry – Part 11: Determination of flexural and compressive strength of hardened mortar*

BS EN 1341:2001, *Slabs of natural stone for external paving- requirements and test methods*

BS EN 12372, *Natural stone test methods – Determination of flexural strength under concentrated load*

BS EN 13755, *Natural stone. Test methods – Determination of water absorption at atmospheric pressure*

BS EN 13877-1:2004, *Concrete pavements – Materials*

BS EN 14157:2004, *Natural stones – Determination of abrasion resistance*

DIN 18555-6, *Testing of mortars containing mineral binders – Part 6: Determination of bond strength of hardened mortar*

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