ADVICE NOTE 2 - Materials and Specifications

1. Introduction

This Advice Note 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 (see also Appendix 1 for a list of standards referred to herein).

BS 7533 encompasses technical standards for the design and construction of both 'rigid' and flexibly constructed paved areas and can be used to construct schemes in excess of 1000 standard axles per day.

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.

Figure 1. Well considered schemes enhance place, prioritise sustainable movement, calm traffic and provide longer term durability.

2. Function

Whilst 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.

3. 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 (See also Table 1).

3.1 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 (See also Figure 2).

Site Category	Heavy Vehicles per day	Typical Applications
IA	<100	
IB	<30	Adopted highways and commercial developments used regularly by heavy vehicles.
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.

Table 1. Traffic Loading

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.

4. Selection of Natural Stone

The following European Standards specify the performance requirements and the corresponding test methods for natural stone materials;

- *EN 1341: 2012* – Slabs of Natural Stone for External Paving – Requirements and Test Methods.
- *EN 1342: 2012* – Setts of Natural Stone for External Paving – Requirements and Test Methods.
- *EN 1343: 2012* – Kerbs of Natural Stone for External Paving – Requirements and Test Methods.
- *EN 12372:2006* Natural stone test methods. Determination of flexural strength under concentrated load.

Figure 2. Self-regulating junction using contrasting surface materials

Slabs, Setts and Kerbs are the principle natural stone paving elements employed in a public realm scheme. These standards set out performance characteristics such as tolerances, compressive strengths, colour and face characteristics, abrasion resistance, freeze thaw resistance, porosity / water absorption, finishes and slip resistance.

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.

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.

4.1 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 their setting, and should include 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 Department 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)*.

5. Slip & Skid Resistance

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

Coarse textured surfaces are assumed to give satisfactory slip resistance. The slip resistance of fine textured surfaces (flamed, peon /bush hammered) of slabs and setts is defined by the Unpolished Slip Resistance Value determined using the Pendulum Friction Tester (Annex D of *BS EN 1341: 2012, BS EN 1338: 2003 & BS EN 1339: 2003* - See Table 2 Below). Whilst there is no requirement in the standards for kerbs, it is recommended that the same requirements for setts & slabs be applied.

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 biannual testing. Records of testing should also be retained.

It is recommended that all hard-landscaping paving material should achieve a 'low risk rating' when tested in wet conditions or at least an unpolished slip resistance (PSV) (*BS EN 1341;2012*) minimum 55 Pendulum Test Value (PTV) or higher at specification stage.

For example, Table NA.2 of BS EN 1338:2003.

Class	Mean slip / skid resistance value C scale units
S1	No value determined.
S2	≥35
S3	≥45
S4	Manufacture's declared value

For special applications - e.g. approaches to traffic lights, a higher value may be appropriate.

Table NA.7 Slip/skid resistance of BS EN 1338:2003.
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.

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

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. For additional information on skid resistance, reference should be made to BS 7976.

RECOMMENDATION:
'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' – The Scots Guide.

Table 2. Slip and Skid resistance advice.

6.1 Material Performance

The magnitude of predicted loading on the principle design elements e.g. traffic tables, public plazas, shared surfaces should they be subject to vehicular traffic must be calculated and predetermined.

The paving selected must have a sufficient bearing and crushing strength for a given application. 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 limestone: Bending Strength (Mpa) / Flexural Strength 10N/mm².
- G603 Grey Granite: Bending Strength (MPa) / Flexural Strength 17N/mm².

Annex B of *BS EN 1341, 1342 & 1343* should be used to calculate the break-loads of stone elements by using Formula 'P'.

$$\text{Formula P} = \frac{\text{Rtf} \times \text{W} \times \text{T}^2}{1500 \times \text{L} \times 1.6}$$

Rtf = Flexural strength
W = Module Width
T= Thickness
L Module Length
1.6 Safety factor

(See example below - Table 3)

6.1 Element Shape

It can be seen from Formula P, that in addition to the certified flexural strength, the relationship of a given paving units dimensions (length, width and depth) 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.

The calculated break load (kN) of the paving unit should at least match or preferably exceed the expected traffic loads. Alternatively, table B1 of BS EN 1341 offers suggested breaking loads for different classes of use (See also Table 4).

Material	Dimensions			Flextural Strength (N/mm²) - (Rtf)	Break Load (kN)	Formula P =
	Length (L)	Width (W)	Thickness (t)			
G603 (Grey granite)	330	100	130	17	36.28	$\frac{\text{Rtf} \times \text{W} \times \text{T}^2}{1500 \times \text{L} \times 1.6}$

Table 3. Material performance example.

Minimum break load (P)	User class	Recommended application
No requirement	0	Decoration
0.75	1	Pedestrian zones only - kerbs bedded in mortar
3.5	2	Pedestrian & cycle zones with normal applications
6	3	Occasional car, light vehicle & motorcyle access - garage entrances
9	4	Pedestrian zones with occasional level of commercial traffic & occasional traffic (incl. delivery trucks & emergency vehicles)
14	5	Pedestrian zones with regular level of commercial traffic & regular traffic (incl. delivery trucks & emergency vehicles)
25	6	Roads with high level of commercial traffic & heavy traffic (incl. delivery trucks & emergency vehicles) - petrol stations

Table B1, BS EN 1341

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	70 / 90,	-	-	-	-	-	-	8 - 12
Size 2B	90/100	100	100	200	-	-	-	
Size 3	150 / 170	150	100	200	180	150	200	10 -15

Table 4. Classifications of Setts/Cubes

7. 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.

7.1 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 (see also Figures 3 and 5)

If planned and designed correctly there are a number of ways to extend the operational life of flexible paving in use and they are (see also Figure 4):

- 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 *BS EN 12620:2002 (2008)* - see slabs, flags and tiles (see also Table 5 below).

Figure 3: Inappropriate road design and specification leading to fatigue and rutted tracks.

Figure 4: Example of flexible paving using 160 x 160 x 60mm deep proprietary concrete brick

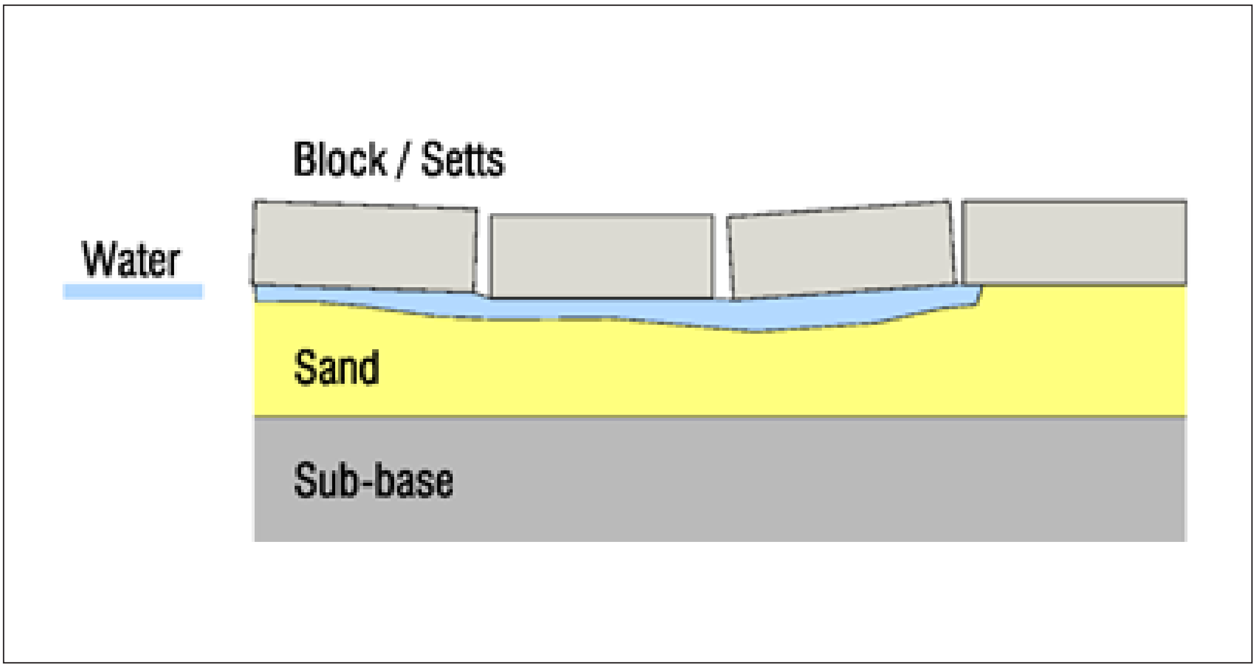

Figure 4: Failure due to water penetration

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

Table 5 - The table above, taken from *BS7533 Part 2*, offers guidance in relation to the subbase structural design of lightly trafficked pavements.

7.2 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 where vehicular traffic loading 'may' occur during its service life.

This standard 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*.

7.3 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 *BS 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:

- The individual grains are angular in nature.
- High proportion of bigger grains (3mm to 6mm).
- Free draining.
- Salt free.
- Low clay / silt content.

Unsuitable sands are:

- Crushed limestone dust.
- Building sands.

7.4 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 to structural performance. Concrete should be used at optimum moisture content.

Layer 1 – the subgrade (see also Figure 5):

(BS EN 1997-2:2007, Geotechnical design. Ground investigation and testing and BS 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 (as per Figure 5):

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 IS EN 13242:2002+A1:2007, SR21: 2004+A1: 2007 (Revised 2012) and manufactured to IS 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). See also Appendix 2 which contains extracts from IS EN 13285.

Layer 3 – the roadbase (see also Figures 5, 6 and Table 6):

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 *IS EN 13877 Part 1*, *Parts 2 and IS EN 206-1* with cement provided in accordance with IS *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 *IS 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.

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 shall comply with the following standards:

- Hot Rolled and Cold Worked Carbon Steel Bars - *IS EN 10080* and *BS 4449 (Grade B500B or B500C)*.
- Steel Wires - *IS EN 10080* and *BS 4482 (Ribbed Grade B500)*.

Figure 5: Subgrade & subbase preparation for traffic table (top) and roadbase construction for traffic table (middle and bottom. .

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	

Table 11 of BS75 33 Part 10 should be referred to

The example below refers to a ramp and table construction designed to Category I or user class 6 (Table B1, BS 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.

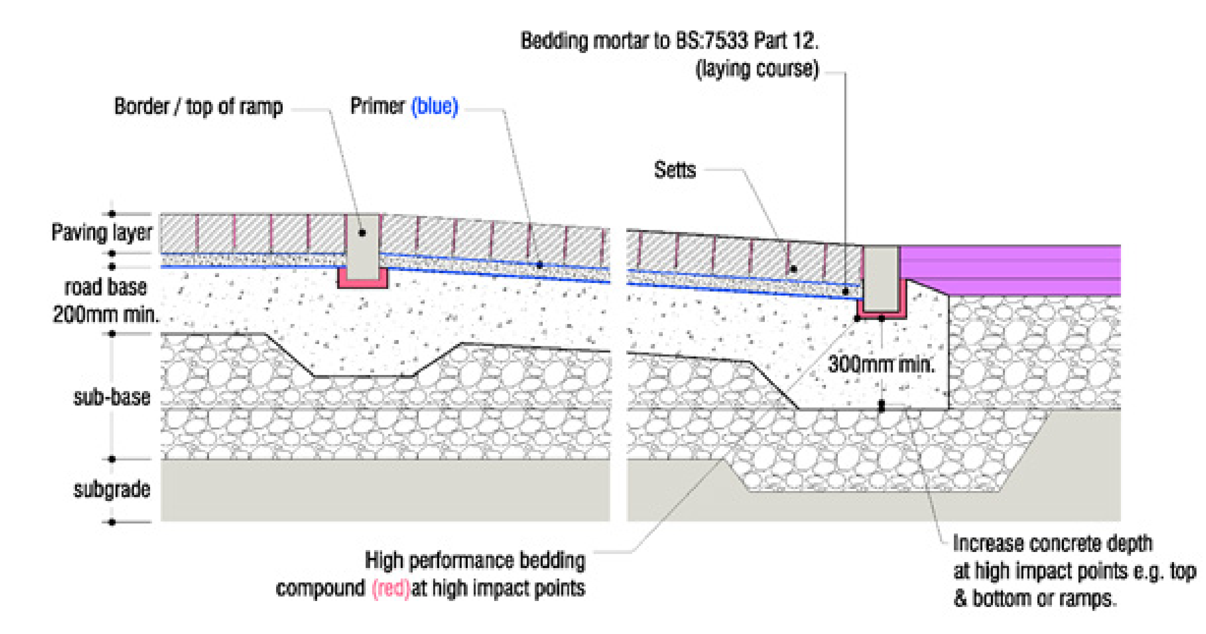

Table 6 and Figure 6: Road-base detail.

- Steel Fabric - *IS 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 NRA 1000 series for additional detail).

Layer 4 – bedding (see also Figure 7):

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/mm^2.

Although priming of the road-base is not a specific requirement of the British Standard, it has now become standard practice 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* and table 3 of *BS 7533-12*

- Minimum compressive strength of 15 N/mm^2 (Measured in accordance with BS 1015-11)
- Minimum adhesive strength of 0.8 N/mm^2 (Measured in accordance with BS 1015-12)
- Modulus of elasticity (15000) N/mm^2 (Measured in accordance with DIN 18555-6)
- Maximum shrinkage of 0.15% (Measured in accordance with *BS 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/m^2 and flexural strength of over 22N/m^2.

Layer 5 – Surface layer (see also Figures 8 and 9):

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 the British Standard. The bond strength will increase from ca1N/mm^2 to above 2N/mm^2 (see also Figure 8).

Figure 7: Ridgid Paving using granite setts bedded in mortar on concrete roadbase

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' paving 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 (see also Figures 10 and 11)

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

There are many benefits to using the slurry method including:

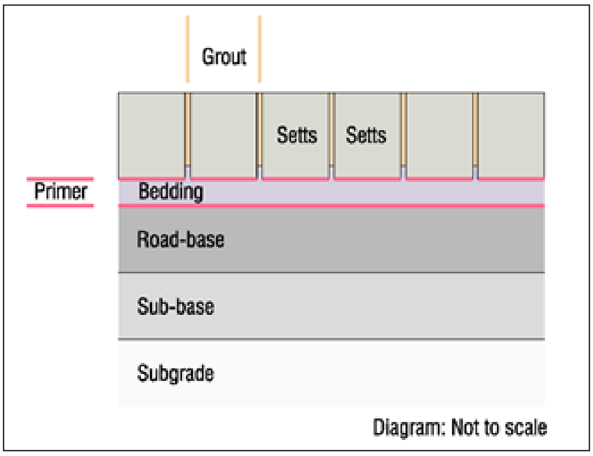

Figure 8: A diagram showing the typical build-up of a BS 7533 compliant pavement construction. This diagram refers to the Moist Bed with Full Depth Slurry method.

Figure 9: Traffic table / rigid paving ready for jointing.

Figure 10: Slurry jointing method

Figure 11: Surplus jointing 'wash off'.

- 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 BS 1015-11)
- Minimum adhesive strength of 1.2 N/mm² (Measured in accordance with BS 1015-12
- Minimum flexural strength of 6 N/mm² Measured in accordance with BS 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 BS 1015-11).
- Maximum shrinkage of 0.15% (Measured in accordance with BS EN 445)

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.

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 predetermined if heavy load conditions are expected.

Edge Restraint (see also Figure 12 and 13):

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 and haunched in concrete.

Figure 12: Granite kerbs being lifted in to place.

Figure 13: Deep granite channel.

8.0 Workmanship

(BS7533-7)

Workmanship & Quality Control:

This is probably the single most important aspect of any successful project. The laying of modular paving surfaces 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 and pattern formation.
- Tolerances on joint widths and bedding courses.
- Consolidation and compaction of materials both bound and unbound.
- Trimming and '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.

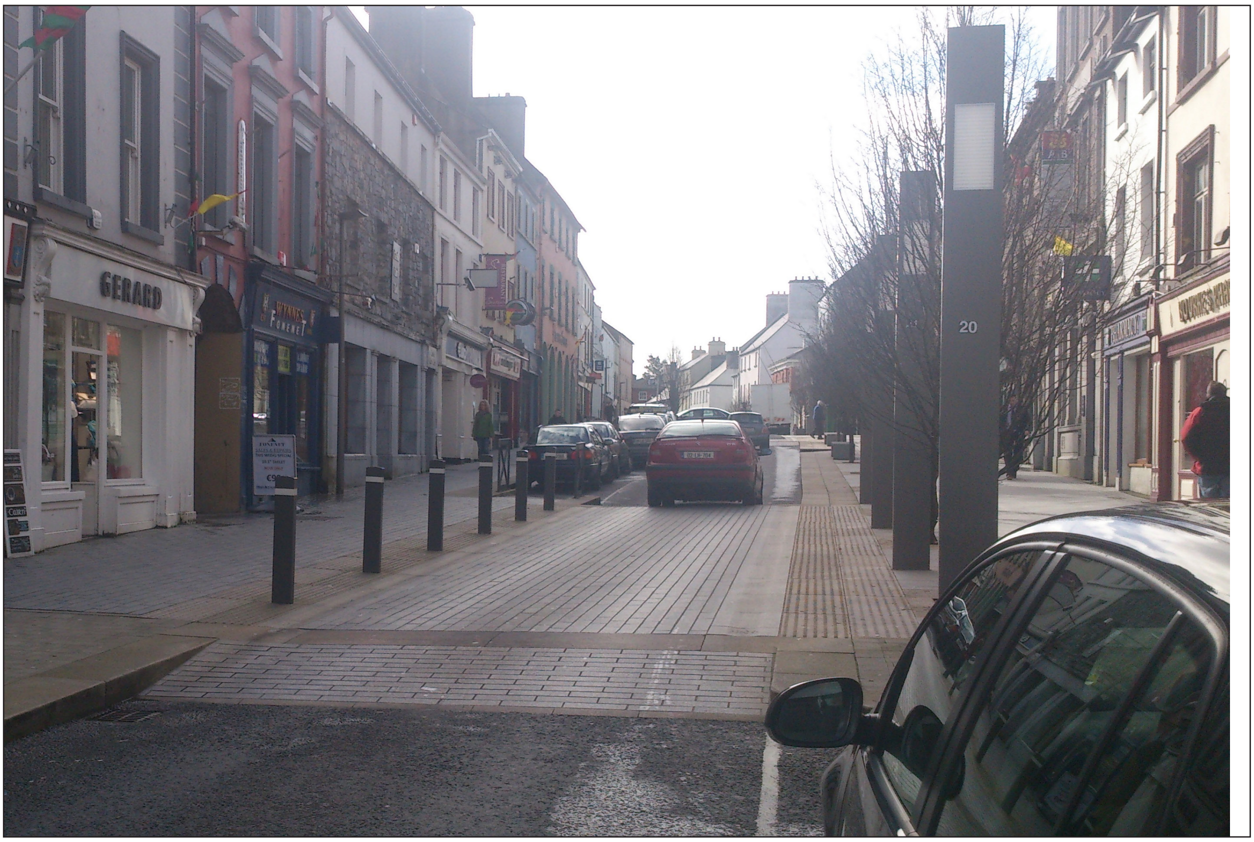

Figure 14: Completed raised table.

- 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.

9. Street Furniture

Access Covers:

(Ref: BS 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 and 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 EN124:2015 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 pavement 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 criteria:

- Compressive strength: 7 days (70N/mm²)
- Tensile strength:7 days (15N/mm²)
- Flexural strength: After 7 days (22N/mm²)
- Density of hardened material: After 24 hours (2050 kg/ m³), 7 days (2070 kg/ m³)
- Compressive modulus: After 7 days (11KN/ mm²)
- Flexural modulus: After 7 days (10GN/m²)
- Bond strength: 45(N/mm²).

Figure 15: Inset Paving Lids

Proprietary Surface Water Channels:

(BS EN 1433:2002 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 BS/ 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 Resistent 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.

Appendix 1 - Reference and 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

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

BS EN 1341: 2012
Slabs of Natural Stone for External Paving – Requirements and Test Methods.

BS EN 1342: 2012
Setts of Natural Stone for External Paving – Requirements and Test Methods.

BS EN 1343: 2012
Kerbs of Natural Stone for External Paving – Requirements and Test Methods.

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

BS EN 1338: 2003
Concrete Paving Blocks – Requirements and test Methods.

BS 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.

NRA 900 & 1100 series
900 Series, Specification for Road Works / NRA.
1100 Series, Footways & Paved Areas / NRA.

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

BS EN ISO 22476
Geotechnical investigation and testing

IS EN 13285: 2010,
Unbound mixtures.

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).

BS EN 12620:2002+A1:2008,
Aggregates for concrete

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

BS EN 1433:2002
Drainage channels for vehicular and pedestrian areas. Classification, design and testing requirements, marking and evaluation of conformity

800 Series, Unbound and Cement bound Mixtures, (NRA), Transport Infrastructure Ireland.
900 Series, Specification for Road Works (NRA), Transport Infrastructure Ireland.

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

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

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

BS EN 12620:2002 (2008), Aggregates for concrete.

IS EN 13877 Part 1: 2013 Concrete pavements – materials.

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

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

Hot Rolled and Cold Worked Carbon Steel Bars - IS EN 10080 and BS 4449 (Grade B500B or B500C).

Steel Wires - IS EN 10080 and BS 4482 (Ribbed Grade B500).

Steel Fabric - IS EN 10080 and BS 4483 (Grade B500A, B500B or B500C).

BS EN 1015-11:1999
Methods of test for mortar for masonry. Determination of flexural and compressive strength of hardened mortar

Appendix 2 - Reference and Standards

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	
		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

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